Synchro-Phasor Data Conditioning and Validation Project

Phase 1, Task 4

Review Meetings with Project Participants

Prepared for the
Office of Electricity Delivery and Energy Reliability,
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1. Introduction

The Synchrophasor Data Conditioning and Validation Project sponsored by the US department of Energy Consortium for Electric Reliability Technology Solutions (CERTS) program was started in December 2012. The project objectives are to develop, prototype, and test various methods for conditioning and validating real-time synchrophasor data. The project is divided into three phases.

- Phase 1: Conceptual Design and Prototype Development
- Phase 2: Prototype Demonstration
- Phase 3: Functional Specifications of the Data Validation System

Electric Power Group (EPG) approached the project by taking a broader look at data quality. Overall quality of data is affected by the equipment that makes the measurement, the communications used to gather it, and the equipment used to process and store it. Those factors in turn are affected by the overall design and management of the data system. To evaluate this, the Task 1 of Phase 1 was a survey of utilities that are implementing synchrophasor projects to determine their data issues and how they dealt with them. It also provided information on the implementation and management of their systems to give some insights as to the source of successes and failures.

Task 2 of Phase 1 was a best practices report based on information gleaned from the interviews. Since the projects were typically not very far along, much of this second report was based on Electric Power Group, LLC (EPG) experience with the many projects they are involved in. The best practices report focused on design, implementation, and administration of these systems.

Task 3 of Phase 1 required design, development, and testing a prototype algorithm for validation and conditioning of the data itself. The prototype testing at this stage was only to confirm operation of the algorithm implementation. Phase 2 will fully test the algorithm using both simulations with error injection and actual data sets.

Task 4 covers outreach with project participants and the larger community users of synchrophasor systems. This report details the meetings and feedback received from participants.

2. Summary of project Phase 1

A summary of each task is presented here. For greater detail see the full report.

A. Task 1, Synchrophasor user survey

The first task of Phase 1 was a survey of utilities that are implementing synchrophasor projects, particularly those sponsored by Smart Grid Investment Grant (SGIG). The purpose was to determine their data issues and how they dealt with them. It also provided information on the implementation and management of their systems to give some insights as to the source of successes and failures.

20 utilities were interviewed. These ranged from transmission operators with a small coverage area to a large ISO. Most of these were still in the process of deploying their synchrophasor system did not have much experience with its operation. Consequently most of the information was drawn planning and deployment rather than operation. Most companies believed that their projects were going well and close to schedule. A few with operational experience reported good reliability and successful operation. Applications that use phasors generally lagged behind development, so little information was provided on user experience with the information. Most companies were planning future expansions of their systems.

B. Task 2, Best practices report

The second task of Phase 1 was a best practices report based on what was observed in the interviews. Since the projects were typically not very far along, much of this second report was based on Electric Power Group, LLC (EPG) experience with the many projects they are involved in. The report focused on design, implementation, and administration of these systems.

Design is the first step. Synchrophasor systems require field measurements, real-time communications, and EMS type analysis-monitor-alarm applications in a tightly couple system. Design should include specialists in all three areas from the start. Consideration is required for initial deployment with less than the optimal system. A design should plan for expansion to a possible final configuration. The design team needs to consider the application performance requirements to be sure the system and selected equipment will meet them.

Implementation largely follows company practices for installation for the specific types of equipment. For example, PMUs are connected to communication, timing, and AC signals in the substation much the same as a DFR or relay would be. The main difference would be that the PMU requires more accurate calibration and timing than most other devices. Overall, the synchrophasor system needs to be checked out as a complete system, end-to end and include measurement comparisons with other data systems. Accurate monitoring of data communication is needed to be sure communications are sufficiently designed to support the system. The report includes appendices with detailed installation validation procedures and troubleshooting guidelines.

System administration from concept through ongoing operation affects every aspect of the project. While this is generally known and accepted, it is being stressed in this case because these projects span operational and jurisdictional boundaries both within and beyond individual companies. It is critically important that lines of communication are opened up and maintained. Planning requires compatible communications, data content, and data identification from end to end. Operation and maintenance (O&M) requires continual coordination. O&M goes on indefinitely, so changes in personnel as well as the system make regular training essential. A strong administration is required to address all these aspects.

C. Task 3, Prototype algorithm development

The third task of Phase 1 was to research, design, develop, and test a prototype algorithm for validation and conditioning of the data itself. The focus was to develop an algorithm that could be adapted to whatever programming type the user needed. Implementation served to validate the assumptions and show places that could be improved as well as demonstrate the effectiveness of the algorithm.

The algorithm was developed based on examination of the error sources and means of detection. The guiding principles included using detection methods provided by the measurement system equipment and that we would not have more than minimal measurement coverage. With the latter, error correction using over determined equations are ineffective. Consequently, the algorithm depended largely on detecting errors in the data and measurement itself.

In examining error sources, the first is the conversion of current and voltage from line values to signal levels that can be used by a PMU. This includes PT/CT devices and related wiring. Next is conversion from analog to digital values in the PMU. The final measurement error source is the algorithm used to estimate the phasor value based on the digitized voltage and current waveforms.

After phasor estimation the data is in digital format, errors are only created by corruption of digital values, incorrect scaling, incorrect identification of measurements, time mismatch, and errors in processing for end interpretation. The algorithm was developed with sections that examine errors based on levels of detection. The first section identifies errors that are detected directly by the communication interface. The next stage looks for errors in message format that could include problems from a corrupted transmitting device. Stage 3 looks at the timestamp for errors and skipped or duplicate data. It also checks for excessive time delay variation. Both stages 2 and 3 can be useful in detecting cyber intrusions. The fourth stage processes the indications in the IEEE Status Flag from the data sending device. These are first sent from the PMU and then updated as needed by other processing elements. Stage 5 applies user set logical limits to detect values out of reasonable ranges of values. This can detect

incorrect scaling and mislabeled information. The last stage applies topological principles to detect measurement errors. These are alarm cases created by the user based on the measurements in relation to the system topology. For example, if all currents into a bus are measured, the sum should be 0. These cases can be entered into the detection algorithm by the user.

This task has been completed with an error analysis and algorithm development reported in the third report of this project. The algorithm was then implemented and the initial testing documented in the fourth report of the project.

D. Task 4, Outreach Activities

This task calls for meetings with project participants and to present outreach to the larger community. The objective of this task is to present progress reports and obtain feedback on results, findings, activities. The deliverable is attendance at meetings, documentation of problems with particular issues that require participant guidance, and listing agreed changes in the task requirements.

Electric Power Group attended and presented updates of the Synchrophasor Data Conditioning & Validation project at four Joint Synchronized Information Subcommittee (JSIS) meetings at the Western Electricity Coordinating Council, two North American Synchrophasor Initiative meetings, a Webinar, and the Department of Energy annual review. In each meeting, valuable discussion and feedback was used to improve the project. The list of these meetings with a brief summary is presented below.

Electric Power Group participated in the following industry meetings:

a) On January 17, 2013, the Joint Synchronized Information Subcommittee of the Western Electricity Coordinating Council, in Phoenix, Arizona -- Ken Martin presented the Data Validation and Conditioning Project, including the project scope – phases, need for the project with examples, overall project, and projected time line.

b) On June 13, 2013, the Joint Synchronized Information Subcommittee of the Western Electricity Coordinating Council, in Salt Lake City, Utah – Iknoor Singh presented a progress report on the data validation and signal conditioning project, including project purpose and scope, system design and implementation, phasor applications in use or planned, and next steps.

c) On June 27, 2013, the Department of Energy Transmission Reliability Program, Washington, DC – Ken Martin presented the Data Validation and Condition Program, including the objective, three phases, approach, risk factors, and plan.

d) On October 13, 2013, the Joint Synchronized Information Subcommittee of the Western Electricity Coordinating Council, in Salt Lake City, Utah – Ken Martin participated in the synchrophasor data validation session agenda item to discuss the progress report of the data validation and signal conditioning project.

e) On October 22, 2013, the North American Synchrophasor Initiative meeting, in Chicago, IL – Ken Martin participated in the Model Validation Technical Workshop / Data Validation and Conditional Project with industry colleagues.

f) On January 23, 2014, the Joint Synchronized Information Subcommittee of the Western Electricity Coordinating Council, in Scottsdale, Arizona – Ken Martin spoke on data quality and recommendations on PMU network design, management and administration.

g) On January 28, 2014, Electric Power Group conducted a webinar which had 64 energy industry participants – Ken Martin presented synchrophasor data diagnostics detection and resolution of data problems for operations and analysis.

h) On March 12, 2014, the North American Synchrophasor Initiative meeting, in Knoxville, TN – Ken Martin participated in the PRSVCC task team and presented an update on the Data Validation and Conditional Project with industry colleagues.

The full presentations are presented in appendices A-G.

3. Feedback from outreach activities

A. Comments from WECC presentations

Several suggestions were received at the JSIS presentation in January 2013. These listed below along with EPG action:

Comment: Talk to Harris and other data handlers such as the Defense industry to see how they handle data quality issues.

EPG follow-up: EPG contacted Harris with both phone calls and Email and did not receive a response for information or an interview. Attempts to contact someone in the defense department were unsuccessful also.

Comment: Review the work done at PNNL (Jeff Dagle) and PG & E (Vahid Madani).

EPG follow-up: Jeff Dagle was contacted but didn't have suggestions beyond what EPG was already doing. Papers and presentations from both PNNL and PG&E were included in the review.

Comment: What are good engineering practices for substations?
EPG follow-up: This topic was covered in detail in the Best Practices report.

Comment: In surveys, ask the question "How much data is lost?"
EPG follow-up: This topic was included in the Surveys and is detailed in the Survey report.

B. Comments from DOE review

Reports at the DOE project review were evaluated by a panel of 5 reviewers. The following table of comments was received from the review. The follow-up to each comment is listed below the report.

Q1 Ranks: (1) Not important (2) Somewhat important (3) Important (4) Very important (5) High Importance

Session: V-A. Presenter: Martin

	Score	Q1 Comments	Q2 Comments
1	not scored	(no comments provided)	(no comments provided)
2	3	Important for NASPI going forward	(no comments provided)
3	4	- This project provides an important need that is highly relevant to the grant recipients at this stage of the technology deployment - A well planned and well executed project that is making a valuable contribution	- Looking for gleaming value-added workproducts prior to the completed functional specifications in mid-2014. That way we can work toward developing a community perspective vs an individual vendor's solution. - Will be looking for opportunities to better integrate this activity into various NASPI activities. One example is recommendations for using data error flags -- raiting awareness for consistent use of flags
4	5	Very useful work.	Even 99.9% isn't good enough; need recommendations how to improve availability.
5	5	Helping PMU users understand the importance of PMU. This is vital work and hopefully lead to better guidance and oversight for PMU validity.	- In your report, you did not specificy which flags: are these only the C37.118-2205 flags, other (non c37.118) flags, or do you include C37.118-2-2011 flags (which are not yet implemented)? - Discuss the specifics of tests to be performed on the PMU data during system design and on commissioning. Proposal: 1) determing the applications for the PMU data of each PMU to be installed; 2) determine the PMU performance needs; 3) determine the configration of the particular PMU model;
6	3	Data validation is essential for technology acceptance & sharing best practices among various installations is	Defining uniform way to set STAT word to vendors would be benefical. Re--survey to collect operations/maint practices & including them in the report would be beneficial.
7	4	Need to begin process of commissioning and accepting all new PMU's data and information.	Need to accelerate team to find methodology that can be standardized, and not just focus on reliability, but functionality. Develop standard commissioning, validation, system test report process, or some follow
8	5	Synchrophasor data validation is paramount to assure the success of the deployment of PMUs in any company.	(no comments provided)
9	5	Good, thorough scope of investigation including all the right pre-data, data-affecting issues.	Provide as much firm guidance and recommendations as possible to Tos and RCs re system design, management, device installation, matching PMUs to applications, and commissioning. Give specific recommendations to vendors about how to make life easier for customers (terminology, settings, advice, etc). Make eventual data
10	5	Critical for using synchrophasor data for operating decision making.	Good progress; industry participation (to increase)

Comments/Feedback from the June 27, 2013, DOE Review Meeting

Response to reviewer Question 2 comments (10 reviewer comments given):

Reviewer comments 1, 2, & 8:

No comments given.

