Synchro-Phasor Data Conditioning and Validation Project

Phase 1, Task 3

Report on

Testing Procedures and Test Results

Prepared for the
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Disclaimer

Preface

Synchrophasor systems have been deployed across the world. Data quality becomes a significant issue when users do not trust that it accurately represents the measured quantities. This not only causes frustration with using existing systems, but sometimes hinders further adoption of synchrophasor technology. To address the data quality problem, Department of Energy (DoE) has funded the Phasor Data Validation and Conditioning project to develop and demonstrate algorithms to detect common data quality issues in real-time (DE-AC02-05CH11231).

As part of Phase 1 task 3, this Report documents Test Procedures and Test Results for testing of algorithms of the Phasor Data Validation and Conditioning (PDVC) prototype system. Electric Power Group's internal testing following the testing procedures indicates that the PDVC prototype system meets the requirements.

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Phase 1, Task 3

Report on: Testing Procedures and Test Results

Summary

The purpose of this document is to outline detailed test procedures and summarize test results based on the functional requirements of the features to be implemented into a Phasor Data Validation and Conditioning (PDVC) demonstration system.

This document consists of the following chapters:

Section 1, Project Background and Summary – Introduces the project and provides a summary of the test procedure.

Section 2, User Stories – Provides stories derived from the requirements.

Section 3, Testing Procedures and Testing Cases.

Section 4, Conclusion.

Appendix A, Data Quality Code used in PDVC.

Appendix B, Screenshots of PDVC application shows the algorithm configuration and example results.

Appendix C, Screenshots of EPG's PMU Simulator application.

1Project Background and Summary

Electric Power Group (EPG) staff initiated this data validation and conditioning project with a series of utility surveys and a literature search to determine the state of current practices. A report on these findings was issued in July 2013. Following that, a summary report of best practices for design, implementation, and operation of synchrophasor systems was produced in August 2013 based on the survey and EPG's domain knowledge. That research was applied to develop algorithms for validation and conditioning synchrophasor data in real-time. The algorithms were developed for 6 separate modules as listed below and reported on in March, 2014.

1. Module 1- Communication Interface: This module is designed to check for errors that may be introduced in the communications chain such as dropped bits, incorrect message frames, and CRC errors.

2. Module 2 – Message Characteristics: This module checks for message format errors such as length, destination address, type identification, and CRC16-check.
3. Module 3 – Timestamp: This module checks time tags for sequencing, data rates and transmission delays.
4. Module 4 – Quality Flags: This module utilizes all the flags available in the C37.118 standard to distinguish between good, bad, and uncertain measurements. Bad data is converted to NaN, suspect data is flagged, and all data is passed on to the next module for further processing.
5. Module 5 – Data Characteristics and Self-Checking: This module incorporates algorithms to check for unreasonably high or low values of voltage, current and frequency, data that is stale (not refreshing), and excessively noisy. Depending on severity, data that fails testing is declared bad and set to NaN or uncertain and flagged.
6. Module 6 – Topology Checking: The last module uses system topology to build algorithmic logic checking. For example, the sum of currents into a bus should be 0, and voltages at the same bus should be the same.

This document addresses test procedures for the algorithms based on use cases and feature list. User stories are derived from the functional requirements that will assure that the requirements are met. The algorithm is then tested against the user stories to be sure it meets the requirements. The functional requirements and the derived user stories are detailed in Section 2. A test procedure is required to test the user stories. These procedures are detailed in Section 3. Each user story has a test procedure that lists the expected results for each step. Once the procedure is completed successfully with the expected outcome at each step, the story is marked complete. The EPG team has completed all of the tests enumerated in this report and all tests were completed with no exceptions.

Figure 1 below illustrates the derivation and testing process.

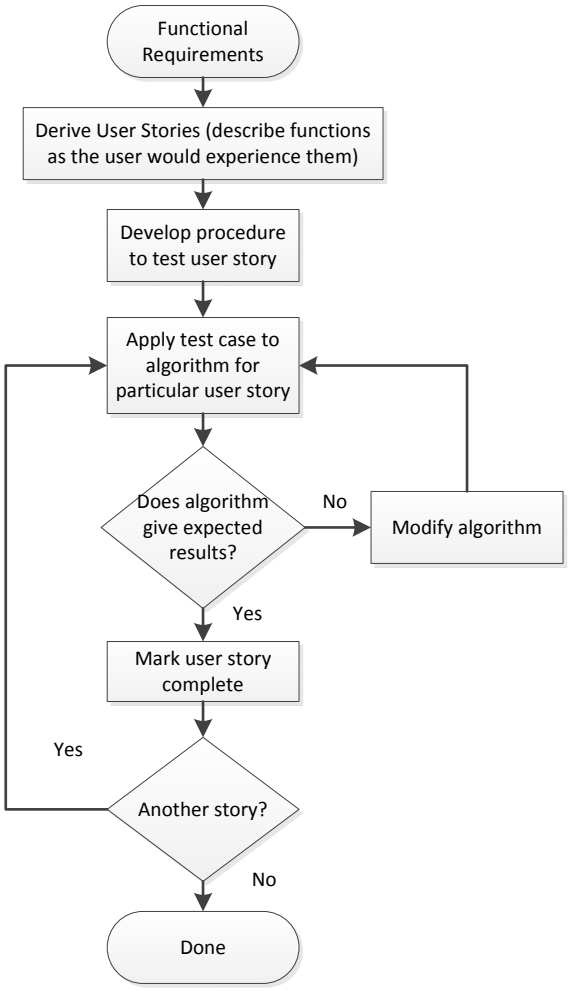


Figure 1. Development & testing of functional requirements through user stories

2. Phasor Data Validation and Conditioning User Stories

2.1 Introduction

This section introduces the methodology in Section 2.2, algorithm structure in Section 2.3, functional requirements in Section 2.4, and user stories in Section 2.5.

2.2 Methodology

EPG has adopted the agile development method in which requirements are defined, user stories are prepared, and application is developed iteratively based on the user stories.

2.3 Algorithm Structure

Figure 2 shows the overall structure of the algorithm. Raw data input is validated and conditioned by a series of individual sub-processes (algorithms). These are arranged in an order that allows each process to build on previous ones without loss of functionality. Flags, as detailed in Appendix A, are built and added to at each step as needed. The conditioned data is then converted back in to the C37.118 data format and output with or without the added flags as the user chooses.

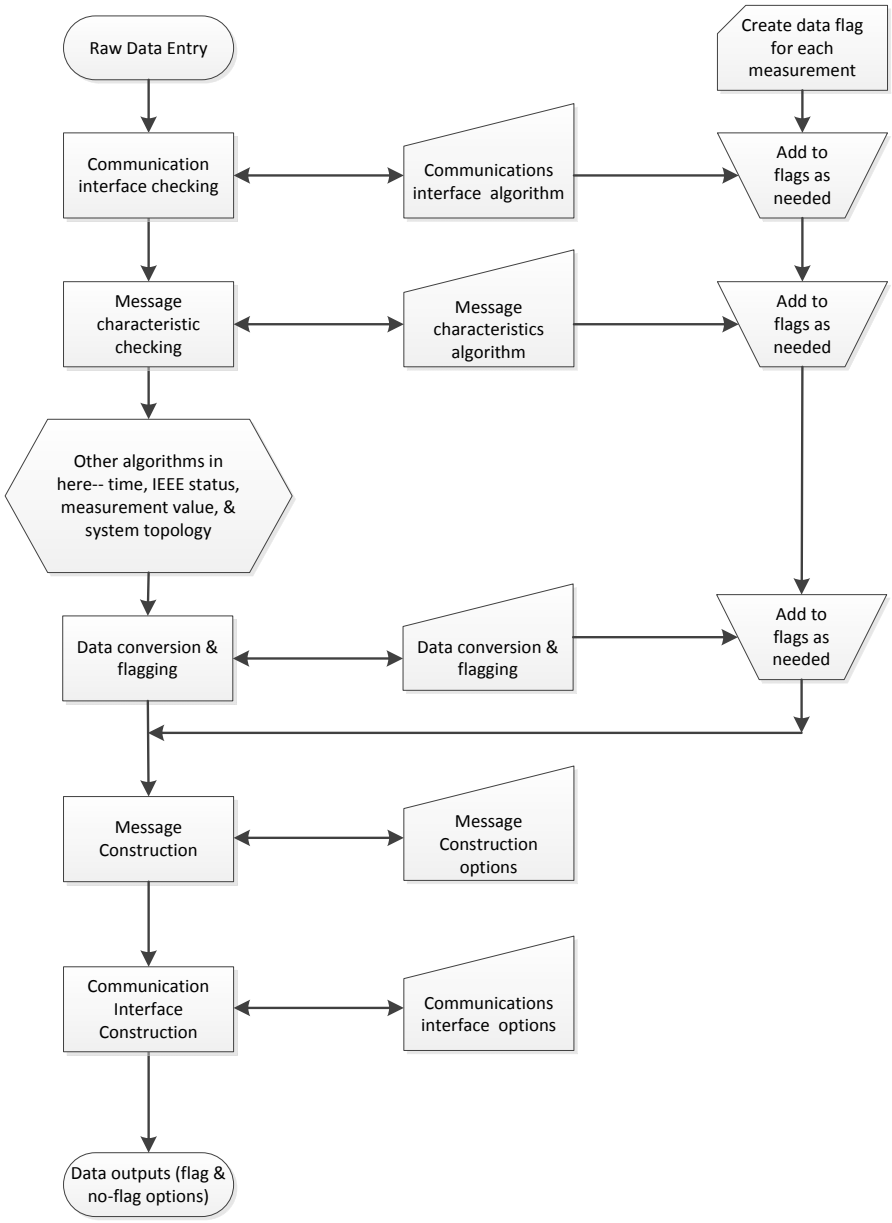


Figure 2. Overall structure of DV & C algorithm

2.4 Functional Requirements

Functional requirements are gathered from EPG experiences, surveys, and functional requirements listed in DE-AC02-05CH11231 contract.

Functional requirements for the validation and conditioning algorithm are listed below. These requirements have been developed by EPG based on surveys, literature research, and experience in working with customers. They are grouped by type of problem and detection. In order to test implementation of these requirements, "user stories" have been developed. These stories describe the way the user should experience the algorithm operation if it was implemented correctly and addressed the problem. The individual stories are given as a group and not keyed to specific requirements. One user story may address several requirements and conversely, some requirements may be addressed by several stories. For example, user story US 02-0010 requires the user wants to be alarmed that if there are data samples out of sequence. This could be due to a corrupted timing reference or intermittent communications, two separate requirements. The user stories are identified as a list with the requirement group that they address.

