

Synchrophasor Data Quality Conditioning

Evangelos Farantatos
Mahendra Patel
Hossein Hooshyar
EPRI

Meng Wang
Joe Chow
RPI

NASPI WG Meeting
Richmond, VA
October 29, 2019



www.epri.com

© 2019 Electric Power Research Institute, Inc. All rights reserved.

EPRI | ELECTRIC POWER
RESEARCH INSTITUTE



Synchrophasor Data Quality Challenges

- Synchrophasor data quality is a major factor for successful integration of synchrophasor technology in utility/ISO operations environment
- Poor synchrophasor data quality reduces the robustness and accuracy of PMU applications

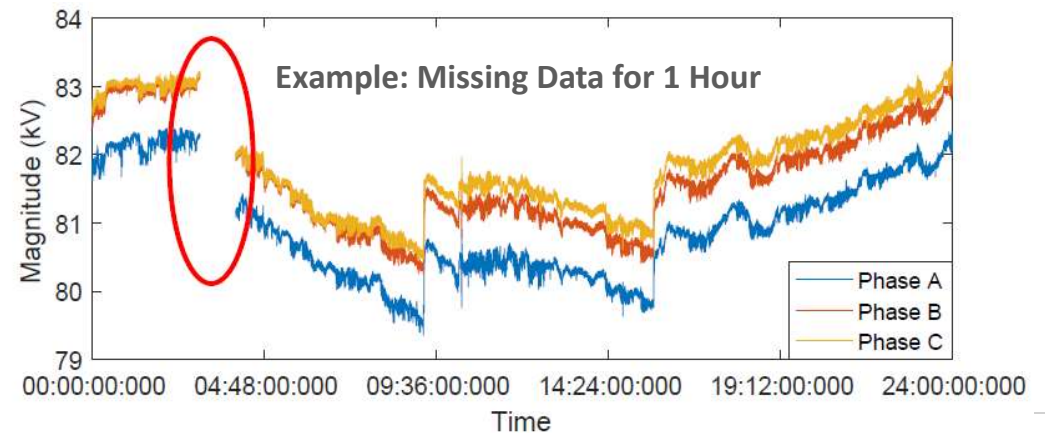
1. Data Availability - Missing Data

- Data loss
- Delivery delays
- PMU hardware failure etc.



2. Data Accuracy

- Time accuracy (GPS)
- Installation/Calibration (Instrumentation, CTs, PTs, etc.)



EPRI Work: Data Quality Conditioning of Streaming Synchrophasor Measurements

Project Goal

- Improve synchrophasor data quality by estimating missing data and replacing bad data in synchrophasor streams

Features of the Method

- Model free technique - no need for topology information or system parameters
- Computationally efficient for real-time implementation

Testing & Validation

- Algorithm has been tested with recorded synchrophasor data provided by several EPRI members

Software Tools

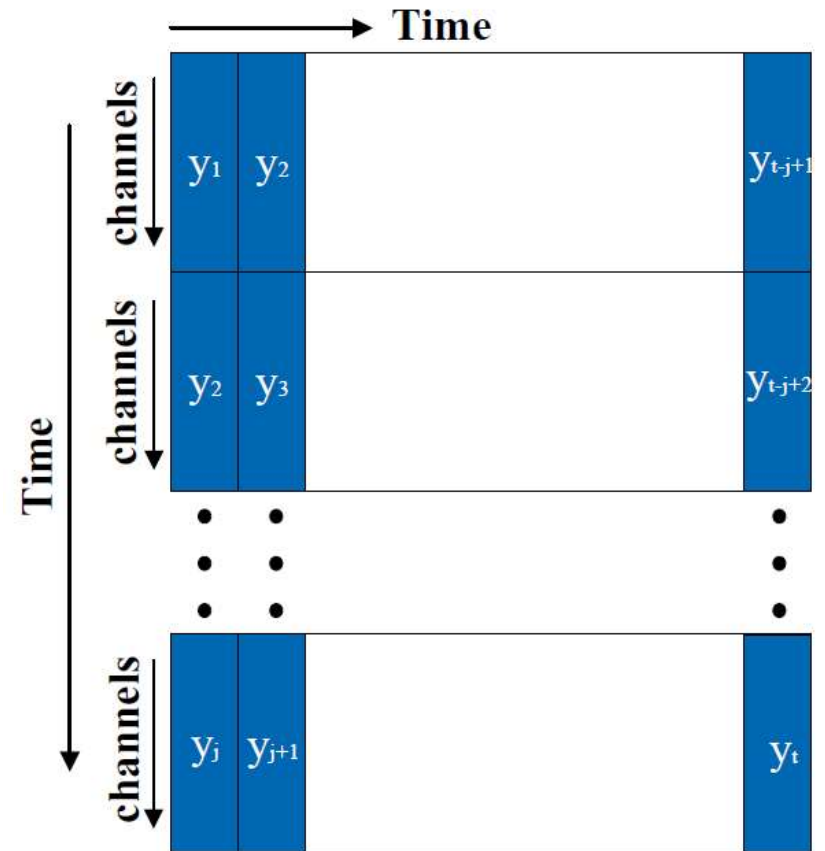
- Streaming Synchrophasor Data Quality (SSDQ) software
- Two Versions
 - Offline
 - Online