Reviewer comment 3:

First comment is very supportive, no action indicated. For the second, EPG is attempting to raise awareness and usability of IEEE C37.118 data flags through the algorithm implementation. Further detail on flag usage will be promoted in the algorithm documentation in Phase 3 of the project.

Reviewer comment 4:

EPG stated 99.9% availability is a minimal target. This is actually a very high standard, considering the type of system. 99.995% is probably achievable, but that level of performance is highly subject to the details of reporting, such as if scheduled maintenance time is included in the statistic. EPG does not believe levels of continuous, full-time availability higher than 99.9% are realistic targets at this time and simply create excess expenditure for deployment.

Reviewer comment 5:

C37.118-2005 and C37.118.2-2011 flags are essentially the same. The report and the algorithm developed in Task 2 includes both.

The test specifics are presented in Task 3 reports (which were not available at this review time).

Reviewer comment 6:

EPG will try to include some more specific definitions and use for the STAT indications. At this time there is no clear way to do this. The essential problem is that the indications are part of a published standard. If the standard setting organization wishes to publish details, it becomes part of a standard and will be universally adopted. There are so many different ways these characteristics can be determined, the standard development group chose not to do this. Any other publication becomes an opinion and will not be universally followed. In time, options will develop and then can b standardized.

If the contract was extended, EPG would be happy to re-survey to see how O & M practices have developed.

Reviewer comment 7:

EPG is not sure it understands the first comment. (These comments were received many months after the presentations.) The best practices report probably addresses that comment and definitely the second.

Reviewer comment 9:

The guidance recommended is covered in the Best Practices report, particularly in Appendix A. EPG has not addressed recommendations to vendors, but will try to include this aspect in Phases 2 and 3.

The validation algorithms will be fully described in phase 3. Any vendor can use this to develop their own validation system, tailored to their wishes. Every vendor uses their own code base, so it is unrealistic to supply code and expect all vendors to use it. EPG will supply the algorithm it produces to demonstrate the project as a library that others can use with their code. This will speed implementation for those that do not want to develop their own code base.

Reviewer comment 10:

No response needed.

C. Project Management Comments

All four reports have been submitted and reviewed by project management and advisors. After submission of the first report draft, a number of improvements were requested for report format and description. These were implemented in that report and have been carried through all reports. Comments have been minimal, most along the line of “well done”, ” interesting”, “impressive”, and “excellent”. Since these have been rather random and have not indicated the need for any correction or expansion, they have not been cataloged. The PI can attest to finding these reports are widely distributed and well read.

4. Report Summary

This task calls for meetings with project participants and to present outreach to the larger community. These activities are summarized in section 1.D of this report. The 7 meetings provided valuable feedback and good opportunity to disseminate this work. In addition this work has received mention in several other presentations at professional meetings including the 2013 PES General Meeting and 2013 ISGT Europe. When completed, the presentations have been posted on the NASPI web site. This has provided further distribution as evidenced by a number of comments and requests for information sent to EPG. This task completes Phase

1 of project. It has been quite successful in achieving its goals to date. EPG is looking forward to moving on with Phase 2.

Appendix A. Presentation at JSIS on January 17, 2013

The following slides were used for the presentation.

DATA VALIDATION & CONDITIONING PROJECT

Joint Synchronized Information Subcommittee Meeting
Tempe, AZ
January 17, 2013

Ken Martin, John Ballance, Simon Mo,
Prashant Chandrasekar, Iknoor Singh,
Ashley Wang

Electric Power Group

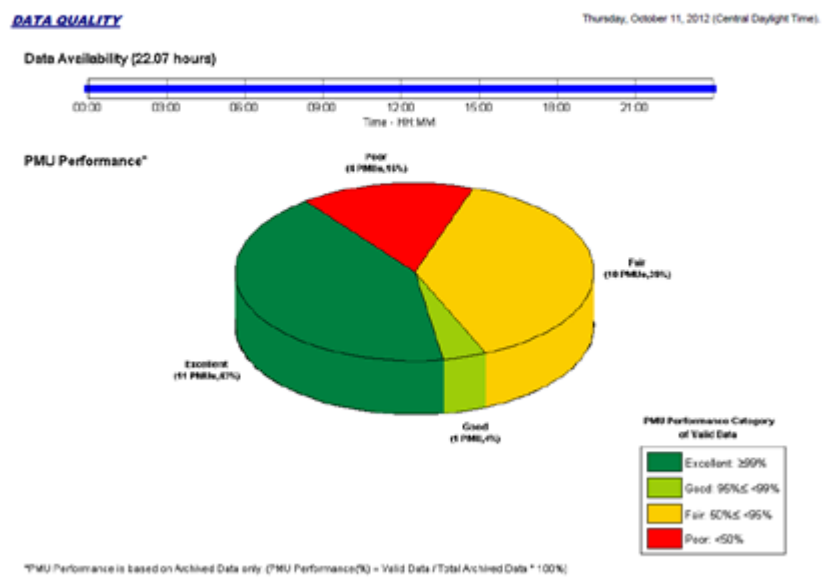
Outline

- Project Scope - Phases
- Need for the Project - Examples
- Overall Project
- Projected Time Line
- Summary

Project Scope - Phases

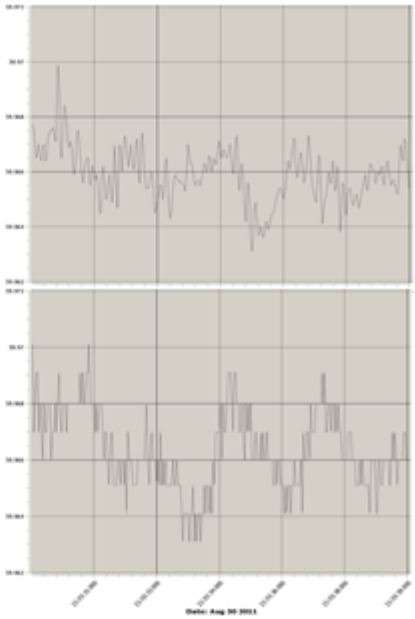
- **Phase 1: Conceptual Design and Prototype Development**
  - Review Existing SGIG Systems
  - Recommendations for Infrastructure and System Administration
  - Research, Design, Develop and Test Prototype
  - Review Meetings
- **Phase 2: Prototype Demonstration**
  - Develop Error Simulation Utility
  - Data Validation Prototype Demonstration
  - Review Meetings/Summary Report
- **Phase 3: Functional Specifications of the Data Validation System**
  - Document Key Lessons Learned
  - Functional Specification
  - Review Meetings

Data Quality – Currently Deficient for Production Grade Systems



Example 1: Reporting Resolution Issue

- Expect smooth changes in measurement
  - Floating point required
- Report looks "steppy"
- Problem:
  - Report from PMU is integer then converted to floating point
- Issue is understanding of whole process



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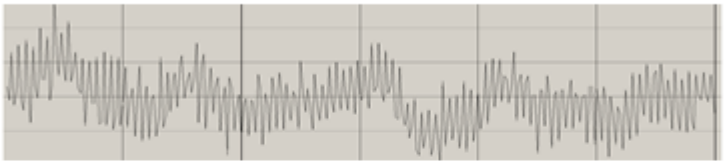
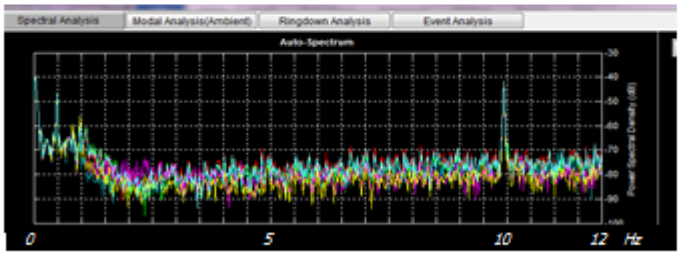
Example 2: Measurement 'noise' Created by PMU

- **"Noisy" frequency signal has oscillation aspect**



- **Modal analysis showed this to be a 10 Hz mode**



- **Detectable & correctable problem**

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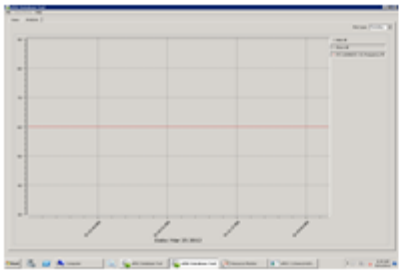
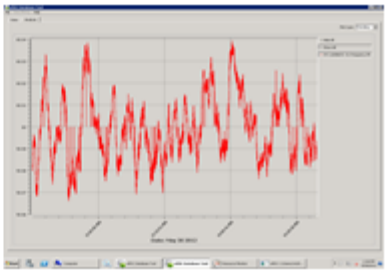
Example 3: Communication Overload

- What was a good link with low data loss became very excessive
- Investigation showed a security camera has been installed and shared the data link
- Both RTU and PMU traffic affected
- Solved with traffic management including QoS additions



While saturated, data lost & frequency flat-lined



Saturation resolved, data & frequency good

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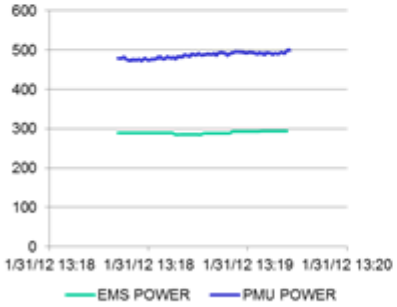
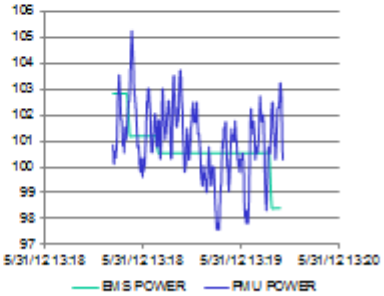
Example 4: Scaling Error

- Comparison of PMU with EMS data showed error factor ~1.73
- Investigation showed PMU current reading was mis-scaled by √3
- PMU – EMS data comparisons are an important part of a verification process





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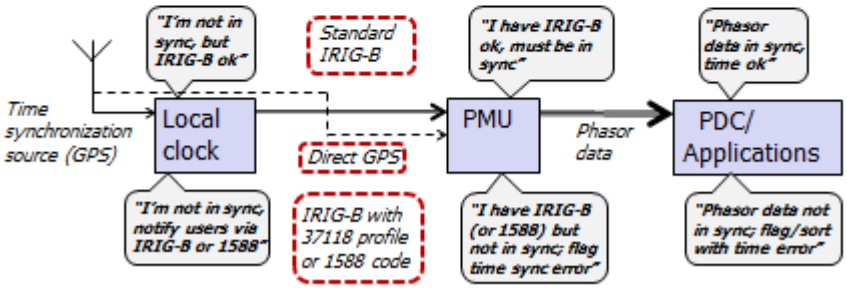
Example 5: Time Error Problem