ID of Requirement Group	Requirements by Error Detection Type	Derived User Story Group
PDVC - 1	Detect Message Errors: • Data corruption • Data tampering	US 01-0010 US 01-0020 US 01-0030 US 01-0040
PDVC - 2	Detect Data Errors • Loss of data from one or several PMUs • Loss of signals in a PMU • Offset in signal magnitude and phase • Corrupted and drifting signals in a PMU • Corrupted and drift timing time reference in one or several PMUs • Intermittent communications, inconsistent data rates and latencies • Frozen or repeated (stale) measurements • Measurement identification • Measurement corruption • Measurement exceeds engineering limits	US 02-0010 US 02-0020 US 02-0030 US 02-0040 US 02-0050 US 02-0060 US 02-0070 US 02-0080 US 02-0090 US 02-0100 US 02-0110 US 02-0120 US 02-0130 US 02-0140 US 02-0150 US 02-0160
PDVC - 3	Flag Errors & Data Correction • Data quality flags (good, suspect, bad)	US 03-0010 US 03-0020

	• Indication for other programs • Indicate safe uses for impaired data • Offer users the choice to auto-correct or only flag errors	US 03-0030 US 03-0040 US 02-0050 US 02-0060
PDVC - 4	Error Detection based on System Topology	US 04-0010 US 04-0020
PDVC - 5	Error Analysis & Logging • Guidance for likely error cause (and thus for resolution)	US 05-0010 US 05-0020
PDVC - 6	Error Detection of Communication, Network, and Program Interfaces	US 06-0010 US 06-0020 US 06-0030 US 06-0040
PDVC - 7	System Level Requirements • Standalone Application • Data Validation and Conditioning as Library	

2.5. Derived User Stories

This section presents each user story and the expected outcome of testing the algorithm for that story. These are also grouped by the error type that they address in each subsection. The last column of the user story table in each subsection table lists the status of the testing the particular story. The method of carrying out the user story test is described in Section 3 for all the stories.

The listed User Stories are derived from PDVC requirements. The status of testing a user story can be:

- **Backlog**: remaining the backlog to be tested
- **Completed**: development done, factory testing completed
- **Accepted**: this will be accomplished by testing prototype with data from BPA and PJM.

Two user roles are defined for PDVC end users:

- **IT Admin**: installs and setups PDVC application.
- **PDVC User (User)**: PDVC application users such as phasor system support and engineer.

2.5.1 User Stories for Error Data Indication

Derived user stories for Error Data Indication, which is within the scope of work for the Phasor Data Validation and Conditioning project, are listed below. A Data Quality Flag (QF) is used to mark measurement data quality. Details about Data Quality Flag definition are described in Appendix A.

ID	Description	Status
US 03-0010	As a user, I want the Data Quality Flag (QF) definition having good, bad, and questionable (uncertain) so that data can be flagged according to these categories.	Completed
US 03-0020	As a user, I want the QF definition following field proven standard(s) so that the definition is well defined without ambiguity.	Completed
US 03-0030	As a user, I want the QF definition having sub-status for bad and uncertain values so that it can provide why or how the value is bad or uncertain.	Completed
US 03-0040	As a user, I want to have an option to include quality flags in the output stream so that the original values can be kept but their qualities are indicated by the quality flags.	Completed
US 03-0050	As a user, I want to have an option to replace bad or uncertain values as NaN in the output so that the bad and/or uncertain values can be identified.	Completed
US 03-0060	As a user, I want to have the ability to output one stream with quality flags and another stream with bad/uncertain data as NaN so that it can meet the downstream applications' data cleaned or data flagged requirements.	Completed
US 03-0070	As a user, I want to have an option to scale and offset phasors so that I can correct measurements which have scaling and offset error.	Completed

2.5.2 User Stories for Message Error Detection

Derived user stories for Message Error Detection are listed below:

ID	Description	Status
US 01-0010	As a user, I want to be alarmed if received packets follow IEEE 37.118/ IEEE 37.118.2 standard by checking the synch bit so that I will know if	Completed

	there are format issues and packets won't be able to be parsed. I also want know the statistics of this format issue overall and hourly basis.	
US 01-0020	As a user, I want to be alarmed if received packet length and specified packet length do not match so that I will know the packets have size problem and cannot be parsed. I also want know the statistics of this size mismatch issue overall and hourly basis.	Completed
US 01-0030	As a user, I want to be alarmed if CRC and the received CRC of C37.118/C37.118.2 configure frame and data frame don't match so that I will know that the configure frame and/or data frame are tampered/corrupted and should be discarded. I also want to know the statistics of this data corruption occurrences overall and hourly basis.	Completed
US 01-0040	As a user, I want to be alarmed if received ID Code in configuration frame and user specified ID Code don't match so that I will know that configuration frame will be requested again.	Completed

2.5.3 User Stories for Data Error Detection

Derived user stories for Data Error Detection, which is within the scope of work for the Phasor Data Validation and Conditioning project, based on value and status word are listed below:

ID	Description	Status
	Data Rate & Latency Inconsistence	
US 02-0010	As a user, I want to be alarmed if there are data samples out of sequence so that I am aware of the situation, inform the input PMU/PDC support about the issue and see if this problem can be fixed. Instead of discarding the out of sequence samples, I want to keep those late samples within the latency limit in the output.	Completed
US 02-0020	As a user, I want to be alarmed if the actual data rate and specified data rate don't match so that I am aware of the situation, can inform the input PMU/PDC support about the issue and see if this problem can be fixed.	Completed
US 02-0030	As a user, I want to be alarmed if the latency is not consistent (within a user set limit) so that I am aware of the situation, can inform the input PMU/PDC support about the issue and see if this problem can be fixed	Completed
	Time Error and Bad Time Quality	

US 02-0040	As a user, I want to be alarmed if MSG_TQ > 4 so that I know that the Time Quality is unlocked for the newer data streams. In this case, I want to set the PMU Status bit 13 to indicate the PMU is having GPS problems.	Completed
	Data Error Determined from PMU Status	
US 02-0050	As a user, I want to be alarmed if there are PMUs missing data (Status word bits 12, 13, 14, 15 are all set) in a sample so that I am aware of the situation and find a way to get those PMUs back to normal. For the missing PMUs, the data values should be marked with QF as bad quality with sub-status as device not connected.	Completed
US 02-0060	As a user, I want to be alarmed if signals have been added or deleted for a particular PMU so that I am aware of the situation.	Completed
US 02-0070	As a user, I want to be alarmed if IEEE 37.118 PMU status's bit 15 is set so that I am aware of that the PMU data is invalid. I also want all the measurements (phasors, frequency, digital, and analog) marked with QF as bad with sub-status as Non-specific.	Completed
US 02-0080	As a user, I want to be alarmed if IEEE 37.118 PMU status's bit 14 is set so that I am aware of that the PMU data is set as PMU Error. When I indicate it, I also want all the measurements (phasors, frequency, digital, and analog) marked as bad with sub-status as Device Failure.	Completed
US 02-0090	As a user, I want to be alarmed if IEEE 37.118.2 PMU status's bits 15/14 is 01 or 11 so that I am aware of that the PMU data is invalid. When I indicate it, I also want all the measurements (phasors, frequency, digital, and analog) marked as bad with sub-status as Non-specific.	Completed
US 02-0100	As a user, I want to be alarmed if IEEE 37.118.2 PMU status's bits 15/14 are 10 so that I am aware of that the PMU data is in test mode and value should not be used. When I indicate it, I also want all the measurements (phasors, frequency, digital, and analog) marked with QF as bad with sub-status as Out of Service.	Completed
US 02-0110	As a user, I want to be alarmed if PMU status's bit 13 is set but bits 14/15 are cleared so that I am aware of that the PMU data is out of synch. I also want all the phasor angle measurements marked with QF as uncertain with sub-status as Sensor Not Accurate (since the angle measurement is of unknown value).	Completed
US 02-0120	As a user, I want to be alarmed if PMU status's bit 12 is set but bits 13/14/15 are cleared so that I am aware of that the PMU data is sort by	Completed

	arrival. I also want all the phasor angle measurements marked with QF as uncertain with sub-status as Sort By Arrival.	
	Data Error Determined from Measurement Value Itself	
US 02-0130	As a user, I want to be alarmed if voltage magnitudes, current magnitude, and frequency, which have passed PMU Status checking, are exceeding engineering limits I configured. I want to those measurements exceeding limits marked with QF as uncertain with sub-status as exceeding engineering unit.	Completed
US 02-0140	As a user, I want to be alarmed if voltage magnitudes, current magnitude, and frequency, which have passed PMU Status checking and Engineering limit checking, appear to be constant because they only vary in a very small range that I have configured. I want to those scaled measurements and associated angle and df/dt marked with QF as uncertain with sub-status as constant value.	Completed
US 02-0150	As a user, I want to be alarmed for a frequency that is calculated from a voltage where the voltage is detected as bad/uncertain. I want the frequency is marked with QF as bad/uncertain also.	Completed
US 02-0160	As a user, optionally I want to be alarmed if voltage magnitude, current magnitude, or frequency has “high frequency” noise. I want those measurements marked with QF as uncertain with sub-status as noisy.	Completed

2.5.4 User Stories for Error Detection Based on Topology

Derived user stories for Topology-based Error Detection are listed below:

ID	Description	Status
US 04-0010	As a user, I want to have the ability to define topology in the form of user defined calculations which support basic arithmetic functions (such as sum, avg, abs, floor etc.), trigonometry functions (such as sin, cos, tan etc.), logic functions (such as and, or, nor, xor etc.), and logical comparison operations (>, >=, ==, <, <=) so that the topology configuration is generic and simplified.	Completed
US 04-0020	As a user, I want to be notified when I define a topology expression with syntax errors so that I can correct the errors.	Completed

US 04-0030	As a user, optionally I want to be alarmed when the calculated value based on my topology definition, such as MW flow over the same (transmission line, magnitude and phase angle offset etc.) violates the threshold I defined so that I am aware of inconsistent measurements and take action as needed.	Completed

2.5.5 Combination of Data Issues

Derived user stories for Error Analysis and Logging are listed below:

ID	Description	Status
US 04-0100	As a user, I want the error detection to follow the order of PMU Time Quality validation, PMU Status validation, measurement value range validation, measurement value stale detection, measurement value noisy detection, and topology based data validation so that once the higher priority step set the measurement QF as bad or uncertain, the following step will avoid the validation again.	Completed

2.5.6 User Stories for Error Analysis and Logging

Derived user stories for Error Analysis and Logging are listed below:

ID	Description	Status
US 05-0010	As a user, I want the error detection results categorized, prioritized, saved into a log file. I want to be able to browse the error log through graphic user interface.	Completed
US 05-0020	As a user, I want the option to receive email notification about the error detection results so that I am aware of the situations without login onto Configuration & Monitoring tool.	Completed
US 05-0030	As a user, optionally I want the error logs sent to Windows Event view or SNMP trap.	Completed
US 05-0040	As a user, I want to be able to study the error results based on overall statistics and hourly statistics.	Completed

2.5.7 User Stories for Network, Communication, and Program Interfaces

Derived user stories for communication system connection and operation are listed below:

ID	Description	Status
US 06-0010	As a user, I want to be alarmed when input PMU/PDC connection cannot be made so that I will know that there might be firewall issue or PMU/PDC is not ready. I want to the application automatically try to reconnect again. I also want the application to switch to alternate source when primary source is not available.	Completed
US 06-0020	As a user, I want to be informed when there is connection to the output stream so that I will know that the output communication is established.	Completed
US 06-0030	As a user, I want to configure the communication options, input/output data format etc. through graphic user interface.	Completed
US 06-0040	As a user, I want to monitor the input communication status through graphic user interface.	Completed

3. Test Procedures

3.1 Introduction

This section describes the detailed test steps intended to demonstrate that the requirements for the features of PDVC Prototype application described in the Section 2 are met. Each story requires a detailed procedure to demonstrate that the algorithm meets the story expectation and satisfies the requirement. Note that the outcome of each test is recorded in Section 2 along with the story.