SSDQ Algorithm

- Process *spatial-temporal blocks* of synchrophasor data collected from PMUs in electrically close regions
- Key feature: *low-rankness* of synchrophasor data blocks and their Hankel matrix.
- *Differentiation between event data and bad data*

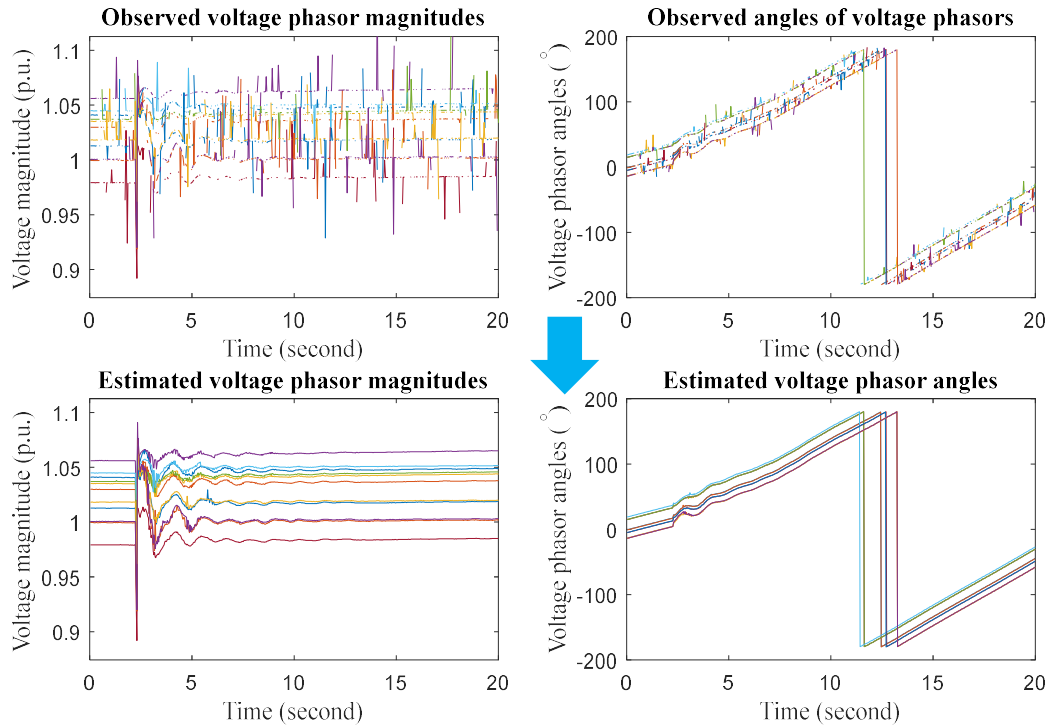
Event: $e(\mathcal{H}(\mathbf{Y})) \gg e(\mathcal{H}(\mathbf{Y}))$ Bad data: $e(\mathcal{H}(\tilde{\mathbf{Y}})) \approx e(\mathcal{H}(\mathbf{Y}))$