- PMU receives unsync time
  - No time quality provided with time signal
- PMU reports data with bad time but sync error flag not set
- PDC synchronizes data by reported PMU time
- PDC time deviates between PMUs
  - Good data is lost
  - No way to distinguish since all times marked good

Case 5: Time Synchronization Chain

- The PMU needs to detect and flag time errors
  - Time directly from GPS provides time quality
  - Time indirect must include time quality
    - e.g: IRIG-B or IEEE1588
  - PMU provides sync information to PDC & applications



Data Problem Summary

- Examples are typical of real issues EPG has worked with
- Most Problems Are Institutional – such as
  - Inadequate design for expected results
  - Lack of complete implementation validation
  - Incomplete installation of equipment in the measurement chain
  - Lack of user understanding of the process
  - Difficulty in identification of the problem source
  - Lack of business process and well defined contact chain for problem resolution
  - Lack of change management procedures
  - Lack of or breaks in change notification & operation chain
- Data Resolution Approaches
  - Mis-configured equipment
  - Equipment implementation problems
  - Failures of system components
  - Identification of problems (most require intervention)

Overall Project

- **Survey existing systems and practices**
  - Create "Best Practice" recommendation document
- **Create one or more algorithms for data validation and conditioning**
- **Demonstrate the algorithm**
- **Document the algorithm and findings**

Phase 1, Task 1 - Survey

- Survey SGIG installations
  - Include all types of systems
    - ISO
    - TO, large and with own PDC and applications
    - TO, small and a few PMUs only
  - Try to get a representative sample
- Survey other significant systems (not just SGIG)
- Review publication of data validation type issues
  - These will include PP presentations as well as books & technical papers
  - Consult authors as needed to obtain relevant facts
- Catalog EPG experience with customers and deployments
  - Product design and deployment
  - Operation with different types of equipment in the field
  - Monitoring and trouble-shooting data streams

Phase 1, Task 2 – Best Practices Summary

- Distill best practices based on surveys and EPG experience
- Summarize findings in a "best practices" document
- Document will include design, installation, validation, operation, maintenance, and administration
- Focus on institutional problems that may be alleviated rather than hardware/software problems

Phase 1, Task 3 – Algorithm Development

- Develop one or more algorithms for bad data detection & data conditioning
- Concepts will come from:
  - Survey of SGIG projects
  - Literature search
  - EPG experience
  - Project Leaders – CERTS, BPA, PJM
- The goal is to come up with a flexible algorithm that operates at various levels depending on available resources including:
  - Only the data and imbedded status flags
  - Communication, network, and program interfaces
  - Simple signal identification logic
  - Basic system topology
  - Inputs from other systems like the EMS or SE

Phase 1, Task 3 – Algorithm Goals

- Detect Data Errors
  - Data corruption
  - Data tampering
- Detect Measurement Errors
  - Measurement timing
  - Measurement scaling
  - Measurement identification
  - Measurement corruption
- Flag Errors
  - Indication for other programs
  - Indicate safe uses for impaired data
- Data Correction
  - Offer users the choice to auto-correct or only flag errors
- Provide Error Analysis
  - Guidance for likely error cause (and thus for resolution)

Phase 2, Task 1 – Simulation Utility

- Phase 2 is the Prototype Demonstration Phase
- Task 1 Develops An Error Generation Simulator That Will Create Types Of Errors In A Data Stream Needed For Test
  - Loss of data from a whole PMU
  - Loss of signals in a PMU
  - Drifting time or signal values
  - Dropouts
  - Etc.
- The Algorithm Will Be Coded Into A Software Tool To Demonstrate Its Operation
  - May be a stand-alone or part of another application

Phase 2, Tasks 2/3 – Prototype Demonstration & Summary Report

- Demonstrate Prototype With Simulated EPG Data
- Demonstrate Prototype With Real Data From PJM & BPA
- Produce Summary Report

Phase 3 – Functional Specifications

- Document Lessons Learned and Recommendations
- Produce Functional Specifications For Algorithm and Prototype Development

Proposed time line

- Phase 1, task 1 – review & report
  - Start to 4-12-13
- Phase 1, task 2 – recommendation document
  - 4-12-13 to 6-28-13
- Phase 1, task 3 – design & development
  - 6-28-13 to 11-29-13
- Phase 2, task 1 – develop error simulation utility
  - 11-29-13 to 2-14-14
- Phase 2, task 2 – demonstrate data validation prototype & report
  - 2-14-14 to 4-18-14
- Phase 3, tasks 1 & 2 – final report and functional specification
  - 4-18-14 to 7-18-14
  - FINISH!

EPG Approach Summary

- **Produce a "Best Practices" Recommendation**
  - Most problems are institutional
  - With just better implementation and management, systems will be successful
  - Recommendation to include design, implementation, operation, and maintenance considerations
- **Produce Data Conditioning and Validation Algorithm**
  - Detect problems and notify users for corrective action
  - Supply notification to programs to prevent use errors
  - Provide guidance on error source for resolution

Appendix B. Presentation at JSIS on June 13, 2013

The following slides were used for the presentation.

Progress Report on Data Validation and Signal Conditioning Project

Project Sponsored by Department of Energy
Lawrence Berkeley National Lab Subcontract 7040521

Iknoor Singh
Electric Power Group

June 13, 2013
Salt Lake City, Utah

Data Validation Team

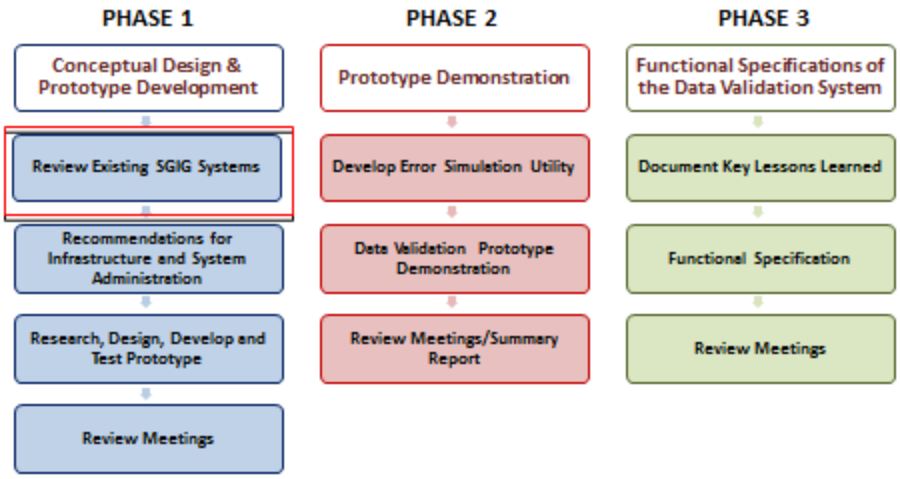
EPG Team

- Ken Martin, PI
- Iknoor Singh
- Prashant Palayam
- Xuanyu Wang
- Chen Sun

- Project Manager – Dejan Sobajic
- Technical Advisors – Mahendra Patel and Dmitry Kosterev
- Project Sponsor – Joe Eto, CERTS Program Manager, LBNL

Project Purpose and Scope

Develop, prototype, and test various methods for conditioning and validating real-time synchrophasor data – 3 Phases



Phase 1, Task 1

Review Existing SGIG Systems

Approach:

- Identify companies with SGIG projects and other companies with significant synchrophasor initiatives
- Conduct surveys – telephonic or questionnaire responses
- Review literature-sources included NASPI presentations and IEEE papers
- Summarize results and findings

Topics Surveyed:

- System Administration
- System Design and Implementation
- Operational Data Validation Systems
- Current Experience and Future Plans

List of 20 Survey Participants

- Alberta Electric System Operator
- Ameren
- American Electric Power
- American Transmission Company
- Arizona Public Service
- Baltimore Gas and Electric
- BC Hydro
- Bonneville Power Administration
- Dominion Power
- Idaho Power Company
- ISO-New England
- Los Angeles Department of Water and Power
- Manitoba Hydro
- New York Power Authority
- Oklahoma Gas and Electric
- ONCOR
- PEPCO
- PJM Interconnection, LLC
- Salt River Project
- Southern California Edison

System Administration

Management Structure

- **Most management teams worked well**
- **Structure depends upon company size, project needs, experience, etc.**
- **Small management: 1-2 people**
- **Large management team: Different members responsible for different tasks (e.g., ISOs)**

Improvements Needed as Identified by Respondents

- **Management diversification**
- **More resources and personnel**
- **Better training**
- **Clearer business processes and procedures**

System Design and Implementation

Design, Signal Selection

- PMU → PDC (substation) → PDC (TO control center) → PDC (ISO control center)
- Different system designs: Basic system with no redundancy to full redundancy and failover designs
- Monitoring locations: Key substations, tie-lines, generators, wind farms, HVDC lines, etc.

PMU Selection & Deployment

- Convenience, cost, vendor familiarity
- Stand-alone PMUs, dual function relays (DFRs)
- Locations based on available infrastructure, communication, and cost considerations

Improvements Needed as Identified by Respondents

- More bandwidth at substations
- Better testing and calibration of PMUs
- Performance of communications network, PDCs and other hardware
- Latency vs. loss of data
- Better processes to address failures

Operational Data Validation Systems

Methods & Applications for Data Validation

- Substation level
  - Meters/Relay test set
- Control Center level
  - Comparison with EMS
- Phasor signal validation
  - PDC applications
  - Real-time visualization
  - Data analysis

Key Issues Identified by Respondents

- Equipment installations not always checked/ verified
- Data Validation not done consistently
- Applications not using error flags, check words or other data validation indicators
- Alarm/Email notifications not enabled

Current Experience & Future Plans

Current Experience of Respondents

- 90% to 99.96% system reliability
- Maintenance/replacement cycle around relay routine
- Budget constraints

Future Plans as Voiced by Respondents

- Most utilities installing more PMUs than originally planned
- Sub-transmission and distribution systems starting to get emphasis at some companies
- Many companies have or are planning to integrate phasor data with SE

Phasor Applications, In Use or Planned

ONLINE

- System Visualization
- Islanding Detection
- Event Detection
- Situational Awareness Alarms
- Line Monitoring
- Fault Location
- Error Monitor And Notification
- Data Quality Monitoring System
- Data Error Detection And Correction
- Validation Of Models In Real-time
- Improved State Estimation
- Wide Area Reactive Control
- Power Flow Control
- On-line Measurement And Model Based Stability Assessment
- Protection

OFFLINE

- System Performance Analysis
- Parameter Validation
- Line Rating Analysis
- Model Validation
- Planning Support
- Islanding Planning

Next Steps in Project

- Report was prepared, reviewed by Project Manager and Technical Advisors (BPA and PJM), will be released soon
- Next Task: Best Practices and Recommendations
- Project Planned Completion Date: Oct, 2014

Thank You.