EPG has been developing and enhancing a PMU Simulator which provides features to manage PMUs/Signals (add, remove, rename PMUs/Signals and formats) and to set signal values for simulation. The Test setup is shown in Figure 3. The PMU Simulator allows setting specific configuration and error conditions that are required for testing the algorithm prototype.

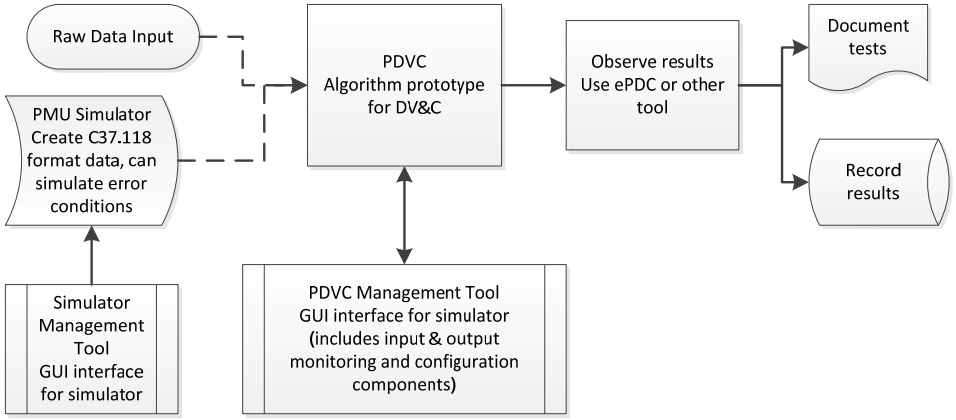


Figure 3. Test setup – using either real data or the PMU simulator

PDVC itself provides real-time data quality monitoring capability through PDVC Management Tool's Input and Output PMU Monitoring panels. PDVC Management Tool will be used for most testing cases. In particular, two instances of PDVC Management Tool applications can be running at same time: one to configure the validation and conditioning options and another to monitor the data quality flags when the validation and conditioning options changed (Figure 3 only shows one tool instance connected, but the application will host more than one).

To test the output of PDVC, EPG's ePDC can be used for testing the NaN values and quality flags in C37.118 analog type.

3.2 IEEE 37.118 & IEEE 37.118.2 Message Error Detection

Purpose: to verify PDVC's ability to detect IEEE C37.118 & IEEE 37.118.2 error at message (frame) level such as CRC error, frame size error, synch byte error etc.

Initial Conditions: PMU Simulator is running and sending data to PDVC, PDVC's Defragment Stream option is disabled (so the streams come in as individual C37.118 data or configure frames). Instructions are give specific to the simulator's control panel (see Appendix 3).

User Stories: US 01-0010

Step	Action	Expected Results
1	On PMU Simulator, click Apply Error button at the bottom right. From the popup Apply Error dialog box, check Header Error and set the number to 60. PDVC input's Defragment Stream is disabled	PMU Simulator will set data frame header error for 60 samples.
2	Check PDVC Management Tool's Operational Log Window	Synch byte errors are logged
3	Check PDVC Management Tool's Input Communication Status	Format error counts increase.
	<End of test>	

User Stories: US 01-0020

Step	Action	Expected Results
1	On PMU Simulator, click Apply Error button at the bottom right. From the popup Apply Error dialog box, check Frame Size Error and set the number to 60. PDVC input's Defragment Stream is disabled	PMU Simulator will set data frame size mismatch for 60 samples.
2	Check PDVC Management Tool's Operational Log Window	Frame size mismatch errors are logged
3	Check PDVC Management Tool's Input Communication Status	Format error counts increase.
	<End of test>	

User Stories: US 01-0030

Step	Action	Expected Results
1	On PMU Simulator, click Apply Error button at the bottom right. From the popup Apply Error dialog box, check CRC Error and set the number to 60. PDVC input's Defragment Stream is disabled.	PMU Simulator will set data frame CRC mismatch for 60 samples.
2	Check PDVC Management Tool's Operational Log Window	CRC size mismatch messages are logged.
3	Check PDVC Management Tool's Input Communication Status	Check word error counts increase.
	<End of test>	

User Stories: US 01-0040

Step	Action	Expected Results
1	PDVC's input PMU ID Code set to 1, PDVC input's Defragment Stream is disabled.	
2	PMU Simulator's PMU ID Code set to 9999	CRC size mismatch errors should be logged
3	Check PDVC Management Tool's Input PMU Monitoring	Data time not refreshing, no new data coming, because PMU Simulator will not send data to PDVC because of PMU ID Code mismatch.
	<End of test>	

3.3 Data Error Detection

Purpose: to verify PDVC's ability to detect IEEE C37.118 & IEEE 37.118.2 error at measurement level.

Initial Conditions: PMU Simulator is running and sending data to PDVC

3.3.1 Data Rate and Latency

User Stories: US 02-0010 (Data sample out of sequence)

Step	Action	Expected Results
1	Set PDVC and PMU Simulator to communicate with the same protocol either C37.118 or C37.118.2.	
2	At PDVC Management Tool PMU Time Validation Panel, enable Sample Shift Detection, save and apply the configuration.	PDVC loads the updated configuration file and ready for sample out of sequence detection
3	From PMU Simulator, simulate an out of sequence situation, and check error log	The out of sequence messages are logged including the current and previous samples timestamps, the number of samples shifted forward or backward.
4	From PMU Simulator, set time offset but still in PDVC latency limits, and check input monitoring panel	The PMU's status is not marked as time error
5	From PMU Simulator, increase the time offset to exceed latency limits, and check the input monitoring panel	The PMU's status is marked as time error
	<End of test>	

User Stories: US 02-0020

Step	Action	Expected Results

1	Set PDVC and PMU Simulator to communicate with the same protocol either C37.118 or C37.118.2.	
2	At PDVC Management Tool PMU Time Validation Panel, enable Data Rate Inconsistent Detection, save and apply the configuration.	PDVC loads the updated configuration file and ready for data rate detection
3	From PMU Simulator, set a disturbance to the data rate, and check error log	Data rate inconsistency message is logged
	<End of test>	

User Stories: US 02-0030

Step	Action	Expected Results
1	Set PDVC and PMU Simulator to communicate with the same protocol either C37.118 or C37.118.2.	
2	At PDVC Management Tool PMU Time Validation Panel, enable Latency Detection, save and apply the configuration.	PDVC loads the updated configuration file and ready for inconsistent latency detection
3	From PMU Simulator, set a disturbance to the time offset, and check error log	Latency inconsistency message is logged
	<End of test>	

3.3.2 Config Frame Change Reporting

User Stories: US 02-0060 (C37.118 and C37.118.2 PMU/Signal configuration frame change reporting)

Step	Action	Expected Results
1	Set PDVC and PMU Simulator to communicate with the same protocol either C37.118 or C37.118.2	
2	Disable a PMU from PMU Simulator, set the first PMU Status's bit 10 for a few second.	PMU Simulator will send a new config frame to PDVC
3	Check PDVC Management Tool's Operational Log Window	PMU removed message(s) are logged. Channels removed message(s) are logged.
4	Enable a PMU Simulator, set the first PMU Status's bit 10 for a few second.	PMU Simulator will send a new config frame to PDVC
5	Check PDVC Management Tool's Operational Log Window	New PMUs found message(s) are logged. New channels messages(s) are logged.
6	Disable channel(s) from PMU Simulator, set the first PMU Status's bit 10 for a few second.	PMU Simulator will send a new config frame to PDVC
7	Check PDVC Management Tool's Operational Log Window	Channels removed message(s) are logged.
8	Enable channels Simulator, set the first PMU Status's bit 10 for a few second.	PMU Simulator will send a new config frame to PDVC

9	Check PDVC Management Tool's Operational Log Window	New channels found message(s) are logged.
10	Enable/disable PMUs/Channels at same time from PMU Simulator, set the first PMU Status's bit 10 for a few second.	
11	Check PDVC Management Tool's Operational Log Window	Mixed PMU/Channel removed/found messages are logged.
	<End of test>	

3.3.3 Time Quality Error

User Stories: US 02-0040

Step	Action	Expected Results
1	Disable all other validation and conditioning options.	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Time Quality (Bit 06-08) check for a selected PMU, save the configuration and apply the changes to PDVC	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 06, 07 to 1, bit 08 can be set or cleared	
4	Check PDVC Management Tool's Input PMU Monitoring	Voltage/current angle's quality flag set as Uncertain, Sensor Not Accurate
5	Check PDVC Management Tool's Operational Log Window	Time Error for the PMU message is logged
6	At PMU Simulator, clear the same PMU's status bit 08. Clear bit 07, bit 06 or both	
7	Check PDVC Management Tool's Input PMU Monitoring	Voltage/current angle's quality flag set as Good
8	Check PDVC Management Tool's Operational Log Window	Time Error for the PMU message is no more logged
	<End of test>	

3.3.4 PMU Status Error

User Stories: US 02-0050 (Missing Data)

Step	Action	Expected Results
1	Disable all other validation and conditioning	

	options.	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Data Invalid (bit 15), PMU Error (bit 14), Out of Synch (bit 13), and Sort by Arrival (bit 12) check for a selected PMU, save the configuration and apply the changes to PDVC	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 15, 14, 13, and 12. Clear all other bits.	
4	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flags set as Bad, Drop out.
5	Check PDVC Management Tool's Operational Log Window	Dropout for the PMU message is logged
6	At PMU Simulator, clear any of bit 15, 14, 13, and 12 the same PMU's	
7	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flag are not set as Bad, Drop out.
8	Check PDVC Management Tool's Operational Log Window	Dropout Error for the PMU message is no more logged
	<End of test>	