The Hankel matrix
An m_j -by- $(t-j+1)$ Hankel matrix

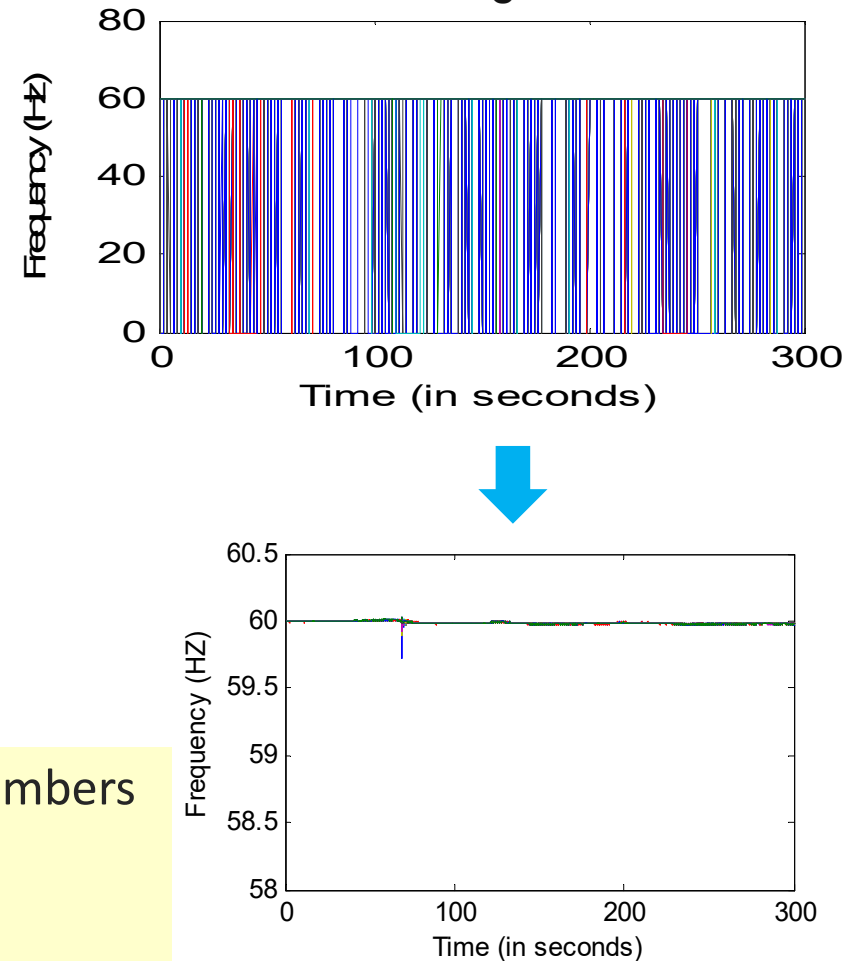


Example Results

Bad Data



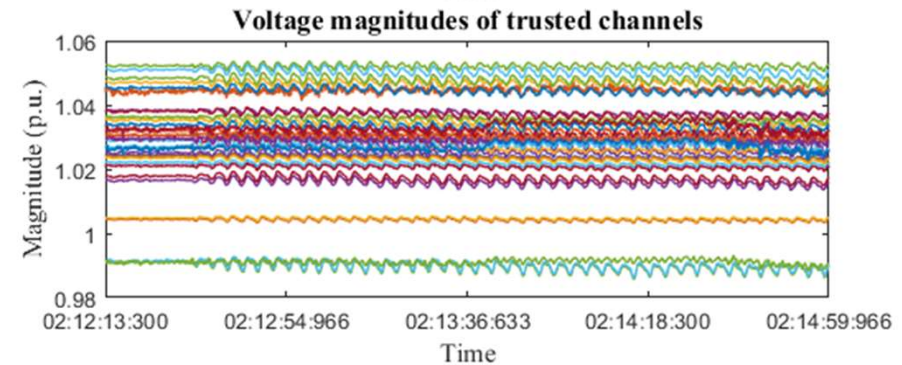
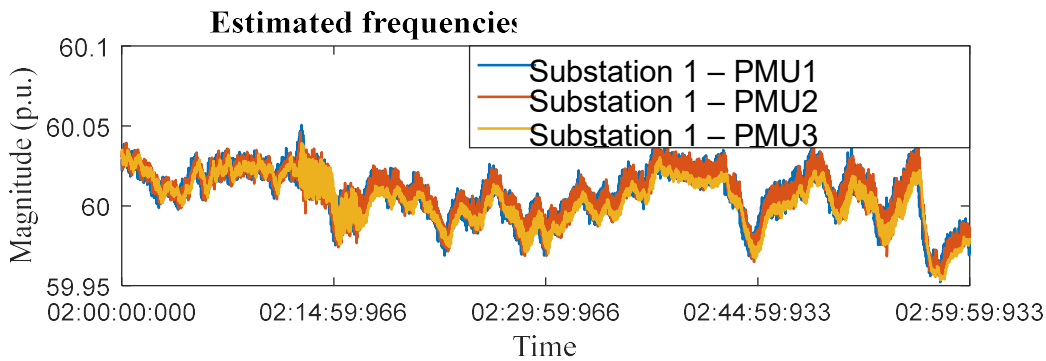
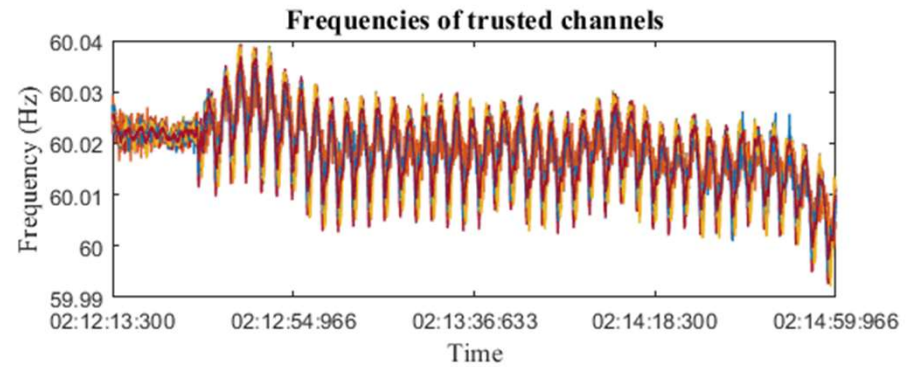
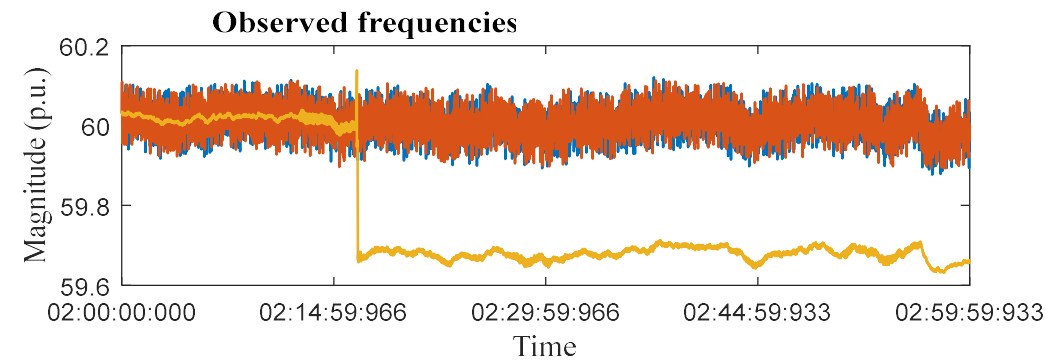
Missing Data