Iknoor Singh

Electric Power Group

201 S. Lake Ave., Suite 400, Pasadena, CA 91101

Tel 626.685.2015 Singh@ElectricPowerGroup.com

Appendix C. Presentation at DOE OE review on June 27, 2013

The following slides were used for the presentation.

DOE/OE Transmission Reliability Program

Data Validation & Conditioning

Kenneth Martin
Electric Power Group
martin@electricpowergroup.com
June 27-28, 2013
Washington, DC

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Consortium for Electric Reliability Technology Solutions

2

The Problem

- Phasors are well known to engineers …
  but synchrophasors are not
- Synchrophasor value dependencies
  - Precise timing source, algorithms, & hardware
- Systems dependent on real-time communications
  - Delay (latency), bandwidth, errors, & dropouts
- Need comparability with established systems (SCADA)
- Wide area, high-speed – faster actions

➡ Need assurance measurements are correct and…
➡ Detect and fix data problems

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Introduction

- Data Validation and Conditioning Project
  - RFP issued in June 2012
  - Awarded to EPG in December 2012
  - Completion by October 2014
- Three stages
  - Stage 1 – survey, study, & prototype development
  - Stage 2 – prototype demonstration
  - Stage 3 – prototype functional specifications

Principle objective

- **Develop, test and prototype various methods for conditioning and validating real-time synchrophasor data**
  - Applicable to SGIG projects
  - Usable in deployed architectures
  - Include consideration of design & deployment
- Output includes cleaned data & quality flags

EPG Proposal

- Data validation based on
  - Flags in data
  - Data relations & logic
  - Comparisons – EMS/model
- Issues go deeper than data
  - Equipment selection & compatibility
  - System design
  - System administration
  - Operation and maintenance
- Plan to tie all aspects together

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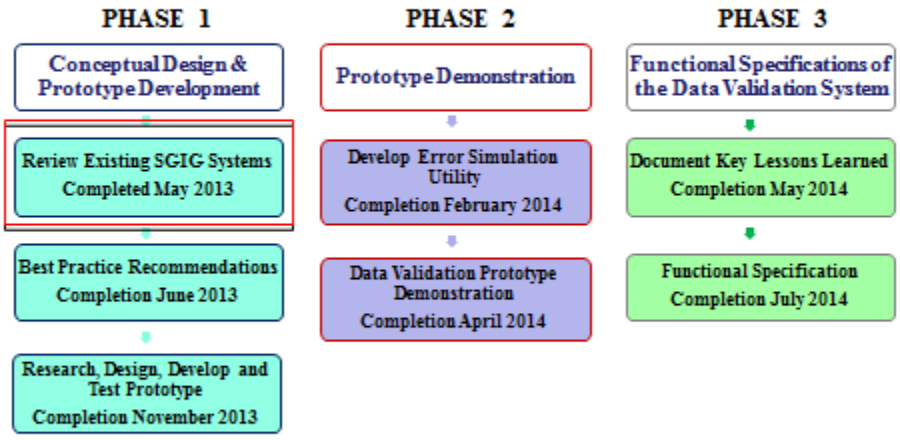
EPG Proposal and Plan



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Phase 1, Task 1

Review Existing SGIG Systems

Approach:

- Survey companies with SGIG projects and other companies with significant synchrophasor initiatives
- Review literature-sources – NASPI, IEEE, etc.
- Summarize findings & report

Topics Surveyed:

- System Administration
- System Design and Implementation
- Operational Data Validation Systems
- Current Experience and Future Plans

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System Administration

Management structure

- **Structure depends upon company size, project needs, experience, etc.**
- **Small management: 1-2 people**
- **Large management team: 5-6 people with task area responsibility**

Comments & conclusions

- **Most management teams worked well**
- **Management focused on implementation, not O&M (new systems)**
- **Some desire for more resources (staff) and better training**
- **Could use clearer procedures**

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System Design and Implementation

Design, Signal Selection

- Typical design: PMU → PDC (TO CC)→PDC (ISO CC)
- Basic system with no redundancy to full redundancy
- Monitoring locations: Key substations, tie-lines, generators, wind farms, HVDC lines, etc.

PMU Selection & Deployment

- Convenience, cost, vendor familiarity
- Stand-alone PMUs, dual function relays (DFRs)
- Locations based on available infrastructure, communication, and cost considerations

Comments & conclusions

- Would like more bandwidth to substations
- Better latency performance
- Need better processes to address problems

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System & Data Validation

Installation Validation

- **Substation level -** Local meters/Relay test set
- **Control Center level -** Comparison with EMS
- **Equipment installations not always checked/ verified**

On-line data Validation

- **On-line data validation by vendor applications**
  - PDC, Real-time visualization & data analysis
- **Data Validation not done consistently**

Operation Problems

- **User applications not using error flags, or other data validation indicators**
- **Alarm/Email notifications not enabled**

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Current Experience & Future Plans

Current Experience of Respondents

- **90% to 99.96% system reliability**
- **Maintenance/replacement cycle same as for relays**
- **Budget constraints**

Future Plans as Voiced by Respondents

- **Most utilities installing more PMUs than originally planned**
- **Some new emphasis on sub-transmission and distribution systems**
- **Many companies have or are planning to integrate phasor data with SE**

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List of 20 Survey Participants

- Alberta Electric System Operator
- Ameren
- American Electric Power
- American Transmission Company
- Arizona Public Service
- Baltimore Gas and Electric
- BC Hydro
- Bonneville Power Administration
- Dominion Power
- Idaho Power Company
- ISO-New England
- Los Angeles Department of Water and Power
- Manitoba Hydro
- New York Power Authority
- Oklahoma Gas and Electric
- ONCOR
- PEPCO
- PJM Interconnection, LLC
- Salt River Project
- Southern California Edison

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Phase 1, Task 2

Best practices recommendations

Approach:

- Identify practices in companies that were reported as being successful
- Combine with EPG experience in working with companies
- Summarize in best practices recommendations

Best Practices Topics:

- System Administration
- System Design and Implementation

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Project status

- Phase 1, Task 1 complete
- Phase 1, Task 2 under way
  - Survey did not yield much operational information
  - Systems are new, little experience past implementation
  - Best practices focus on installations
- Phase 1, Task 3
  - Conceptual work under way

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Overall project schedule

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EPG Project Team

Principal Investigators

- Ken Martin
- John Ballance

Engineers

- Iknoor Singh
- Prashant Palayam
- Xuanyu Wang
- Chen Sun

Software architect

- Simon Mo

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Risk Factors

- Some key SGIG grantees did not participate in survey
- Implementation & operation practices not universal
  - Utility procedures & work rules differ
- Real-time data validation
  - Different interpretation of data flags
  - Data dependencies definable but vendor differences
  - Data comparisons require interface to operational systems
- Algorithms may not adapt to all systems
- Test systems & data difficult to access

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Questions?

?

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Appendix D. Presentation at JSIS on October 17, 2013

The following slides were used for the presentation.

Joint Synchronized Information Subcommittee of the WECC

Data Validation & Conditioning

Ken Martin

Electric Power Group

October 17, 2013

Salt Lake City, UT

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2

Presentation

- Introduction of project
- Review first report - survey
- Review of second report – recommendations

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The Problem

- Phasors are well known to engineers …
  but synchrophasors are not
- Synchrophasor value dependencies
  - Precise timing source, algorithms, & hardware
- Systems dependent on real-time communications
  - Delay (latency), bandwidth, errors, & dropouts
- Need comparability with established systems (SCADA)
- Wide area, high-speed – faster actions

➡ Need assurance these measurements are correct

Introduction

- Data Validation and Conditioning Project
  - RFP issued in June 2012
  - Awarded to EPG in December 2012
  - Completion by October 2014
- Three stages
  - Stage 1 – survey, study, & prototype development
  - Stage 2 – prototype demonstration
  - Stage 3 – prototype functional specifications

Principle objective

- **Develop, test and prototype various methods for conditioning and validating real-time synchrophasor data**
  - Applicable to SGIG projects
  - Usable in deployed architectures
  - Include consideration of design & deployment
- Output includes cleaned data & quality flags

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EPG Proposal

- Issues go deeper than data
  - Equipment selection & compatibility
  - System design
  - System administration
  - Operation and maintenance
- Intent to tie all aspects together
- Data validation
  - Real-time
  - Data itself

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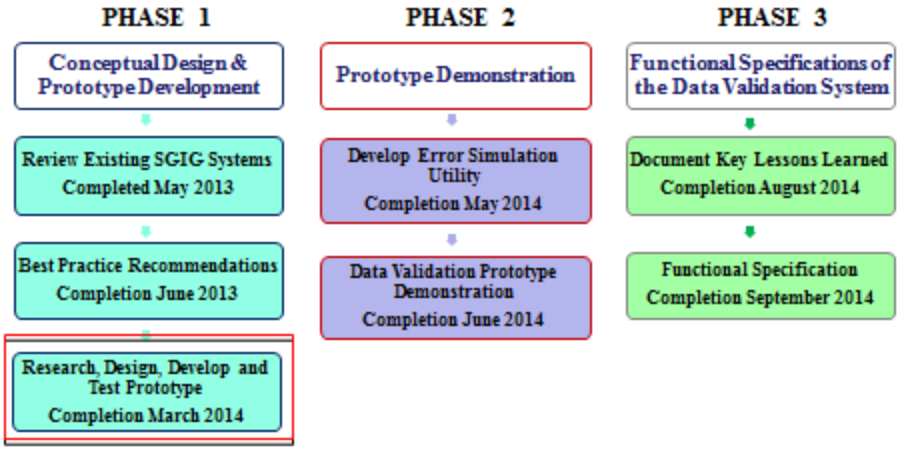
EPG Proposal and Plan



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Phase 1, Task 1

Review Existing SGIG Systems

Approach:

- Survey companies with SGIG projects and other companies with significant synchrophasor initiatives
- Review literature-sources – NASPI, IEEE, etc
- Summarize findings & report

Topics Surveyed:

- System Administration
- System Design and Implementation
- Operational Data Validation Systems
- Current Experience and Future Plans

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System Administration

Management structure

- Structure depends upon company size, project needs, experience, etc.
- Small management: 1-2 people
- Large management team: 5-6 people with task area responsibility

Comments & conclusions

- Most management teams worked well
- Management focused on implementation, not O&M (new systems)
- Some desire for more resources (staff) and better training
- Could use clearer procedures

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System Design and Implementation

Design, Signal Selection

- Typical design: PMU → PDC (TO CC)→PDC (ISO CC)
- Basic system with no redundancy to full redundancy
- Monitoring locations: Key substations, tie-lines, generators, wind farms, HVDC lines, etc.