User Stories: US 02-0070 (C37.118 PMU Status Bit 15 – Data Invalid)

Step	**Action**	**Expected Results**
1	Disable all other validation and conditioning options. Set PDVC input format as C37.118. Set PMU Simulator output format as C37.118.	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Data Invalid (bit 15), PMU Error (bit 14), Out of Synch (bit 13), and Sort by Arrival (bit 12) check for a selected PMU, save the configuration and apply the changes to PDVC.	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 15. For bit 14, 13, and 12, at least one is set. Clear all other bits.	
4	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flags set as Bad, Device Failure.
5	Check PDVC Management Tool's Operational Log	Data Invalid for the PMU message is

	Window	logged
6	At PMU Simulator, clear bit 15.	
7	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flag are not set as Bad, Device Failure.
8	Check PDVC Management Tool's Operational Log Window	Data Invalid Error for the PMU message is no more logged
	<End of test>	

User Stories: US 02-0080 (C37.118 PMU Status Bit 14 – PMU Error)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC input format as C37.118. Set PMU Simulator output format as C37.118.	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Data Invalid (bit 15), PMU Error (bit 14), Out of Synch (bit 13), and Sort by Arrival (bit 12) check for a selected PMU, save the configuration and apply the changes to PDVC.	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 14. For bit 13 and 12, either can be set or cleared. Clear all other bits.	
4	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flags set as Bad, Device Failure.
5	Check PDVC Management Tool's Operational Log Window	Out of Service Error for the PMU message is logged
6	At PMU Simulator, clear bit 14.	
7	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flag are not set as Bad, Device Failure.
8	Check PDVC Management Tool's Operational Log Window	Out of Service Error for the PMU message is no more logged
	<End of test>	

User Stories: US 02-0090, US 02-0100 (C37.118.2 PMU Status Bit 15 & 14)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC input format as C37.118.2. Set	

	PMU Simulator output format as C37.118.2.	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Data Invalid (bit 15), PMU Error (bit 14), Out of Synch (bit 13), and Sort by Arrival (bit 12) check for a selected PMU, save the configuration and apply the changes to PDVC.	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 14 & 15. For bit 13 and 12, at least one is cleared. Clear all other bits.	
4	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flags set as Bad, Unspecified.
5	Check PDVC Management Tool's Operational Log Window	Out of Service Error for the PMU message is logged
6	At PMU Simulator, set the same PMU's status Bit 14 and clear Bit 15. For bit 13 and 12, at least one is cleared. Clear all other bits.	
7	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flags set as Bad, Unspecified.
8	Check PDVC Management Tool's Operational Log Window	Data Invalid Error for the PMU message is logged
9	At PMU Simulator, set the same PMU's status Bit 15 and clear Bit 14. For bit 13 and 12, at least one is cleared. Clear all other bits.	
10	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flags set as Bad, Out of Service.
11	Check PDVC Management Tool's Operational Log Window	Out of Service Error for the PMU message is logged
12	At PMU Simulator, clear Bit 14 and Bit 15.	
13	Check PDVC Management Tool's Input PMU Monitoring	Digital, Analog (except ToA Latency), Frequency/DFDT, Voltage/current magnitude and angle's quality flag are not set as uncertain.
14	Check PDVC Management Tool's Operational Log Window	Out of Service Error for the PMU message is no more logged
	<End of test>	

User Stories: US 02-0110 (C37.118 or C37.118.2 PMU Status Bit 13 – Out of Synch)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Data Invalid (bit 15), PMU Error (bit 14), Out of Synch (bit 13), and Sort by Arrival (bit 12) check for a selected PMU, save the configuration and apply the changes to PDVC.	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 13. Bit 12 can be set or cleared. Clear all other bits.	
4	Check PDVC Management Tool's Input PMU Monitoring	Voltage/current angle's quality flags set as Uncertain, Sensor Not Accurate.
5	Check PDVC Management Tool's Operational Log Window	GPS Out of Synch Error for the PMU message is logged
6	At PMU Simulator, clear bit 13.	
7	Check PDVC Management Tool's Input PMU Monitoring	Voltage/current angle's quality flags are not set as Uncertain, Sensor Not Accurate.
8	Check PDVC Management Tool's Operational Log Window	GPS Out of Synch Error for the PMU message is no more logged
	<End of test>	

User Stories: US 02-0120 (C37.118 or C37.118.2 PMU Status Bit 12 – Sort by Arrival)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2	
2	At PDVC Management Tool PMU Status Validation Panel, configure PDVC to enable Data Invalid (bit 15), PMU Error (bit 14), Out of Synch (bit 13), and Sort by Arrival (bit 12) check for a selected PMU, save the configuration and apply the changes to PDVC.	New configuration should be applied to PDVC
3	At PMU Simulator, set the same PMU's status Bit 12. Clear all other bits.	
4	Check PDVC Management Tool's Input PMU Monitoring	Voltage/current angle's quality flags set as Uncertain, Sort by Arrival.
5	Check PDVC Management Tool's Operational Log Window	Sort by Arrival Error for the PMU message is logged
6	At PMU Simulator, clear bit 12.	
7	Check PDVC Management Tool's Input PMU Monitoring	Voltage/current angle's quality flags are not set as Uncertain, Sort by

		Arrival.
8	Check PDVC Management Tool's Operational Log Window	Sort by Arrival Error for the PMU message is no more logged
	<End of test>	

3.3.5 Measurement Validation

User Stories: US 02-0130 (voltage magnitude, current magnitude, frequency range check)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2	
2	At PDVC Management Tool Value Validation Panel, configure PDVC to enable range check for a selected voltage magnitude, save and apply the configuration to system.	New configuration should be applied to PDVC
3	Adjust the voltage magnitude value at PMU Simulator so that it is smaller than the Passband Low limit	
4	Check PDVC Management Tool's Input PMU Monitoring	Voltage magnitude quality flags set as Uncertain, Engineering Unit Exceeded Low Limit.
5	Check PDVC Management Tool's Operational Log Window	Out of Range exceeding low limit Error for the voltage magnitude message is logged
6	Adjust the voltage magnitude value at PMU Simulator so that it is smaller than the Passband High limit	Voltage magnitude quality flags set as Uncertain, Engineering Unit Exceeded High Limit.
7	Check PDVC Management Tool's Input PMU Monitoring	Out of Range exceeding high limit Error for the voltage magnitude message is logged
8	At PDVC Management Tool Value Validation Panel, configure PDVC to also enable frequency correlated check for the same selected voltage magnitude, save and apply the configuration to system.	New configuration should be applied to PDVC
9	Check PDVC Management Tool's Input PMU Monitoring	Frequency's quality flag is set to same as Uncertain, Engineering Unit Exceeded.
10	Repeat step 2-7 for current magnitude and frequency measurements.	
	<End of test>	

User Stories: US 02-0140 (voltage magnitude, current magnitude, frequency stale check)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2	
2	At PDVC Management Tool Value Validation Panel, configure PDVC to enable stale check for a selected voltage magnitude, save and apply the configuration to system.	New configuration should be applied to PDVC
3	Adjust the voltage magnitude value at PMU Simulator so that it is kept the same for longer than the stale check duration limit.	
4	Check PDVC Management Tool's Input PMU Monitoring	Voltage magnitude quality flags set as Uncertain, Stale Value.
5	Check PDVC Management Tool's Operational Log Window	Stale signal values Error for the voltage magnitude message is logged
6	Repeat step 2-5 for current magnitude and frequency measurements.	
	<End of test>	

User Stories: US 02-0150 (voltage magnitude, current magnitude, frequency noise check)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2	
2	At PDVC Management Tool Value Validation Panel, configure PDVC to enable noisy check for a selected voltage magnitude, save and apply the configuration to system.	New configuration should be applied to PDVC
3	Add noise to the voltage magnitude value at PMU Simulator.	
4	Check PDVC Management Tool's Input PMU Monitoring	Voltage magnitude quality flags set as Uncertain, Noisy.
5	Check PDVC Management Tool's Operational Log Window	Noisy signal values Error for the voltage magnitude message is logged
6	Repeat step 2-5 for current magnitude and frequency measurements.	
	<End of test>	

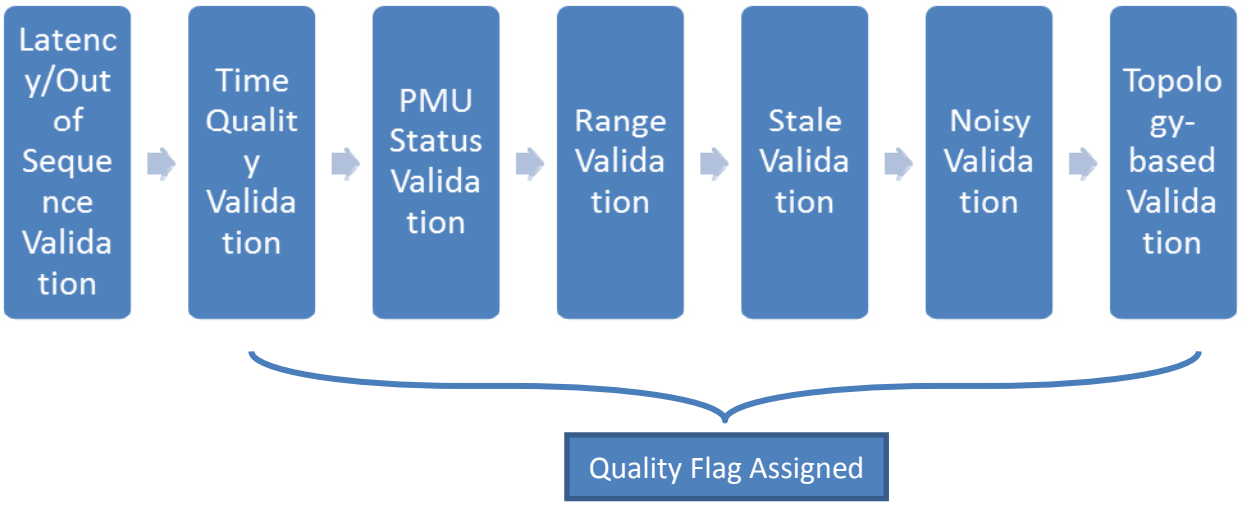
3.3.6 Topology-based Measurement Validation

User Stories: US 04-0010, US 04-0020, US 04-0030 (cross measurements validation through topology definitions)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2	
2	At PDVC Management Tool Topology Validation Panel, configure a topology expression for line MWs comparison between two PMUs measuring the same line, save and apply the configuration to system. For example: abs($TEST.PMU1.V21.VM$ * $TEST.PMU1.C21.IM$ * cos($TEST.PMU1.V21.VA$ - $TEST.PMU1.C21.IA$) - $TEST.PMU2.V31.VM$*$TEST.PMU2.C31.IM$*cos($TEST.PMU2.V31.VA$-$TEST.PMU2.C31.IA$)) < 1	New configuration should be applied to PDVC
3	Add a parenthesis "(" at the very beginning of the expression, click Validate button	A warning message popup indicating that there are mismatched brackets
4	Correct the expression by removing the just added parenthesis "(", click Validate button again	A message popup indicating the expression is valid
5	PMU Simulator to have two PMUs PMU1 and PMU2. PMU1 has V21 voltage phasor and C21 current phasor. PMU2 has V31 voltage phasor and C31 current phasor. Set V21's output value the same as V31 at 500 kV. Set C21's output the same as C31 at 200A.	No topology failure error is detected at PDVC
6	Change V21's magnitude to 550 kV.	
7	Check PDVC Management Tool's Input PMU Monitoring	Voltage magnitude quality flags set as Uncertain, Topology Validation Failure.
8	Check PDVC Management Tool's Operational Log Window	Topology test failed Error for the voltage magnitude message is logged
	<End of test>	

3.3.7 Measurement Validation Hierarchy (US 04-0100)

PDVC current implemented the validation in the order as shown below. That is, if the higher order detects a measurement as not GOOD (BAD or UNCERTAIN) and flagged it, that measurement will not participate in the lower order of validation.