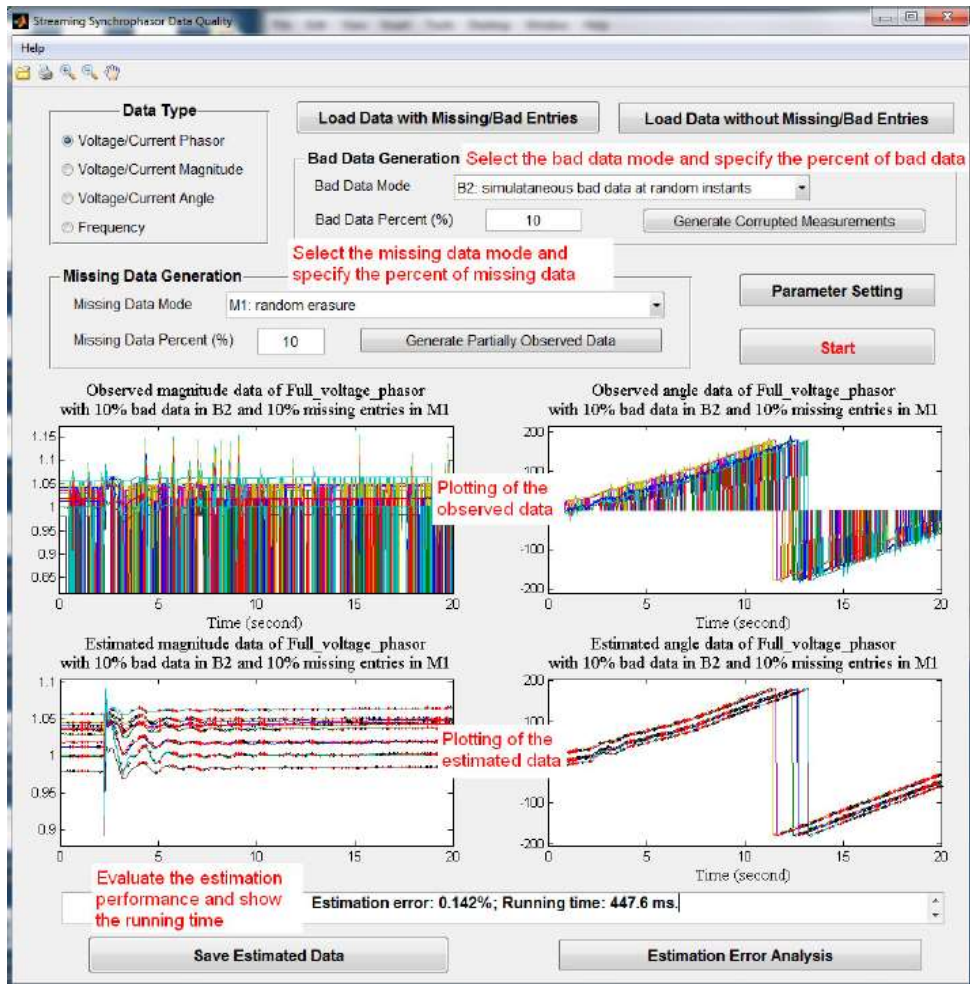
- SSDQ tested with various datasets provided by EPRI members
 - Bad measurements are identified and corrected effectively
 - Missing entries are filled in with high accuracy
 - Event data are not misidentified as bad data

SSDQ - Entergy Case Study

- Entergy provided 1 hour of recorded synchrophasor data during a 2017 oscillations event
- Event data were not misinterpreted as bad data



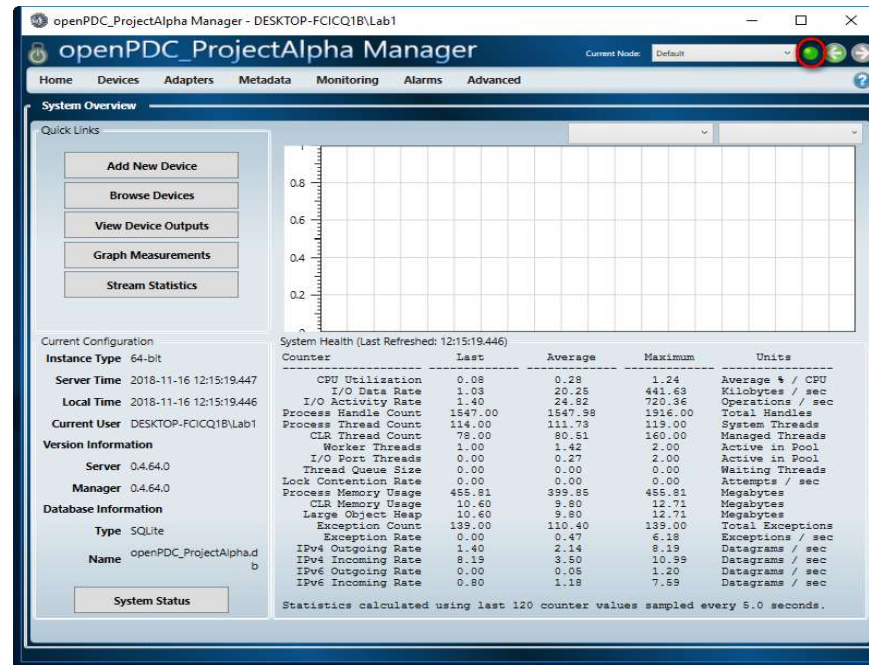
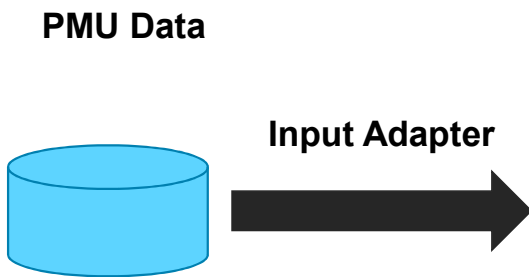
SSDQ - Matlab Based Software for Offline Testing