PMU Selection & Deployment

- Convenience, cost, vendor familiarity
- Stand-alone PMUs, dual function relays (DFRs)
- Locations based on available infrastructure, communication, and cost considerations

Comments & conclusions

- Would like more bandwidth to substations
- Better latency performance
- Need better processes to address problems

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System & Data Validation

Installation Validation

- **Substation level -** Local meters/Relay test set
- **Control Center level -** Comparison with EMS
- **Equipment installations not always checked/ verified**

On-line data Validation

- **On-line data validation by vendor applications**
  - PDC, Real-time visualization & data analysis
- **Data Validation not done consistently**

Operation Problems

- **User applications not using error flags, or other data validation indicators**
- **Alarm/Email notifications not enabled**

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Current Experience & Future Plans

Current Experience of Respondents

- 90% to 99.96% system reliability
- Maintenance/replacement cycle same as for relays
- Budget constraints

Future Plans as Voiced by Respondents

- Most utilities installing more PMUs than originally planned
- Some new emphasis on sub-transmission and distribution systems
- Many companies have or are planning to integrate phasor data with SE

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List of 20 Survey Participants

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Phase 1, Task 2

Best practices recommendations

Approach:

- Identify practices in companies that were reported as being successful
- Combine with EPG experience in working with companies
- Summarize in best practices recommendations

Best Practices Topics:

- System Administration
- System Design and Implementation

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Best practices report

- Administration
- Planning
- Operation
- Maintenance
- Appendix A: detailed description of installation validation procedures
- Appendix B: troubleshooting guideline and procedures

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Project administration

- Individual components managed by usual department
- Multi-disciplinary coordination
  - Component operation tightly coupled across disciplines
  - Set policy, resolve issues
  - Coordinate all areas of system management
- Documentation & change management
  - Configuration management
  - Standard company documentation but add system aspects
  - Troubleshooting guide and history
- Problem resolution support
  - Troubleshooting, recommendations for system modification

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System implementation

- Coordination with other participants
- Application requirements drive specifications
  - PMU locations, signals measured, measurement details
  - Communication requirements
  - Application & data storage needs
- System design
- Equipment selection & procurement
  - Specification compliance
  - System operation testing (mockups)
  - Calibration

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System validation

- Comparisons in the substation
  - Installed instruments (limited accuracy, good reference)
  - Portable test instruments (high accuracy, basic signals)
- Validation at TO control center
  - Comparisons with SCADA or other metering
  - Validate location of measurement (line, bus) & scaling
  - Validate against other substations
  - Compare with state estimator (power flow, angles)
- Validate at RTO control center
  - Same as at TO CC, but wider scope
  - Inter-area phase angles (regional phasing)

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System operation

- On-line data validation
  - Checks on data flags & data cross checks
  - Live & historical performance information, alarms
- Off-line data validation
  - Look at data regularly!
  - Event analysis using measurement data
  - Measurement dynamic comparisons such as with DFR
- Analyze disturbance data
  - Monitor dynamic responses

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Maintenance

- System maintenance program
  - Follow established practices (substation equipment, communication system, servers, etc.)
  - Analog signal sources & PMU A/D (nothing else degrades)
- Trouble maintenance
  - Tools and procedures
- Configuration and document management
- Replacement program (probably in future)

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Project status

- Phase 1, Tasks 1 & 2 complete
- Phase 1, Task 3 under way
  - Conceptual development continuing
    - Flagged error detection & processing algorithms done
    - Data comparison algorithms under way
    - Topology based algorithms under development
  - Software implementations in design stage
- 2 months behind original plan, within contract schedule

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Questions?

?

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Data validation – JSIS feedback

- How far do we go for data repair?
  - Any data that is repaired is not a measurement
  - Risk masking real events and real problems
- How much delay can we put in a real-time stream?
- How to indicate errors?
  - Set data to NaN
  - Separate quality flags
  - Both?
- More??

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Appendix E. Presentation at NASPI on October 22, 2013

The following slides were used for the presentation.

NASPI North American SynchroPhasor Initiative

Data Validation & Conditioning

Ken Martin
Electric Power Group
martin@electricpowergroup.com

Oct 22, 2013
Chicago, IL

Electric Power Group

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Consortium for Electric Reliability Technology Solutions

Presentation

- Introduction of project
- Review first report - survey
- Review of second report – recommendations

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Introduction

- Data Validation and Conditioning Project
  - Awarded to EPG in December 2012
  - Completion by October 2014
- Three stages
  - Stage 1 – survey, study, & prototype development
  - Stage 2 – prototype demonstration
  - Stage 3 – prototype functional specifications

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Principle objective

- **Develop, test and prototype various methods for conditioning and validating real-time synchrophasor data**
  - Applicable to SGIG projects
  - Usable in deployed architectures
  - Include consideration of design & deployment
- Output includes cleaned data & quality flags

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EPG Proposal

- Issues go deeper than data
  - Equipment selection & compatibility
  - System design
  - System administration
  - Operation and maintenance
- Ties all aspects together
- Data validation
  - Real-time
  - Data itself

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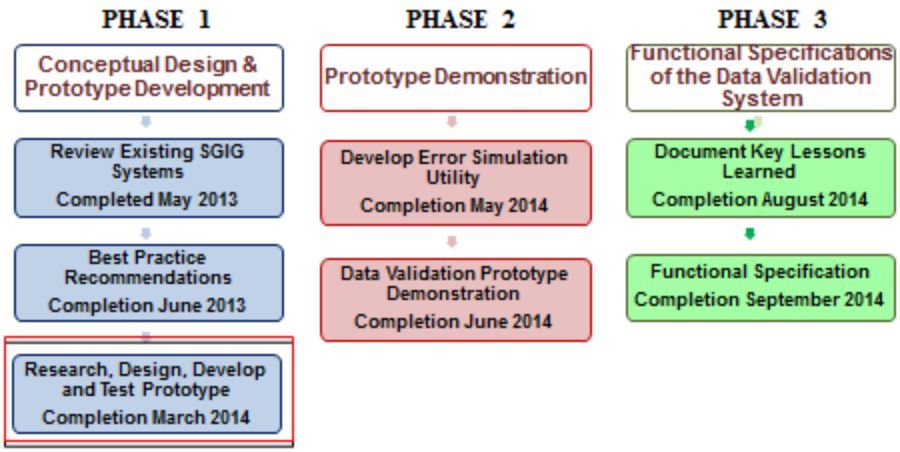
EPG Proposal and Plan



Phase 1, Task 1

Review Existing SGIG Systems

Approach:

- Survey companies with SGIG projects and other companies with significant synchrophasor initiatives
- Review literature-sources – NASPI, IEEE, etc
- Summarize findings & report

Topics Surveyed:

- System Administration
- System Design and Implementation
- Operational Data Validation Systems
- Current Experience and Future Plans

System Administration

Management structure

- Structure depends upon company size, project needs, experience, etc.
- Small management: 1-2 people
- Large management team: 5-6 people with task area responsibility

Comments & conclusions

- Most management teams worked well
- Focus was on implementation, not O&M (new systems)
- Some desire for more resources (staff) and better training
- Could use clearer procedures

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System Design and Implementation

Design, Signal Selection

- Typical design: PMU → PDC (TO)→PDC (ISO)
- Basic system, redundancy from none to full
- Monitoring locations: Key substations, generators, tie lines, etc

PMU Selection & Deployment

- Convenience, cost, vendor familiarity
- Stand-alone PMUs, dual function relays (DFRs)
- Locations based on available

Comments & conclusions

- Would like more bandwidth to substations
- Better latency performance
- Need better processes to address problems

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System & Data Validation

Installation Validation

- Substation level - Local meters/Relay test set
- Control Center level - Comparison with EMS
- Equipment installations not always checked/ verified

Data Validation

- On-line data validation by vendor apps
  - PDC, Real-time visualization & data analysis
- Off-line validation – records & snapshots

Operation Problems

- Data Validation not done consistently
- User applications not using error flags, or other data validation indicators
- Alarm/Email notifications not enabled

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Current Experience & Future Plans

Current Experience of Respondents

- 90% to 99.96% system reliability
- Maintenance/replacement cycle same as for relays
- Budget constraints

Future Plans as Voiced by Respondents

- Most utilities installing more PMUs than originally planned
- Some new emphasis on sub-transmission and distribution systems
- Many companies have or are planning to integrate phasor data with SE

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- Dominion Power
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- Los Angeles Department of Water and Power
- Manitoba Hydro
- New York Power Authority
- Oklahoma Gas and Electric
- ONCOR
- PEPCO
- PJM Interconnection, LLC
- Salt River Project
- Southern California Edison

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Phase 1, Task 2

Best practices recommendations

Approach:

- Identify practices in companies that were reported as being successful
- Combine with EPG experience in working with companies
- Summarize in best practices recommendations

Best Practices Topics:

- System Administration
- System Design and Implementation

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Best practices report

- Administration
- Planning
- Operation
- Maintenance
- Appendix A: detailed description of installation validation procedures
- Appendix B: troubleshooting guideline and procedures

© Electric Power Group

Project administration

- Individual components managed by traditional department
- Multi-disciplinary coordination team
  - Operation is tightly coupled across disciplines
  - Set policy, resolve issues
  - Coordinate all areas of system management
- Documentation & change management
  - Configuration management
  - Standard company documentation but add system aspects
  - Troubleshooting guide and history
- Problem resolution support
  - Troubleshooting, recommendations for system modification

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System implementation

- Coordination with other participants
- Application requirements drive specifications
  - PMU locations, signals measured, measurement details
  - Communication requirements
  - Application & data storage needs
- System design
- Equipment selection & procurement
  - Specification compliance
  - System operation testing (mockups)
  - Calibration

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System validation

- Comparisons in the substation
  - Installed instruments (limited accuracy, good reference)
  - Portable test instruments (high accuracy, basic signals)
- Validation at TO control center
  - Comparisons with SCADA or other metering
  - Validate location of measurement (line, bus) & scaling
  - Validate against other substations
  - Compare with state estimator (power flow, angles)
- Validate at RTO control center
  - Same as at TO CC, but wider scope
  - Inter-area phase angles (regional phasing)

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System operation

- On-line data validation
  - Checks on data flags & data cross checks
  - Live & historical performance information, alarms
- Off-line data validation
  - Look at data regularly!
  - Event analysis using measurement data
  - Measurement dynamic comparisons such as with DFR
- Analyze disturbance data
  - Monitor dynamic responses

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Maintenance

- System maintenance program
  - Follow established practices (substation equipment, communication system, servers, etc.)
  - Analog signal sources & PMU A/D (nothing else degrades)
- Trouble maintenance
  - Tools and procedures
- Configuration and document management
- Replacement program (probably in future)

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Project status

- Phase 1, Tasks 1 & 2 complete
- Phase 1, Task 3 under way
  - Conceptual development continuing
    - Flagged error detection & processing algorithms done
    - Data comparison algorithms under way
    - Topology based algorithms under development
  - Software implementations in design stage
- A little behind plan, but within schedule!

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Questions?

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Appendix F. Presentation at JSIS on January 23, 2014

The following slides were used for the presentation.