3.4 Data Error Indication and Output

Purpose: to verify PDVC's ability to set flags and change values to NaN for non-good quality for IEEE C37.118 & IEEE 37.118.2 output.

Initial Conditions: PMU Simulator is running and sending data to PDVC, and PDVC is sending data to ePDC

User Stories: US 03-0040 (Output phasor/frequency quality flags as float analog and value replacing as NaN for flagged values)

Step	Action	Expected Results
1	Disable all other validation and conditioning options. Set PDVC and PMU Simulator using the same protocol either C37.118 or C37.118.2.	
2	Create a PDVC named ORIGINAL output without enabling Convert to NaN for Flagged Values and Include Quality Flags	
3	Create a PDVC named NAN output without Include Quality Flags but enabling Convert to NaN for Flagged Values	
4	Create a PDVC named FLAGGED output without enabling Convert to NaN for Flagged Values but	

	enabling Include Quality Flags	
5	At PDVC Management Tool Topology Validation Panel, configure a validation configuration for a voltage magnitude as stale, save and apply the changes to the system.	New configuration should be applied to PDVC
6	Check PDVC Management Tool's Input PMU Monitoring	The data quality for the selected voltage magnitude is properly flagged
7	Create three inputs at ePDC (ORIGINAL, NAN, FLAGGED) corresponding to PDVC's outputs.	
8	Check ePDC's input monitoring for ORIGINAL input	Same analog signal numbers as PDVC ORIGINAL output. Same Voltage values as PDVC output.
9	Check ePDC's input monitoring for NAN input	Same analog signal numbers as PDVC NAN output. The voltage value is set as NAN.
10	Check ePDC's input monitoring for FLAGGED input	Analog signals are added for each phasor with name starting with QF_. Same Voltage values as PDVC output. But its quality flag is set to stale.
	<End of test>	

3.5 Error Analysis and Logging

Purpose: to verify PDVC's ability to log validation results messages.

Initial Conditions: PMU Simulator is running and sending data to PDVC, various validations as described in previous test cases have been conducted during the process

User Stories: US 05-0010, US 05-0020, US 05-0030, US 05-0040

Step	Action	Expected Results
1	From Windows explorer, navigate to the folder of $PDVC_DATA_FOLDER/operationlog where $PDVC_DATA_FOLDER is configured by datadir in the my-pdvc.ini runtime configuration file.	Log files are listed and being updated.
2	At PDVC Management Tool, click Error Log button on the toolbar.	The Operation Log window is popped up showing log messages for Input System, Data Manager, Output System, Watchdog, and Others. Log messages have time stamp, priority, system name, code, and description

		fields.
3	At PDVC Management Tool, click context menu Configuration->Logging System. From the PDVC Log Configuration GUI, configure Mail Log.	Emails of selected log message types will be sent to recipients. It may require PDVC service restart.
4	At PDVC Management Tool, click context menu Configuration->Logging System. From the PDVC Log Configuration GUI, configure SNMP Log.	Selected log message types will be sent to SNMP traps. It may require PDVC service restart.
5	At PDVC Management Tool, click Input Monitoring button from the toolbar. At the left tree view, navigate to the input from Input System. Click Input Communication Status tab on the right panel.	Hourly and overall statistics over missing data, checkword error, time error, GPS Unsynch, and format are updating.
	<End of test>	

3.6 Communication, Network, and Program Interface Error Detection

Purpose: to verify PDVC's ability to monitor and log communication and network failures.

Initial Conditions: PMU Simulator is running and sending data to PDVC

User Stories: US 06-0010 (Input failover functionality)

Step	Action	Expected Results
1	Setup two PMU Simulators. Each with same PMUs configuration. Configure the commination options so that the primary Simulate sends to port A, and another send to port B of PDVC. Start both simulator	Log files are listed and being updated.
2	At PDVC Management Tool, click Input Configuration button from the tool-bar, select the input to configure the fail-over parameters, save the configuration and apply the changes to system	PDVC configuration files is updated to PDVC service
3	Stop the primary simulator. Check the PDVC error log.	PDVC reports no data from primary input. At configured seconds later, PDVC switches to the backup simulator.
	<End of test>	

User Stories: US 06-0020, US 06-0030, US 06-0040 see Appendix A.

Use PDVC error and PDVC Monitoring panels to check the communication status.

4. Conclusion

EPG technical team set up the testing environment as shown in Figure 3. Each of the tests outlined above were conducted and results compared with the expected results for each user story. The internal testing (also referred to as Factory Acceptance Testing) has been completed following the testing procedures described. The test results indicate that the PDVC prototype system meets the requirements. The next step is to demonstrate the prototype and perform testing using data from BPA and PJM.

Appendix A: Quality Code Definition, Error Flagging and Indication (US 03-0010, US 03-0020, US 03-0030, US 03-0040, US 03-0050. US 03-0060)

The flags represent the quality state for an item's data value. It is designed to be similar to OPC DA 3.0/Field Bus standards. The design makes it easy for down-stream application to interpret the data quality without ambiguities.

The 8 bits of the Quality flags are currently defined in the form of three bit fields; Quality, Substatus and Limit status. The 8 Quality bits are arranged as follows:

QQSSSSLL

Appendix A.1 Quality Flag Bit Field

QQ	BIT VALUE	DEFINE	DESCRIPTION
0	00SSSSLL	Bad	Value is not useful for reasons indicated by the Substatus.
1	01SSSSLL	Uncertain	The quality of the value is uncertain for reasons indicated by the Substatus.
2	10SSSSLL	N/A	Not used by
3	11SSSSLL	Good	The Quality of the value is Good.

Comment:

It is recommended that clients minimally check the Quality Bit field (first 2 bits) of all results (even if they do not check the substatus or limit fields).

The Substatus BitField:

The layout of this field depends on the value of the Quality Field.

Appendix A.2 Substatus for BAD Quality

SSSS	BIT VALUE	DEFINE	DESCRIPTION
0	000000LL	Non-specific	The value is bad but no specific reason is known. For C37.118.2 Data invalid with or without PMU error (10 or 11) is mapped to this sub-status

			unless the user indicates 10 indicates test mode.
1	000001LL	Configuration Error	There is some server specific problem with the configuration. For example the item in question has been deleted from the configuration.
2	000010LL	Not Connected	The input is required to be logically connected to something but is not. This quality may reflect that no value is available at this time, for reasons like the value may have not been provided by the data source. Dropout is mapped to this sub-status.
3	000011LL	Device Failure	A device failure has been detected.
4	000100LL	Sensor Failure	A sensor failure had been detected (the 'Limits' field can provide additional diagnostic information in some situations).
5	000101LL	Last Known Value	Communications have failed. However, the last known value is available. Note that the 'age' of the value may be determined from the timestamp.
6	000110LL	Comm Failure	Communications have failed. There is no last known value is available.
7	000111LL	Out of Service	The block is off scan or otherwise locked. This quality is also used when the active state of the signal is InActive/Disabled. For C37.118.2 The user may indicate that PMU status bits 15/14 at 10 show test mode which is mapped to this sub-status.
8	001000LL	Waiting for Initial Data	After Items are added, it may take some time for the server to actually obtain values for these items. In such cases the client might perform a read (from cache), and/or execute a Refresh on such a subscription before the values are available.
9-15		N/A	Reserved for future use

Appendix A.3 Substatus for UNCERTAIN Quality

SSSS	BIT VALUE	DEFINE	DESCRIPTION
0	010000LL	Non-specific	There is no specific reason why the value is uncertain.
1	010001LL	Last Usable Value	Whatever was writing this value has stopped doing so. The returned value should be regarded as 'stale'. Note that this differs from a BAD value with Substatus 5 (Last Known Value). That status is associated specifically with a detectable communications error on a 'fetched' value. This error is associated with the failure of some external source to 'put' something into the value within an acceptable period of time.
2-3		N/A	Not used
4	010100LL	Sensor Not Accurate	Either the value has 'pegged' at one of the sensor limits (in which case the limit field should be set to 1 or 2) or the sensor is otherwise known to be out of calibration via some form of internal diagnostics (in which case the limit field should be 0). Out of synch for angles is mapped to this sub-status Data is sort by arrival when data is not correlated into its frame by timetag.
5	010101LL	Engineering Units Exceeded	The returned value is outside the limits defined for this parameter. Note that in this case the 'Limits' field indicates which limit has been exceeded but does NOT necessarily imply that the value cannot move farther out of range.
6	010110LL	Sub-Normal	The value is derived from multiple sources and has less than the required number of Good sources.
7	010111LL	Noisy	The value has high frequency noise.
8	011000LL	SBA	Sort by arrival (local timetag)

9	011001LL	Topology error	The value doesn't meet topology evaluation
10-15		N/A	Reserved for future use

Appendix A.4 Substatus for GOOD Quality

SSSS	BIT VALUE	DEFINE	DESCRIPTION
0	110000LL	Non-specific	The value is good. There are no special conditions
1-5		N/A	Not used
6	110110LL	Local Override	The value has been Overridden. Typically this is means the input has been disconnected and a manually entered value has been 'forced' (manual substitution).
7-15		N/A	Reserved for future use

Appendix A.5 The Limit BitField

The Limit Field is valid regardless of the Quality and Substatus. In some cases such as Sensor Failure it can provide useful diagnostic information. Low Limited and High Limited are used as part of Engineering Units Exceeded uncertain quality.