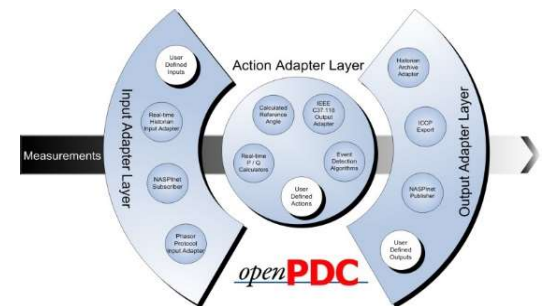
- Streaming Synchrophasor Data Quality Tool (SSDQ) – Offline version
- Detecting missing and invalid bad data, and replacing it with accurate estimated data
- Value: improve results of off-line synchrophasor applications

SSDQ – OpenPDC Implementation

- Streaming Synchrophasor Data Quality Tool (SSDQ) – Online version
- Algorithm implementation on GPA's OpenPDC Project Alpha
- SSDQ .dll file



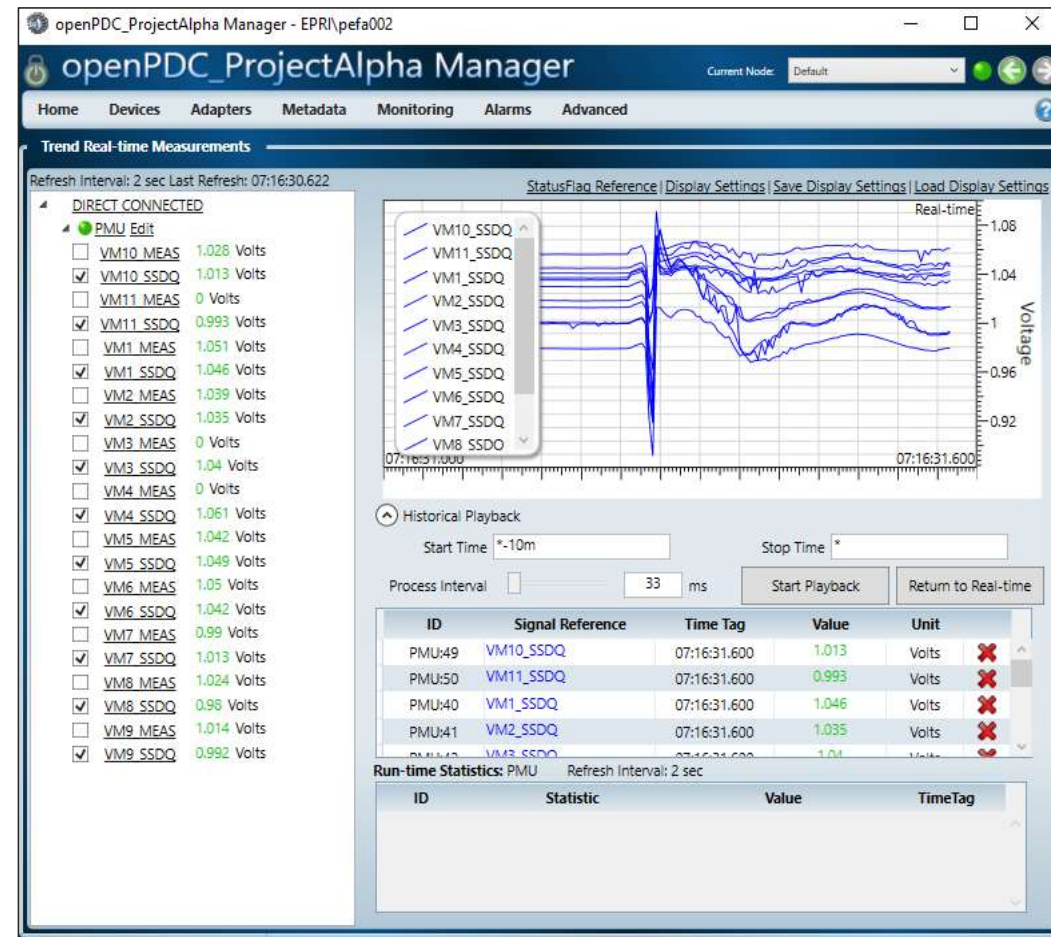
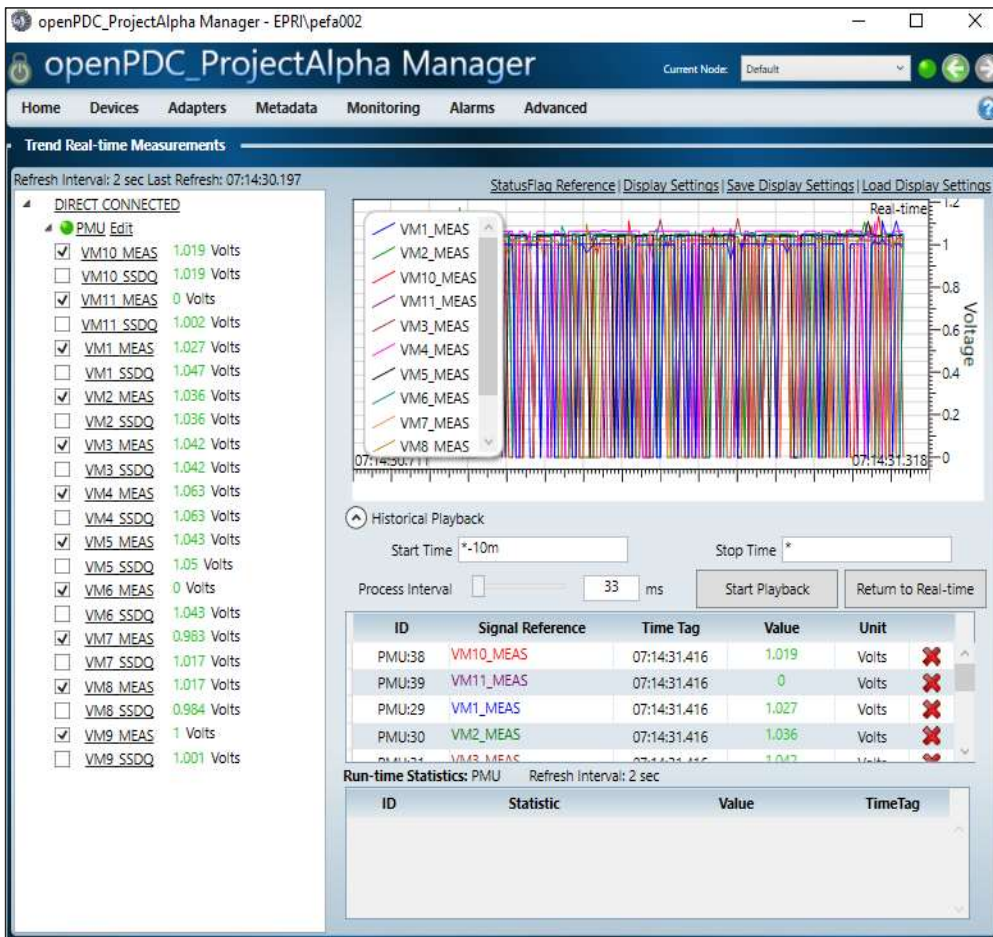
Action Adapter SSDQ Algorithm