WECC JSIS

Data Validation & Conditioning

Ken Martin
Electric Power Group
martin@electricpowergroup.com
Jan 23, 2014
Phoenix, AZ

Presentation

- Introduction of project
- First report - survey
- Review of second report – recommendations
- Algorithm & implementation

Introduction

- Data Validation and Conditioning Project
  - RFP issued in June 2012
  - Awarded to EPG in December 2012
  - Completion by October 2014
- Three stages
  - Stage 1 – survey, study, & prototype development
  - Stage 2 – prototype demonstration
  - Stage 3 – prototype functional specifications

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Principle objective

- **Develop, test and prototype various methods for conditioning and validating real-time synchrophasor data**
  - Applicable to SGIG projects
  - Usable in deployed architectures
  - Include consideration of design & deployment
- Output includes cleaned data & quality flags

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EPG Proposal

- Issues go deeper than data
  - Equipment selection & compatibility
  - System design
  - System administration
  - Operation and maintenance
- Intent to tie all aspects together
- Data validation
  - Real-time
  - Data itself

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EPG Proposal and Plan

PHASE 1

- Conceptual Design & Prototype Development
- Review Existing SGIG Systems
  Completed May 2013
- Best Practice Recommendations
  Completion June 2013
- Research, Design, Develop and Test Prototype
  Completion March 2014

PHASE 2

- Prototype Demonstration
- Develop Error Simulation Utility
  Completion May 2014
- Data Validation Prototype Demonstration
  Completion June 2014

PHASE 3

- Functional Specifications of the Data Validation System
- Document Key Lessons Learned
  Completion August 2014
- Functional Specification
  Completion September 2014

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Phase 1, Task 1

Review Existing SGIG Systems

- Surveyed companies with synchrophasor systems
- Reviewed literature-sources – NASPI, IEEE, etc.
- System Administration adapted to company
  - Some need for better procedures
- System Design and Implementation procedures varied
  - Need better design of system
  - Need more installation validation
- Operational Data Validation System little used
  - Need on-line validation
- Good current experience and Plan future expansion
  - 90-99% reliability reported

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Phase 1, Task 2

Best practices recommendations

- Administration
- Planning
- Operation
- Maintenance
- Appendix A: detailed description of installation validation procedures
- Appendix B: troubleshooting guideline and procedures

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Project administration

- Individual components managed by usual department
- Multi-disciplinary coordination
  - Component operation tightly coupled across disciplines
  - Set policy, resolve issues
  - Coordinate all areas of system management
- Documentation & change management
  - Configuration management
  - Standard company documentation but add system aspects
  - Troubleshooting guide and history
- Problem resolution support
  - Troubleshooting, recommendations for system modification

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System implementation

- Coordination with other participants
- Application requirements drive specifications
  - PMU locations, signals measured, measurement details
  - Communication requirements
  - Application & data storage needs
- System design
- Equipment selection & procurement
  - Specification compliance
  - System operation testing (mockups)
  - Calibration

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System validation

- Comparisons in the substation
  - Installed instruments (limited accuracy, good reference)
  - Portable test instruments (high accuracy, basic signals)
- Validation at TO control center
  - Comparisons with SCADA or other metering
  - Validate location of measurement (line, bus) & scaling
  - Validate against other substations
  - Compare with state estimator (power flow, angles)
- Validate at RTO control center
  - Same as at TO CC, but wider scope
  - Inter-area phase angles (regional phasing)

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System operation

- On-line data validation
  - Checks on data flags & data cross checks
  - Live & historical performance information, alarms
- Off-line data validation
  - Look at data regularly!
  - Event analysis using measurement data
  - Measurement dynamic comparisons such as with DFR
- Analyze disturbance data
  - Monitor dynamic responses

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Maintenance

- System maintenance program
  - Follow established practices (substation equipment, communication system, servers, etc.)
  - Analog signal sources & PMU A/D (nothing else degrades)
- Trouble maintenance
  - Tools and procedures
- Configuration and document management
- Replacement program (probably in future)

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Phase 1, Task 3

Develop DV algorithm, implement, & test

- Algorithms developed for problem detection
  - Detects all specified errors
  - Addresses situations that can cause errors
- Implementation in a software package
- Testing with basic scenarios
- Testing with real data sets

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Validation algorithm – overall process

- Overall process execution
- Individual model for each algorithm
- Written descriptions for details no on diagram
- Code developed on the basis of model

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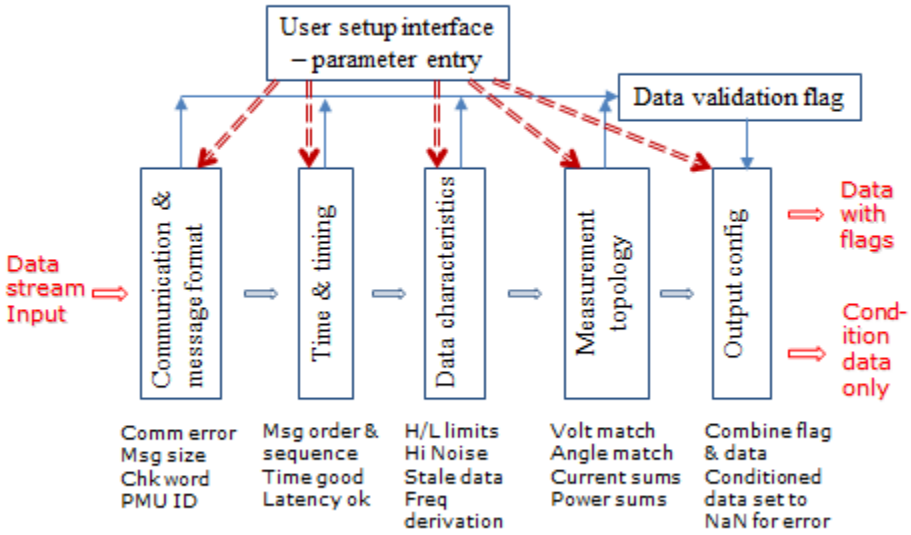
Algorithm process & stages



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Project status

- Phase 1, Tasks 1 & 2 complete
- Phase 1, Task 3 under way
  - Conceptual development completed
  - Software implementation just completed
  - User interface nearly done
  - Testing to start in February
- Will start data set tests in March

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Questions?

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Appendix G. Presentation on EPG WebX on January 28, 2014

The following slides were used for the presentation.

Electric Power Group Presents
Operationalizing Phasor Technology

Welcome!

The presentation will begin at:
2:00 p.m. EDT / 11:00 a.m. PDT

January 28, 2014

Presenter: Ken Martin

Topic: **Synchrophasor Data Diagnostics: Detection and Resolution of Data Problems for Operations and Analysis**

Webinar Teleconference Number: 1-650-479-3208
Access code: 662 746 127

Please mute your phone during the presentation.
We will address questions at the end.
Thank you for your cooperation.

For any technical issues with this webinar, please contact Kosareff@electricpowergroup.com or call (626) 685–2015

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Operationalizing Phasor Technology

Synchrophasor Data Diagnostics: Detection & Resolution of Data Problems for Operations and Analysis

Webinar

January 28, 2014

Presented by
Ken Martin

Electric Power Group

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Why Is There Concern About Synchrophasor Data Quality?

▪ Data – high resolution means lots of data	More errors & missing data
▪ Applications and Uses - Visualization and Analysis	Need bad data detection and suppression
▪ Understanding data	Noise, spikes, swings – real or bad data?
▪ Parameters – many	What do they mean?
▪ Experience with synchrophasor systems	Limited, longer time to detect problems and repair, less knowledge and experience in finding root causes

Frequently Asked Questions

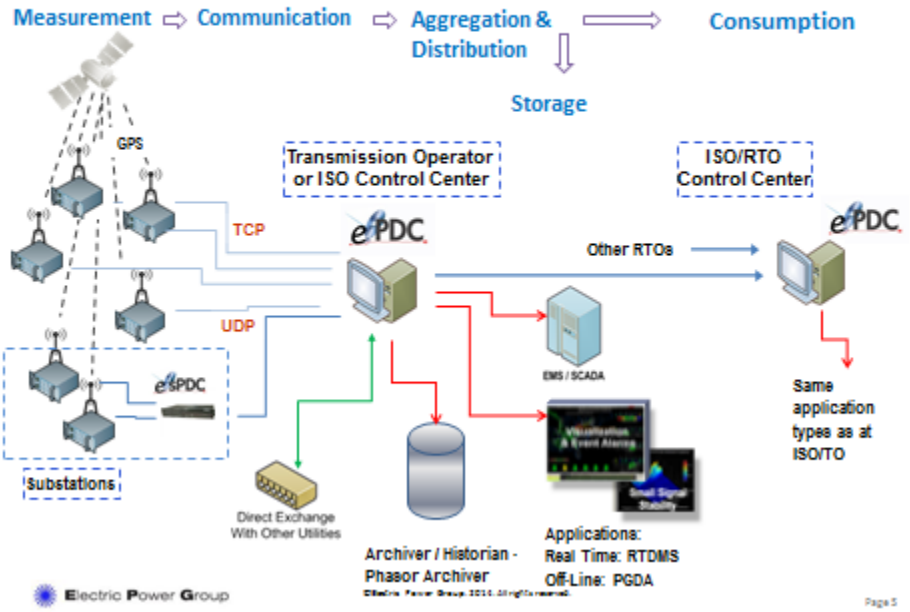
- What can I expect from phasor data?
- How do I make sure that data is good and usable?
- How do I detect and diagnose data problems?
- How do I get problems fixed?

When Can I trust the data for Operations and Analysis?

Presentation Outline

- Synchrophasor systems
- Comparison with SCADA
- Building Blocks of a Synchrophasor System for High Data Quality
- Typical Data Problem Examples
- Data Quality System Approach
- Summary
- Q & A

Typical Synchrophasor System



Phasor vs. SCADA Measurements

Why are we implementing Synchrophasors in addition to existing SCADA systems?

ATTRIBUTE	SCADA	PMU
Resolution	1 sample every 2-4 seconds *(Steady State Observability)*	10-60 samples per second *(Dynamic/Transient Observability)*
Measured Quantities	Magnitude Only	Magnitude & Phase Angle
Time Synchronization	No, correlation at master only *(1-4 sec data skew)*	Yes, at measurement *(no data skew)*
Data reporting	Polled by master, delay on poll & re-poll *(1+ sec)*	Pushed by PMU, minimal delay *(<100 ms)*
Data easier to use	MW/MVAR need estimation to give bus angles	Direct application to model, Linear State Estimation
Focus	Local utility monitoring; load flow & steady-state limit control	Wide area monitoring; steady-state & dynamic performance control

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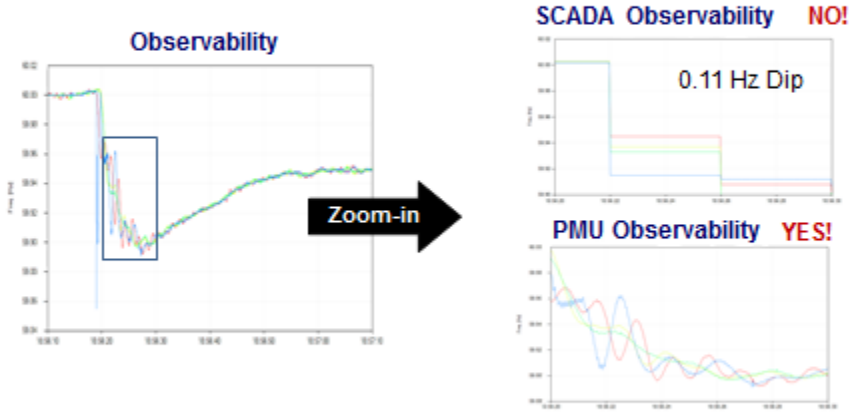
SCADA and PMU Observability - *Example*

Dynamic System Interactions as seen in the Frequency Measurement



SCADA - Frequency appears to be similar at all locations – no oscillations
PMU's - Frequency measurements show dynamic interaction
– allows investigation of inter-area dynamics

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Synchrophasor and SCADA Systems