LL	BIT VALUE	DEFINE	DESCRIPTION
0	QQSSSS00	Not Limited	The value is free to move up or down
1	QQSSSS01	Low Limited	The value has 'pegged' at some lower limit
2	QQSSSS10	High Limited	The value has 'pegged' at some high limit.
3	QQSSSS11	Constant	The value is a constant and cannot move.

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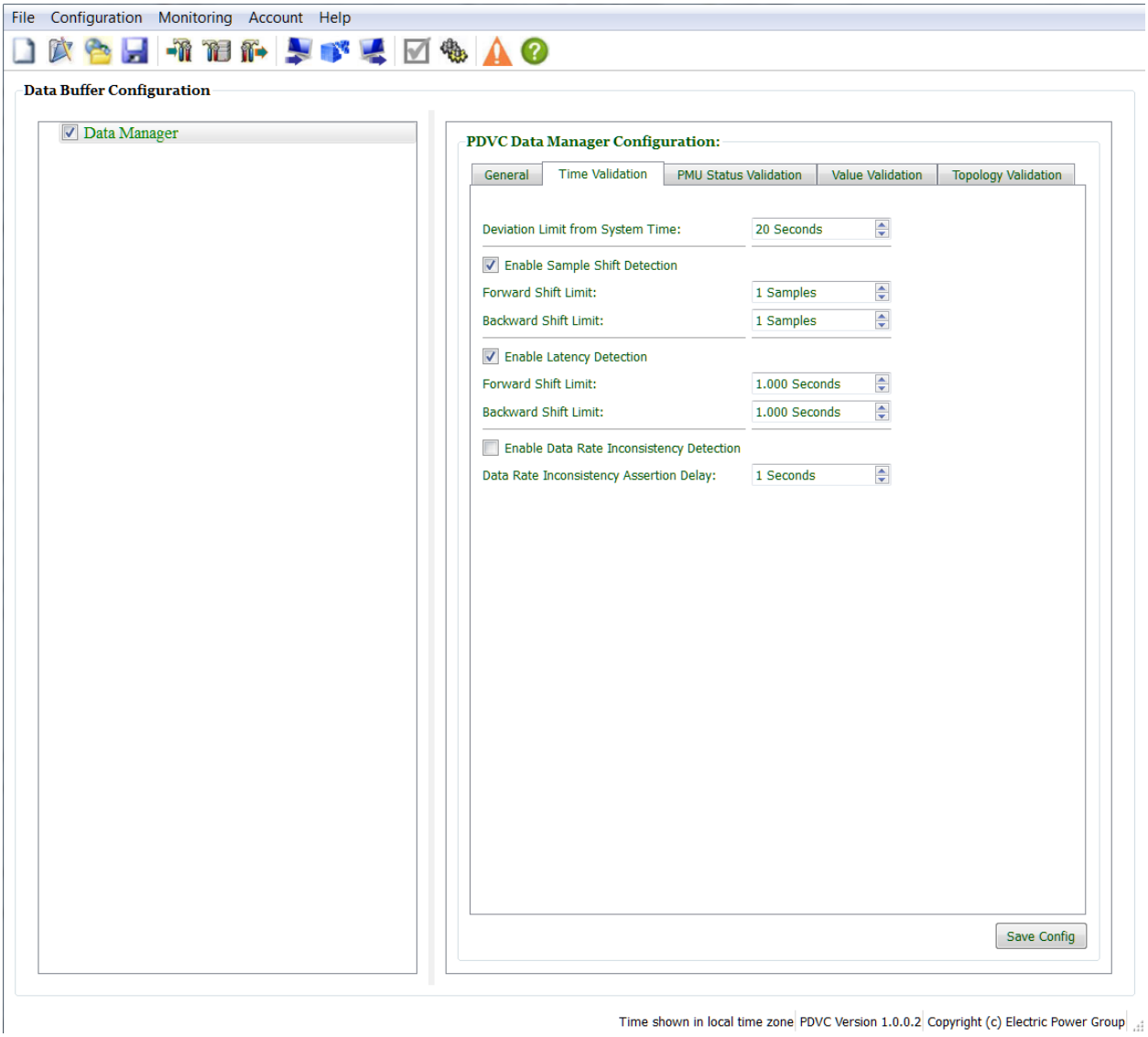
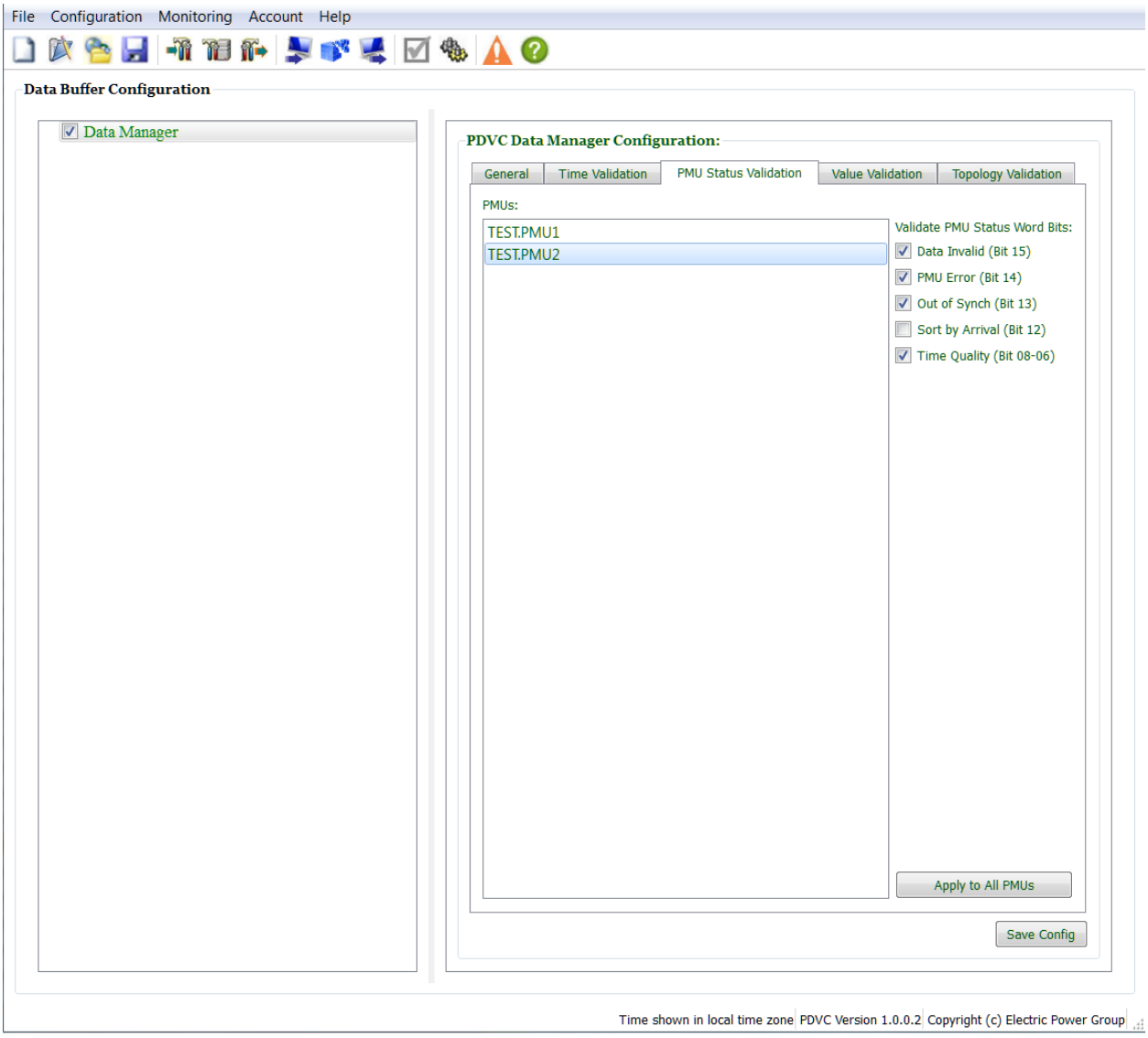
Appendix B: Screenshots of PDVC Application

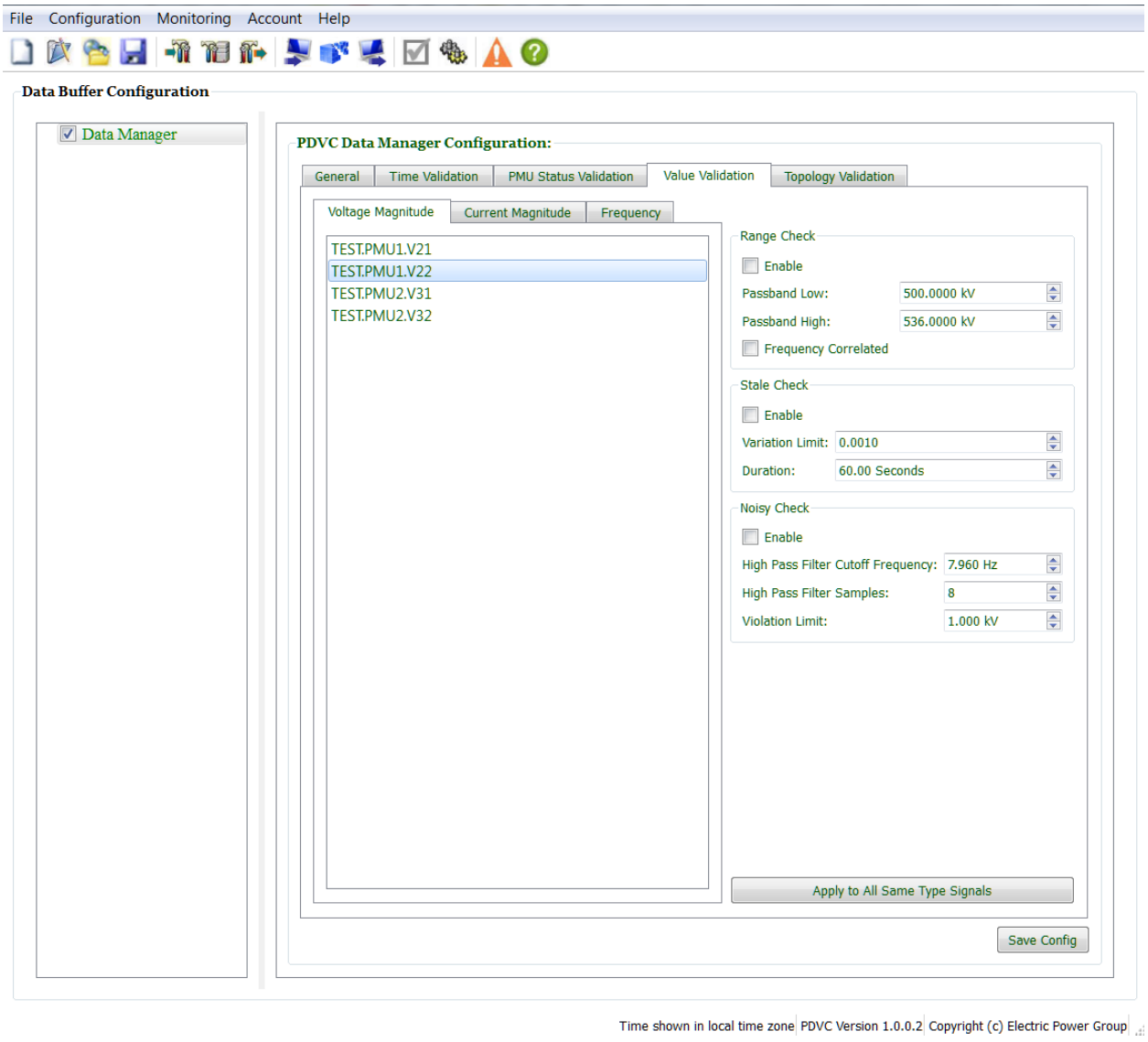
Appendix B.1 Timestamp and Data Rate Validation Configuration