SSDQ – OpenPDC Implementation - Results

Original Measurement Set

Corrected Measurement Set

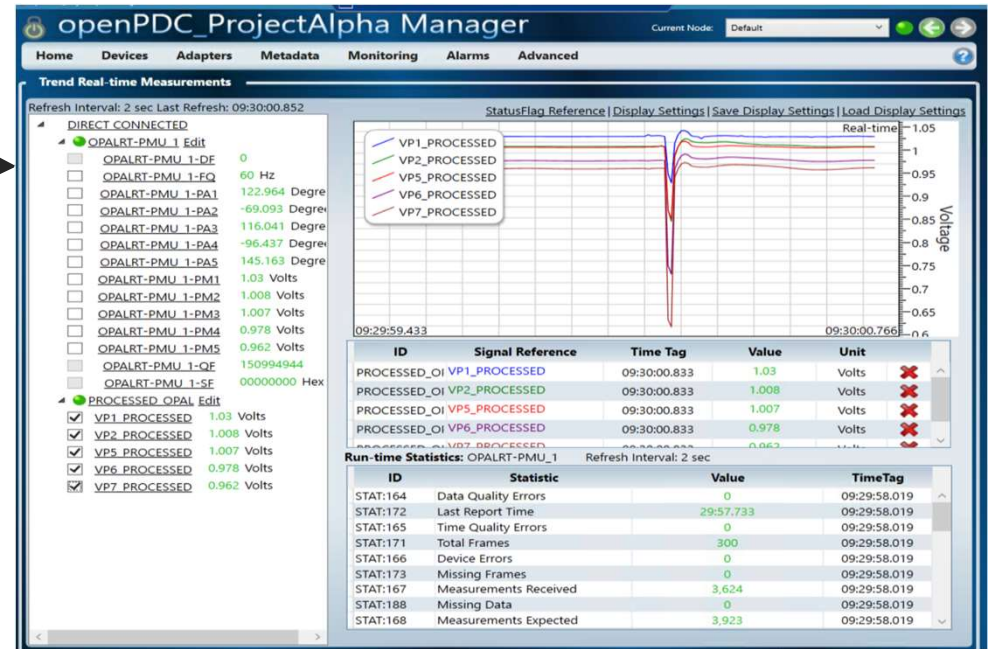
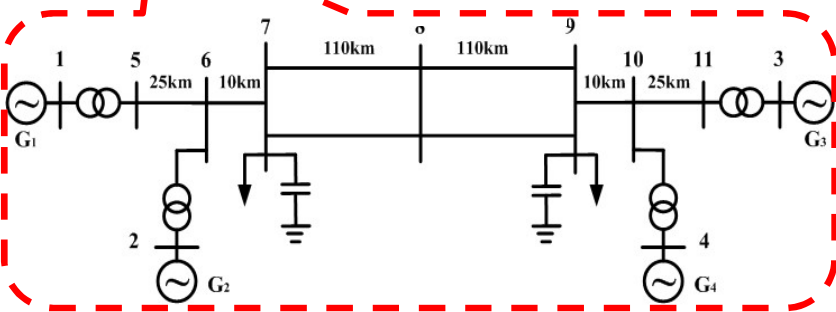