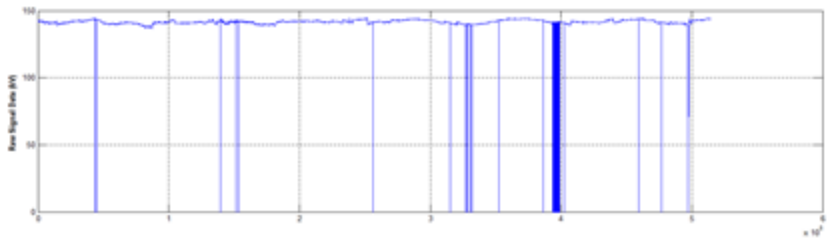
- **Similarities – Both Systems:**
  - Report power system measurements & other parameters
  - Gather data from substations & power stations
  - Report system data
- **Synchrophasor Data – Attributes:**
  - Gather data at a much higher data rate
  - Push data, do not poll
  - Measure all system phase angles
  - Utilize high accuracy timing
  - Use a complex algorithm to compute values
  - Precisely timetag all data
  - Wide Area Coverage – Not Limited to Control Area Footprint

Synchrophasor System Data Issues

- More elements required – more things can go wrong
- Data gathered at a higher data rate
  - Momentary interruptions & network congestion – data loss
  - With high-resolution applications, data loss very visible
- Data pushed from PMU/PDC
  - No retransmission
- Require high accuracy timing
  - High-accuracy, continuous timing has many failure modes
  - Newer technology, many unexpected errors
- Complex algorithm required to compute values
  - New technology, many unanticipated difficulties

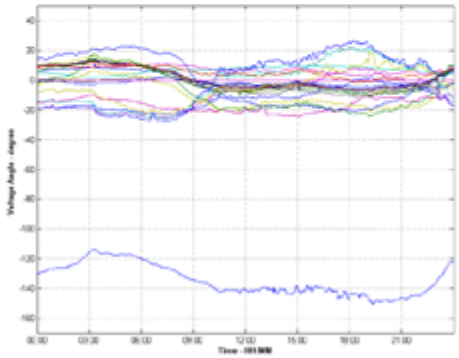
Data Problem - Dropouts

- Data dropouts – communication issues
- Resolution:
  - Investigate & correct communication problem
  - Flag data to prevent use of "filler" data



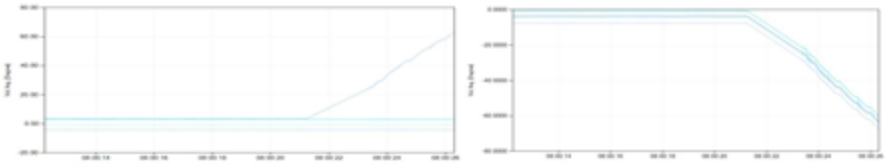
Data Problem – Phase Angle Offset

- One phase angle 120° offset from others
- Resolution
  - Correct phase reference
  - Use data system to adjust angle



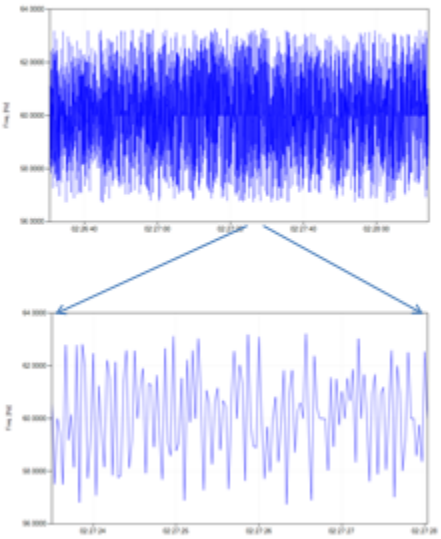
Data Problem – PMU Sync

- One angle drifts away from group—PMU sync is lost
- All angles drift away—sync for reference PMU is lost
- Resolution:
  - Repair timing input to PMU
  - Data system flags block use of errored angles



Data Problem – High Noise on Signal

- Noisy signal – but wait!
- When expanded we see the problem is an oscillation
  - Could be a real system event
  - Could be PMU error
- Resolution:
  - Investigate unusual signal indications carefully
  - Use filtering, downsampling, & other data system improvements only after problem confirmation



System Implementation for High Quality Data

- Qualify System Elements
  - PMUs meet measurement standards & utility requirements
  - Communications meets bandwidth, latency, & reliability
  - Applications interpret flags & execute test algorithms
- Validate Installations
  - Assure naming, wiring, polarity, signal identifications correct
  - Calibrate measurements
- Use Flags for Error Detection and Timely Repairs
  - Detect, flag, and identify problems
  - Repair data where possible

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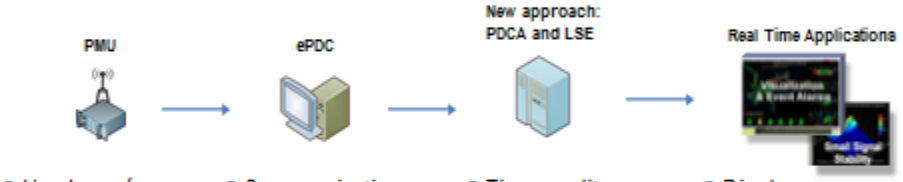
High Data Quality Synchrophasor System

Detect & Flag Problems at Each Stage



- Hardware/ firmware check
- Algorithm solution validation
- GPS sync check
- Trigger detection

- Communication
- Dropouts
- Latency check
- Status check
- Time quality check

- Time quality check
- Range check
- Stale check
- Noise check
- Topology check
- Scaling factor check

- Display adjustment for status flag
- Range adjustment
- Time quality check

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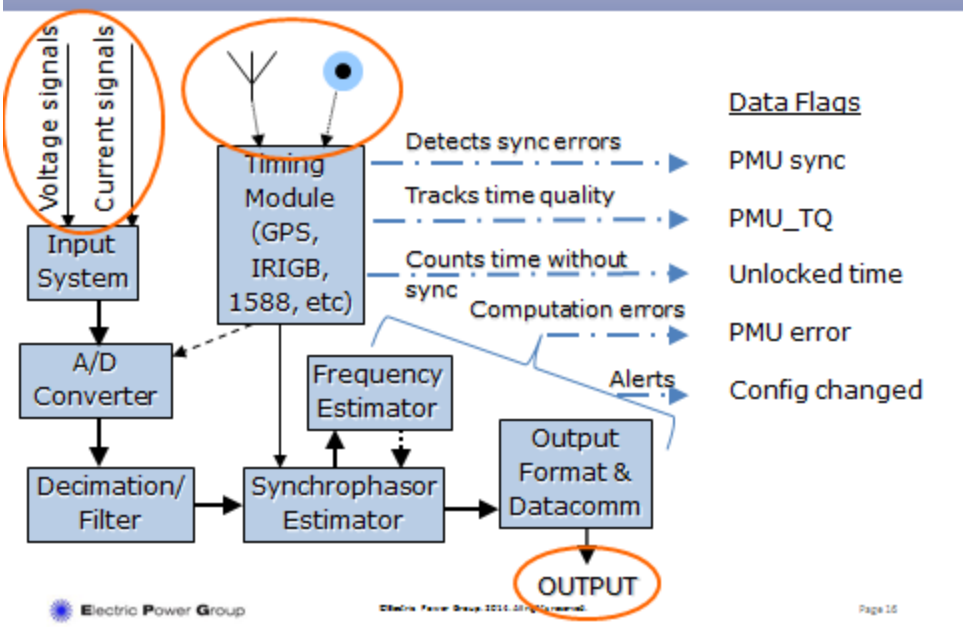
Problem Detection & Flagging – PMU



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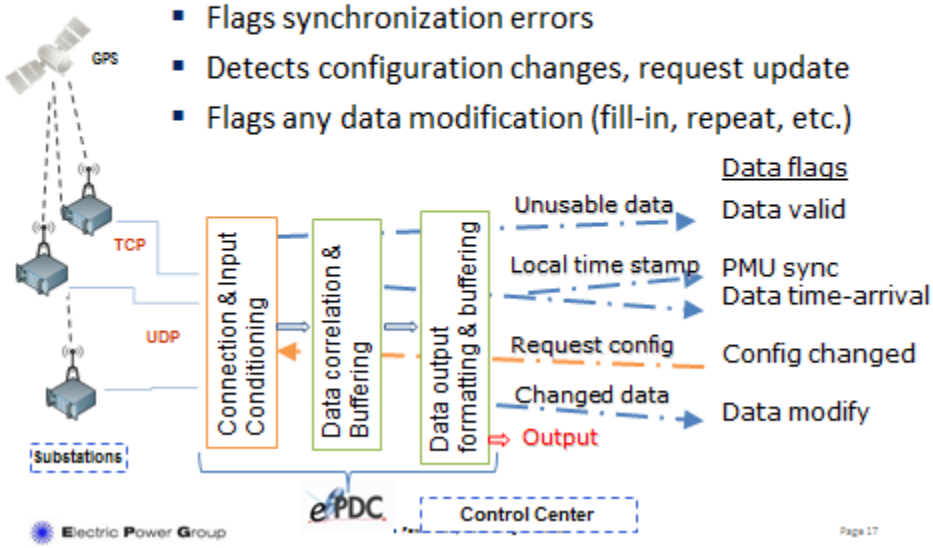
Using Flags for Problem Detection – PDC

- Detects/flags transmission errors & lost data
- Flags synchronization errors
- Detects configuration changes, request update
- Flags any data modification (fill-in, repeat, etc.)



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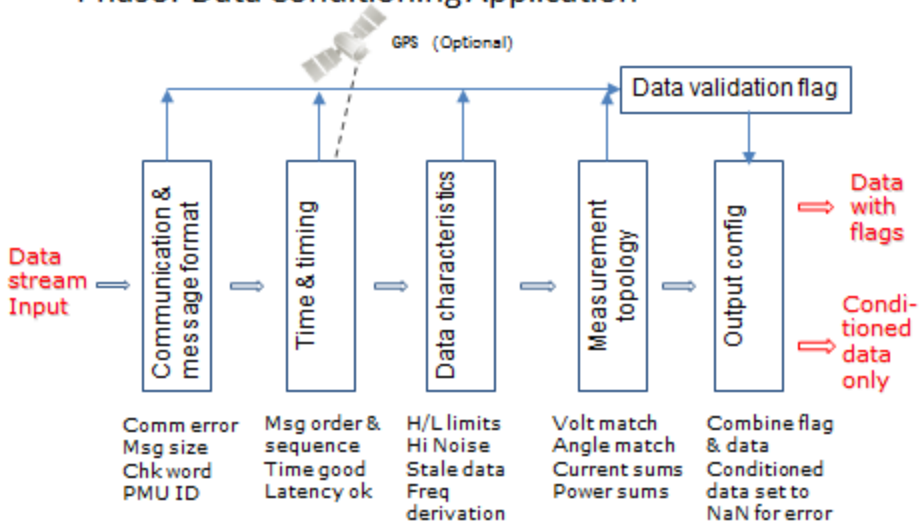
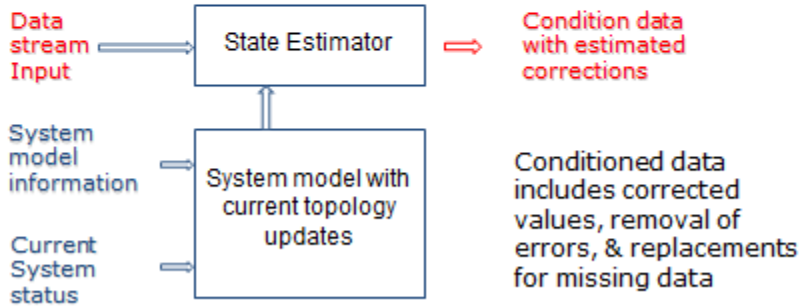
Algorithmic Problem Detection and Data Conditioning – PDCA