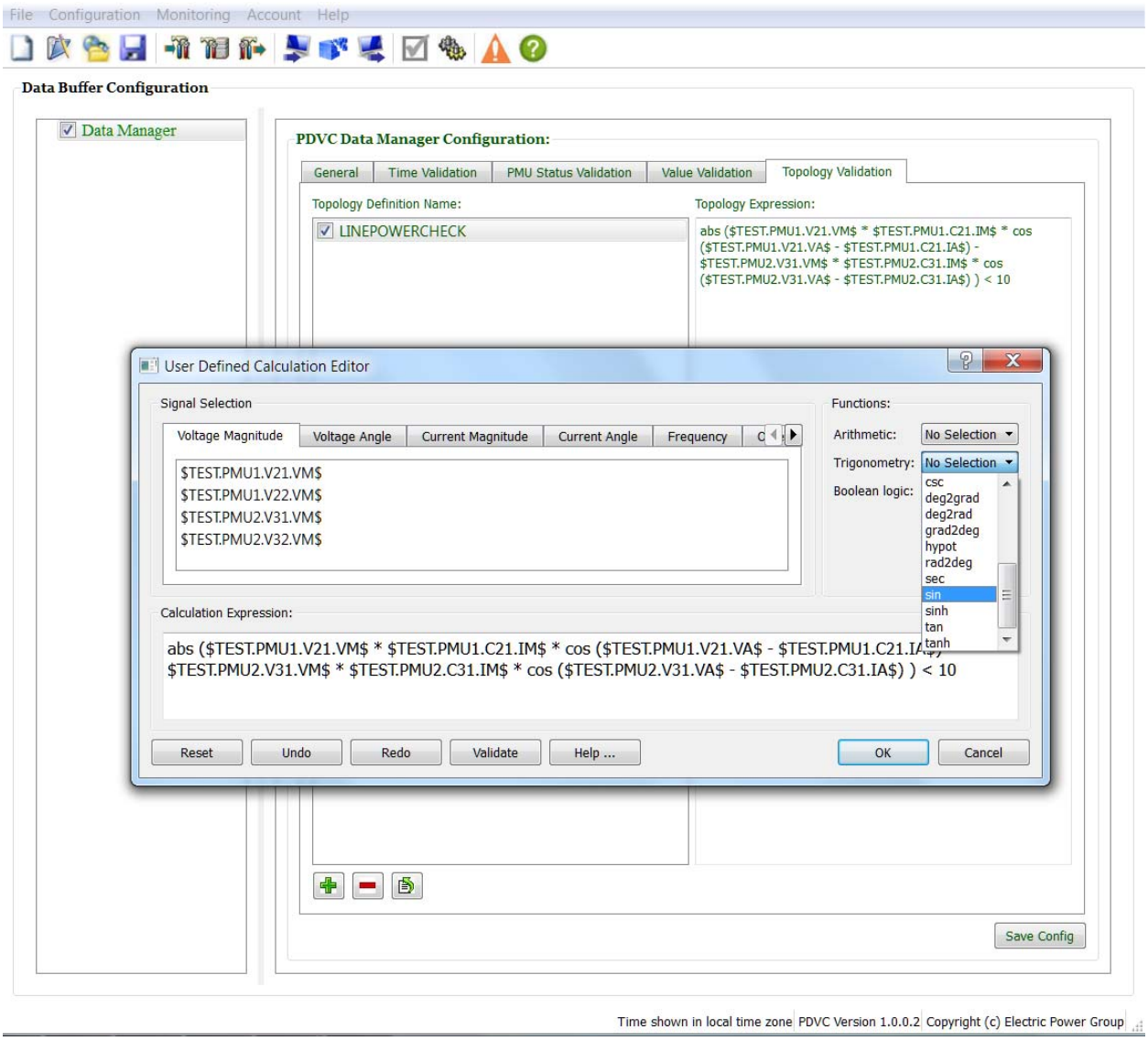
Appendix B.2 PMU Status Word-based Validation Configuration



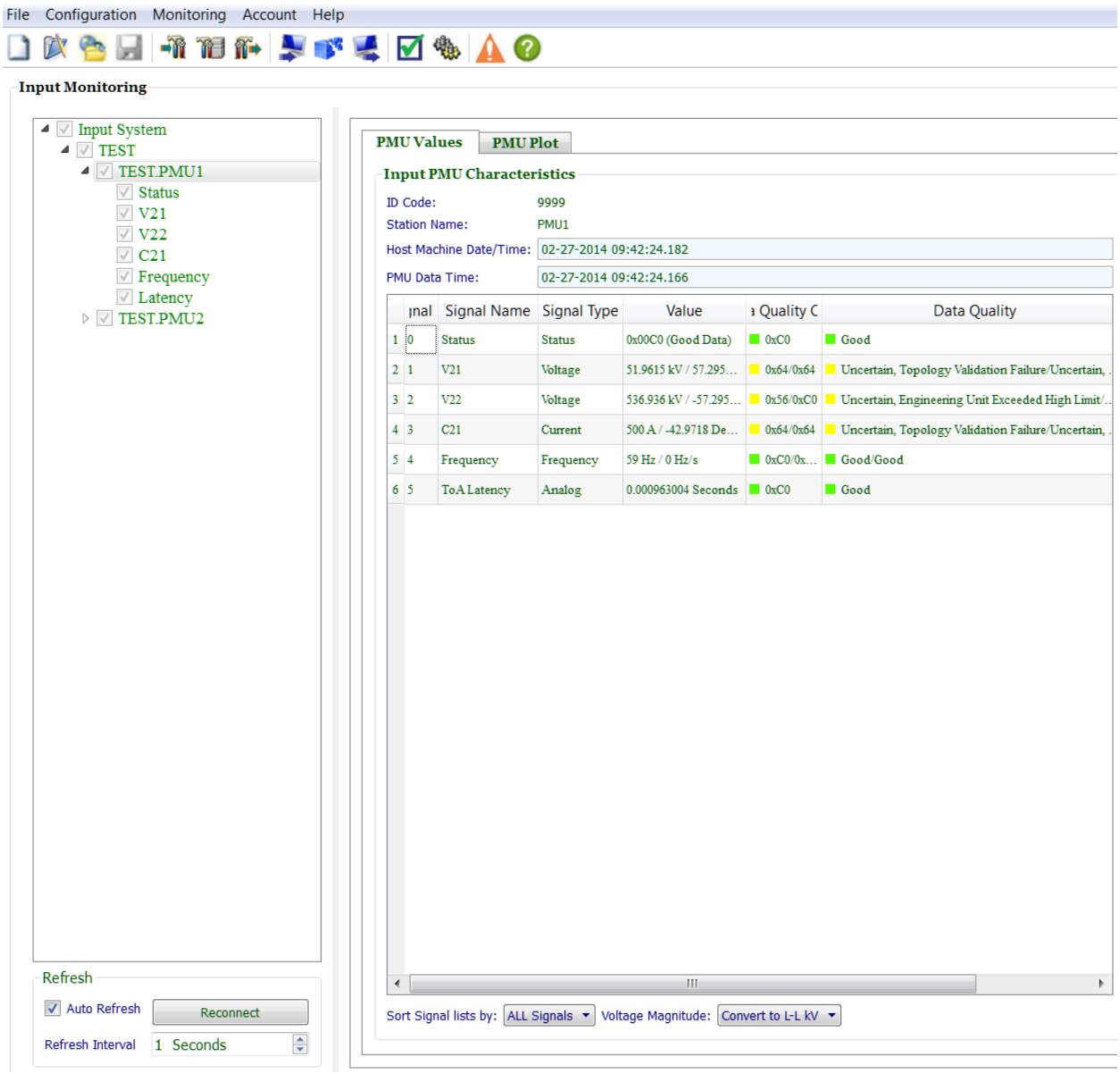
Appendix B.3 Measurement Range Check, Stale Check, and Noisy Detection Configuration



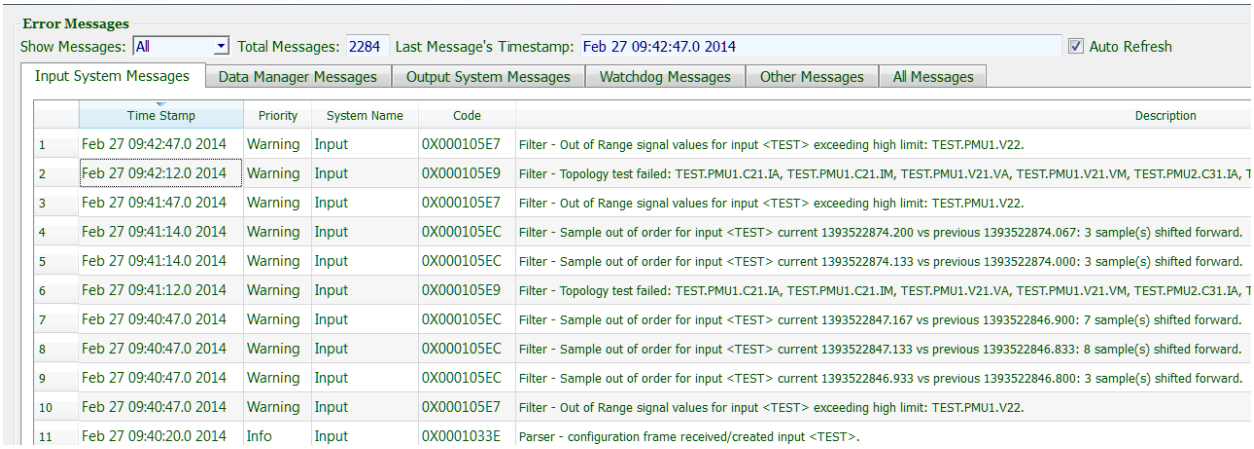
Appendix B.4 Topology-based Configuration