SSDQ – OpenPDC Implementation – OPAL-RT

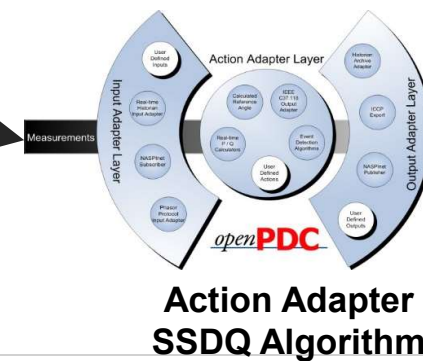
PMU stream (C37.118.2) over TCP/IP



OPAL-RT Simulator



Raw PMU data



Processed PMU data

SSDQ – OpenECA Implementation

SSDQ openECA Configuration

EPRI
ELECTRIC POWER
RESEARCH INSTITUTE

SSDQOpenECA Configuration

Provide Stored openECA Framework CSV File
C:\Users\ptba006\Box\Projects\SSDQ\GUI\Stage-8\Stored_confignew.csv Search

Stored openECA Framework Details

Device List
Update Input Devices

- PMU_A
- PMU_B
- PMU_C
- PMU_D
- PMU_E
- PMU_F
- PMU_G

Select All Deselect All

Measurement Type
Update Measurement Types

- Voltage Magnitude
- Frequency

Select All Deselect All

Input Measurement Channels Details
Refresh Input Measurement Channels

- A_VMAG1
- B_VMAG1
- C_VMAG1
- D_VMAG1
- E_VMAG1
- F_VMAG1
- G_VMAG1
- H_VMAG1
- I_VMAG1
- J_VMAG1
- K_VMAG1
- A_FREQ1
- B_FREQ1
- C_FREQ1
- D_FREQ1
- E_FREQ1
- F_FREQ1

Select All Deselect All

Output Measurement Channel Details
Select Output Device
PMU_Q

Create/Update Output Measurement Channels

- SSDQ_A_VMAG1
- SSDQ_B_VMAG1
- SSDQ_C_VMAG1
- SSDQ_D_VMAG1
- SSDQ_E_VMAG1
- SSDQ_F_VMAG1
- SSDQ_G_VMAG1
- SSDQ_H_VMAG1
- SSDQ_I_VMAG1
- SSDQ_J_VMAG1
- SSDQ_K_VMAG1
- SSDQ_A_FREQ1
- SSDQ_B_FREQ1
- SSDQ_C_FREQ1
- SSDQ_D_FREQ1

SSDQ Actions

Parameter Settings

Run SSDQ

Stop SSDQ

Data Visualization

PLOT

Record Data

Load openECA Framework

Save openECA Framework

Save

Recent Saved Framework (.csv) Location:

“The openECA platform provides a Common Analytics Interface (CAI) for integration of a diverse set of platform analytics along with structured integration of platform configuration, display and storage systems.”

OpenECA: <https://www.gridprotectionalliance.org/products.asp>

OpenECA SSDQ

Measurement Type Selection

Output Channels

Data Source Selection

The screenshot shows the 'SSDQopenECA Configuration' window. The interface is divided into several sections:

- Framework Settings:** Includes 'Select Data Source' with checkboxes for 'openECA' and 'External PDC Subscription'. Below it is a 'Get Input Devices' button and a list of device options: 'TESTDEVICE', 'OPENPDC_GISHELBY', 'OPENPDC_GIPMU1_EPRI', 'OPENPDC_GIPMU2_EPRI', and 'OPENPDC_GIPMU_OPAL_RT'. 'OPENPDC_GIPMU1_EPRI' is selected.
- Measurement Types:** A section with a 'Get Available Measurement Types' button and checkboxes for 'Voltage Magnitude', 'Voltage Angle', 'Current Magnitude', 'Current Angle', and 'Frequency'. 'Frequency' is checked.
- Input Channels Selection:** A list of measurement channels with checkboxes, including 'OPENPDC_GIVM1' through 'OPENPDC_GIFREQ8'. All are checked.
- Output Channels:** A 'Select Output Device' dropdown menu showing 'PMU_OUT' and 'Same Device Allocation'. Below it is a list of output channels with checkboxes, including 'SSDQ_OPENPDC_GIVM1' through 'SSDQ_OPENPDC_GIFREQ6'. All are checked.
- SSDQ Actions:** Includes 'Parameter Settings', 'Run SSDQ', and 'Stop SSDQ' buttons.
- Data Visualization:** Includes 'PLOT' and 'Record Data' buttons.
- Configuration Save:** A 'Save openECA Framework' button and a text field for 'Recent Saved Framework (.csv) Location:'.