- Phasor Data Conditioning Application

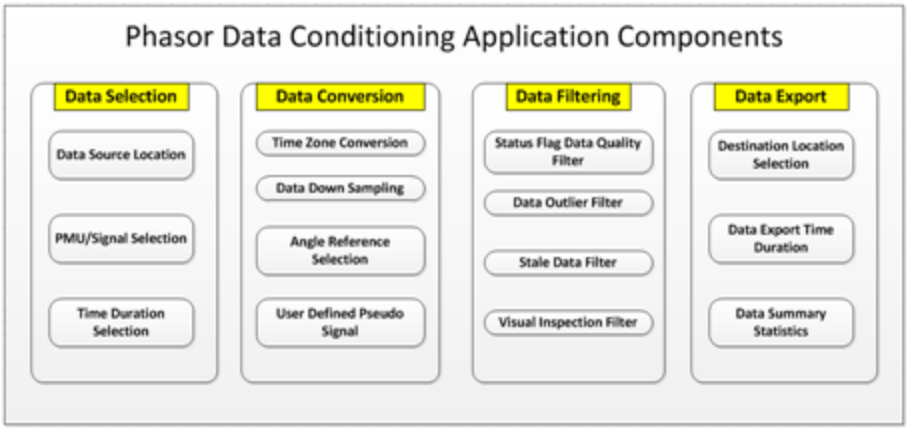


State Estimation – Model Based Error Detection & Repair

- State Estimation
  - Traditional
  - Linear
- Improve accuracy
- Detect errors
- Supply missing values



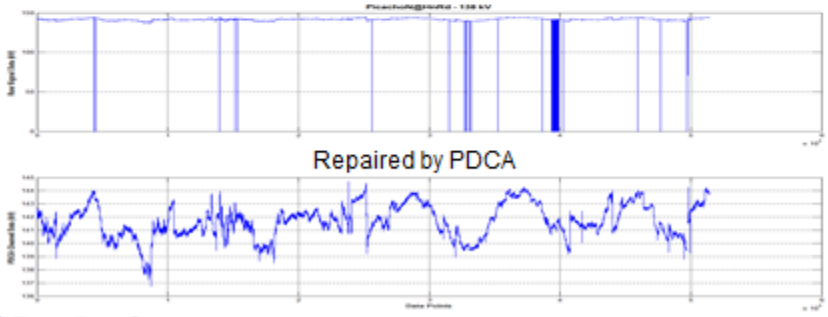
Use of PDCA for Historical Data Validation and Conditioning



Used for cleaning 6-months worth of ERCOT data

Example – Dropout Data Repair

- Data dropouts – flagged by PDC
- Repair by PDCA:
  - Data approximated by linear or quadratic interpolation
  - Close approximation to original (limited by reporting bandwidth)



Data System Management

- Assure that applications correctly identify & handle error flagged data
- Create catalog of data problem signatures
  - Allows quick identification of typical problems
- Use output of high data quality system to alert users for needed repairs
- Keep log of problems and their resolution
  - Helps new personnel to 'come up to speed'
  - Identify persistent problem areas for redesign or equipment replacement
- Update procedures as needed

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Summary

- **Data quality starts with good design & implementation**
- **Data problems can be detected with a high quality phasor system**
- **Continued high performance requires good system management**
- **With Quality Management, Phasor Data Can Be Used With Confidence**

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Feedback

Your feedback and suggestions are important!
PLEASE do let us know…

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Q&A

Thank You!

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Appendix H. Presentation at NASPI on March 12, 2014

The following slides were used for the presentation.

NASPI North American SynchroPhasor Initiative

Data Validation & Conditioning

Ken Martin
Electric Power Group
martin@electricpowergroup.com

March 12, 2014
Knoxville, TN

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2

Presentation

- Introduction of project
- Task 1 - survey
- Task 2 – recommendations
- Task 3 – algorithm
- Algorithm description

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Introduction

- Data Validation and Conditioning Project
  - Awarded to EPG in December 2012
  - Completion by October 2014
- Three stages
  - Stage 1 – survey, study, & prototype development
  - Stage 2 – prototype demonstration
  - Stage 3 – prototype functional specifications

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Principle objective

- **Develop, test and prototype various methods for conditioning and validating real-time synchrophasor data**
  - Applicable to SGIG projects
  - Usable in deployed architectures
  - Include consideration of design & deployment
- Output includes cleaned data & quality flags

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EPG Proposal

- Issues go deeper than data
  - Equipment selection & compatibility
  - System design
  - System administration
  - Operation and maintenance
- Ties all aspects together
- Data validation
  - Real-time
  - Data itself

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EPG Proposal and Plan

PHASE 1

- Conceptual Design & Prototype Development
- Review Existing SGIG Systems
  Completed May 2013
- Best Practice Recommendations
  Completion June 2013
- Research, Design, Develop and Test Prototype
  Completion March 2014

PHASE 2

- Prototype Demonstration
- Develop Error Simulation Utility
  Completion May 2014
- Data Validation Prototype Demonstration
  Completion June 2014

PHASE 3

- Functional Specifications of the Data Validation System
- Document Key Lessons Learned
  Completion August 2014
- Functional Specification
  Completion September 2014

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Phase 1, Task 1

Review Existing SGIG Systems

- Surveyed 20 companies that have SGIG projects or significant synchrophasor development
- Reviewed literature-sources – NASPI, IEEE, etc.

Findings:

- System Administration tailored to project
- Various design procedures – generally seemed adequate
- Implementation checkout procedures usually minimal
- Few operational Data Validation Systems
- Most utilities planning future expansion

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Phase 1, Task 2

Best practices recommendations

- Drew up best practice recommendations based on -
  - Survey – practices that work
  - EPG experience in working with companies

Best Practice Recommendations:

- Recommend multi-disciplinary system administration
- Coordinate between parties working on the project
- Validate the system at every level to be sure the measurements are accurate and correctly identified
- Use on-line data validation catch problems
- Institute a maintenance program

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Phase 1, Task 3

Algorithm development & initial testing

Algorithm development – approach:

- Create a generic enough algorithm for wide use
- Use existing validation methods as much as possible
  - C37.118 validation flags
  - Additional primary considerations like message format
- Use secondary considerations that are available
  - Communication interface flags
  - Known data relationships & reasonable limits
- Offer methods using system relationships, but not requiring a full model

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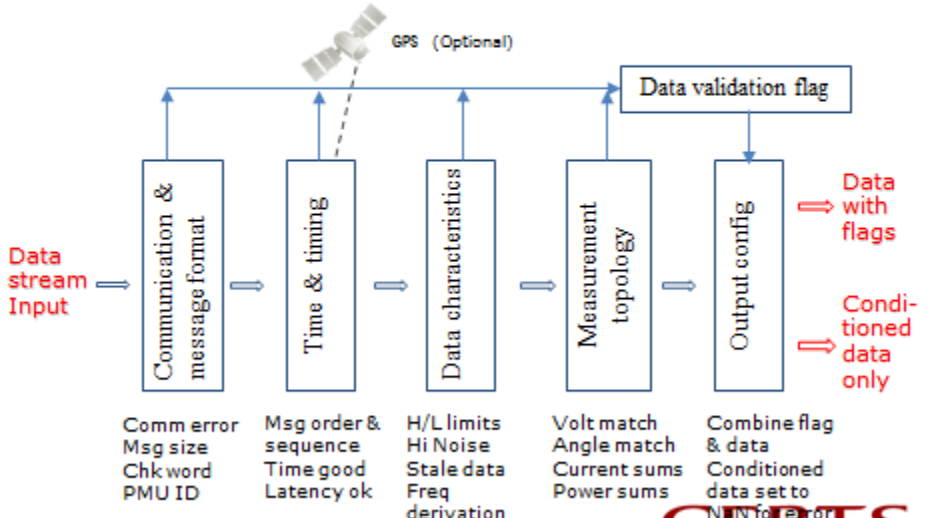
Data Validation and Conditioning Algorithm



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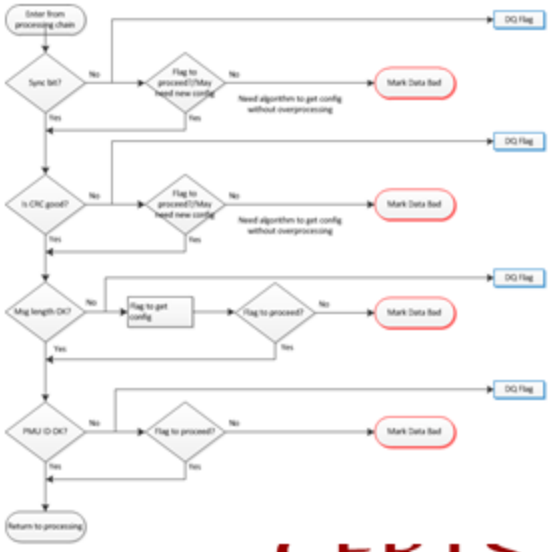
Algorithm is a series of processes

- Input data converted to FP-polar
  - No loss of resolution
  - Can separate phase (time) and amplitude errors
- Processes follow logical progression
  - After some errors, no further processing needed
- Data output can be with or w/o conditioning
  - Conditioning declares data bad by setting to NaN
  - Data flags can be included



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Initial – communication, format, & time

- Communication error
  - From the interface, such as frame error, dropped TCP link, etc.
- Message format error
  - Frame too long, bad CRC, wrong PMU-ID
- Time stamp error
  - Time within bounds
  - Message out of sequence
- Latency calculation
  - Within user set bounds
  - Large variation
- These error types also can provide security (intrusion)

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Second – 118 flags & data characteristics

- C37.118 status flags indicate many detectable problems
  - Data validity, time stamp, and modification
  - Time synchronization
  - PMU error
  - Small differences between 2005 & 2011 versions
- Data characteristics
  - Continuing repetition of values (stale or "stuck" output)
  - High noise (signal content above passband)
  - Readings within H/L limits
  - Values that invalidate other measurements (frequency from voltage phasor)

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Last stage – topology & output

- User configurable topology
  - Generic math & logic available (+, -, /, *, =, ≤, ≥, ≠, etc.)
  - Combine signals to detect possible errors
    - Sum of currents through a bus
    - Match currents at ends of lines
    - Match voltages on connected busses
    - Other appropriate combinations
- Bad data set to NaN to prevent further use
- Data with fatal errors always set to bad (NaN)
- Dual outputs
  - Output partially conditioned with flags (only fatal errors cleaned)
  - Output with fully conditioned data

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Data Quality Flag

- Data quality flag – 8 bit
  - Flag for each value
    - Phasor magnitude , angle,
    - Frequency & ROCOF
  - Can be sent in 118 stream – 2 flags into integer analog/digital

Q	Q	S	S	S	S	L	L
Quality		Sub-status				Limit	

- Quality – good, bad, uncertain, reserved
- Sub-status – reason for the quality indication
- Limit – value at H/L limit, cannot move, or ok
- Flag similar to OPC DA or field-bus flag

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Project status

- Phase 1, Tasks 1 & 2 complete
- Phase 1, Task 3 near completion
  - Conceptual development completed
  - Software developed & test ongoing
  - Last 2 reports nearly complete
- Phase 2, Task 1 started concurrently
  - Developing test algorithm

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Questions?

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