Appendix B.5 Validation Results Monitoring



Appendix B.6 Validation Results Logging



Error Messages

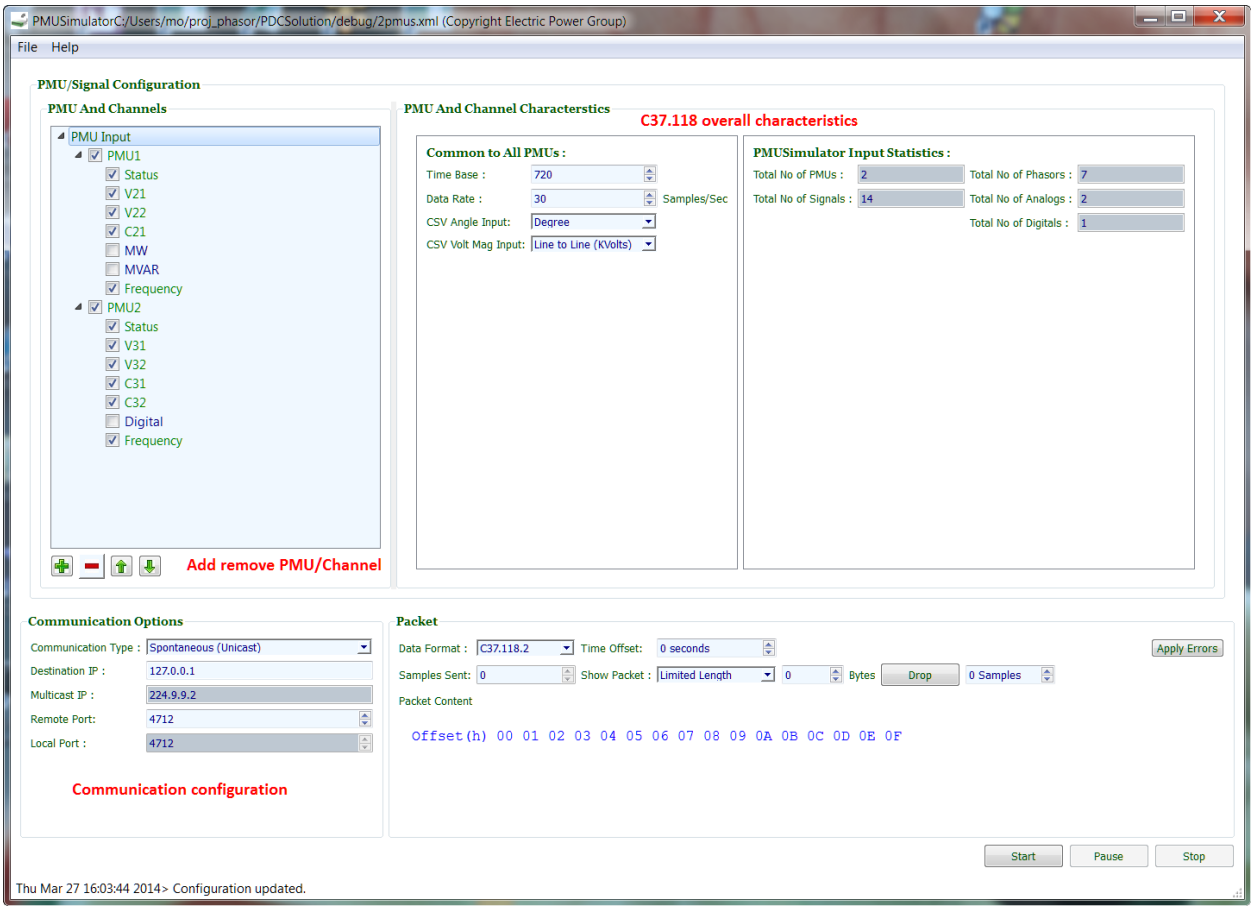
Show Messages: All | Total Messages: 2284 | Last Message's Timestamp: Feb 27 09:42:47.0 2014 | Auto Refresh

Input System Messages | Data Manager Messages | Output System Messages | Watchdog Messages | Other Messages | All Messages

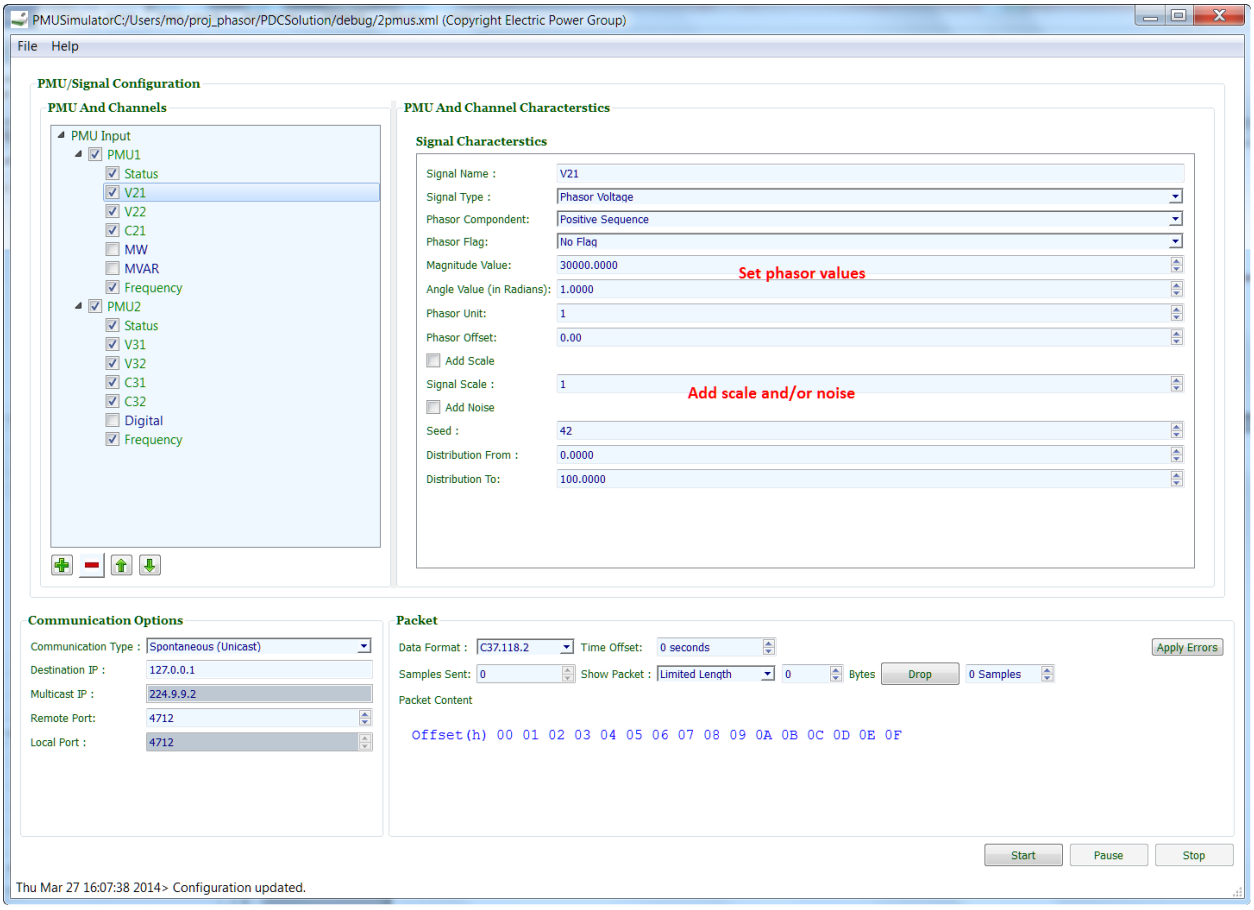
	Time Stamp	Priority	System Name	Code	Description
1	Feb 27 09:42:47.0 2014	Warning	Input	0X000105E7	Filter - Out of Range signal values for input <TEST> exceeding high limit: TEST.PMU1.V22.
2	Feb 27 09:42:12.0 2014	Warning	Input	0X000105E9	Filter - Topology test failed: TEST.PMU1.C21.IA, TEST.PMU1.C21.IM, TEST.PMU1.V21.VA, TEST.PMU1.V21.VM, TEST.PMU2.C31.IA, T
3	Feb 27 09:41:47.0 2014	Warning	Input	0X000105E7	Filter - Out of Range signal values for input <TEST> exceeding high limit: TEST.PMU1.V22.
4	Feb 27 09:41:14.0 2014	Warning	Input	0X000105EC	Filter - Sample out of order for input <TEST> current 1393522874.200 vs previous 1393522874.067: 3 sample(s) shifted forward.
5	Feb 27 09:41:14.0 2014	Warning	Input	0X000105EC	Filter - Sample out of order for input <TEST> current 1393522874.133 vs previous 1393522874.000: 3 sample(s) shifted forward.
6	Feb 27 09:41:12.0 2014	Warning	Input	0X000105E9	Filter - Topology test failed: TEST.PMU1.C21.IA, TEST.PMU1.C21.IM, TEST.PMU1.V21.VA, TEST.PMU1.V21.VM, TEST.PMU2.C31.IA, T
7	Feb 27 09:40:47.0 2014	Warning	Input	0X000105EC	Filter - Sample out of order for input <TEST> current 1393522847.167 vs previous 1393522846.900: 7 sample(s) shifted forward.
8	Feb 27 09:40:47.0 2014	Warning	Input	0X000105EC	Filter - Sample out of order for input <TEST> current 1393522847.133 vs previous 1393522846.833: 8 sample(s) shifted forward.
9	Feb 27 09:40:47.0 2014	Warning	Input	0X000105EC	Filter - Sample out of order for input <TEST> current 1393522846.933 vs previous 1393522846.800: 3 sample(s) shifted forward.
10	Feb 27 09:40:47.0 2014	Warning	Input	0X000105E7	Filter - Out of Range signal values for input <TEST> exceeding high limit: TEST.PMU1.V22.
11	Feb 27 09:40:20.0 2014	Info	Input	0X0001033E	Parser - configuration frame received/created input <TEST>.

Appendix C: Screenshots of PMU Simulator Application

Appendix C.1 C37.118 Stream Level Configuration User Interface



Appendix C.2 Set Phasor Values, Scaling Factor, and Noise



Appendix C.3 User Interface to Introduce Format Error, Data Corruption, and Missing Samples