PMUs Selection

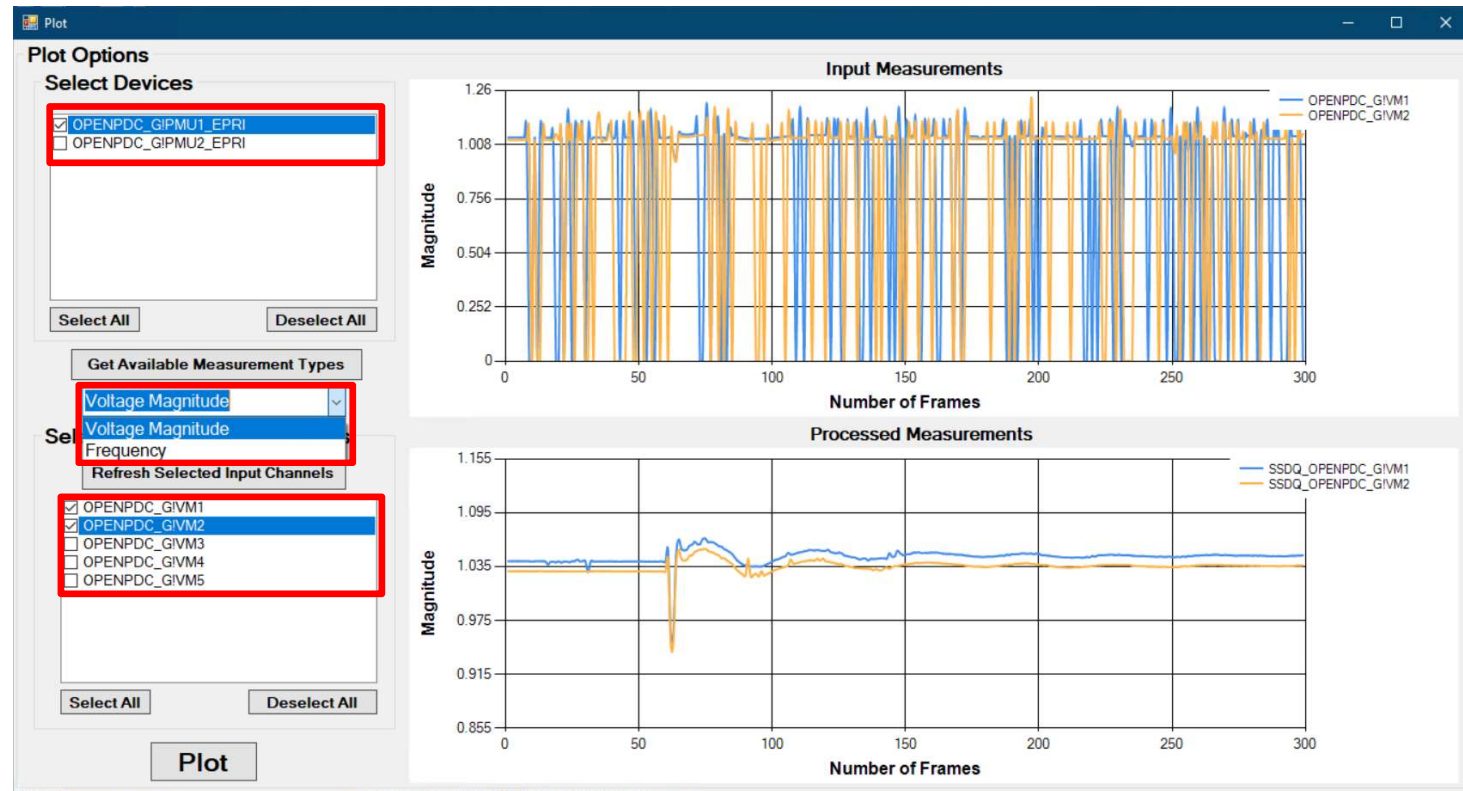
Input Channels Selection

Plotting & Recording

Configuration Save

OpenECA SSDQ – Plotting

- Plots the processed measurements versus the input measurements
- Gives the option to choose the PMU device, the measurement type and the measurement channels for plotting



OpenECA SSDQ - Recording

- Records the processed measurements and the input measurements in CSV format
- Gives the option to choose the PMU device, the measurement type and the measurement channels for recording

Record Data

Record Data Settings

Select Devices

- OPENPDC_GIPMU1_EPRI
- OPENPDC_GIPMU2_EPRI

Select All Deselect All

Select Measurement Type

Get Available Measurement Types

- Voltage Magnitude
- Frequency

Select All Deselect All

Select Measurement Channels

Refresh Selected Input Channels

- OPENPDC_GIVM1
- OPENPDC_GIVM2
- OPENPDC_GIVM3
- OPENPDC_GIVM4
- OPENPDC_GIVM5
- OPENPDC_GIVM6
- OPENPDC_GIVM7
- OPENPDC_GIVM8
- OPENPDC_GIVM9
- OPENPDC_GIVM10
- OPENPDC_GIVM11
- OPENPDC_GIFREQ1
- OPENPDC_GIFREQ2
- OPENPDC_GIFREQ3
- OPENPDC_GIFREQ4
- OPENPDC_GIFREQ5
- OPENPDC_GIFREQ6
- OPENPDC_GIFREQ7
- OPENPDC_GIFREQ8
- OPENPDC_GIFREQ9
- OPENPDC_GIFREQ10
- OPENPDC_GIFREQ11

Select All Deselect All

Export Data to a CSV File

Destination File Location C:\Users\NXIC0224\Desktop\SSDQ_Processed_Data Save As

Start Stop

Case Studies/Demonstrations & Vendor Engagement

- New recorded PMU datasets with missing/bad data are welcome
- Pursuing demonstrations of the OpenPDC and/or OpenECA SSDQ
- Interested for vendor engagement and implementation of the models in commercial platforms





Together...Shaping the Future of Electricity