Dominion Energy

Synchrophasor Design, Deployment and Applications

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What are Synchrophasors and PMUs?

Synchrophasor

- Synchronized Phasor Measurement

$2\angle 45°$

PMU

- Phasor Measurement Unit

Why are these important?

Phasor magnitudes and angles are captured

- All data representing health of the system

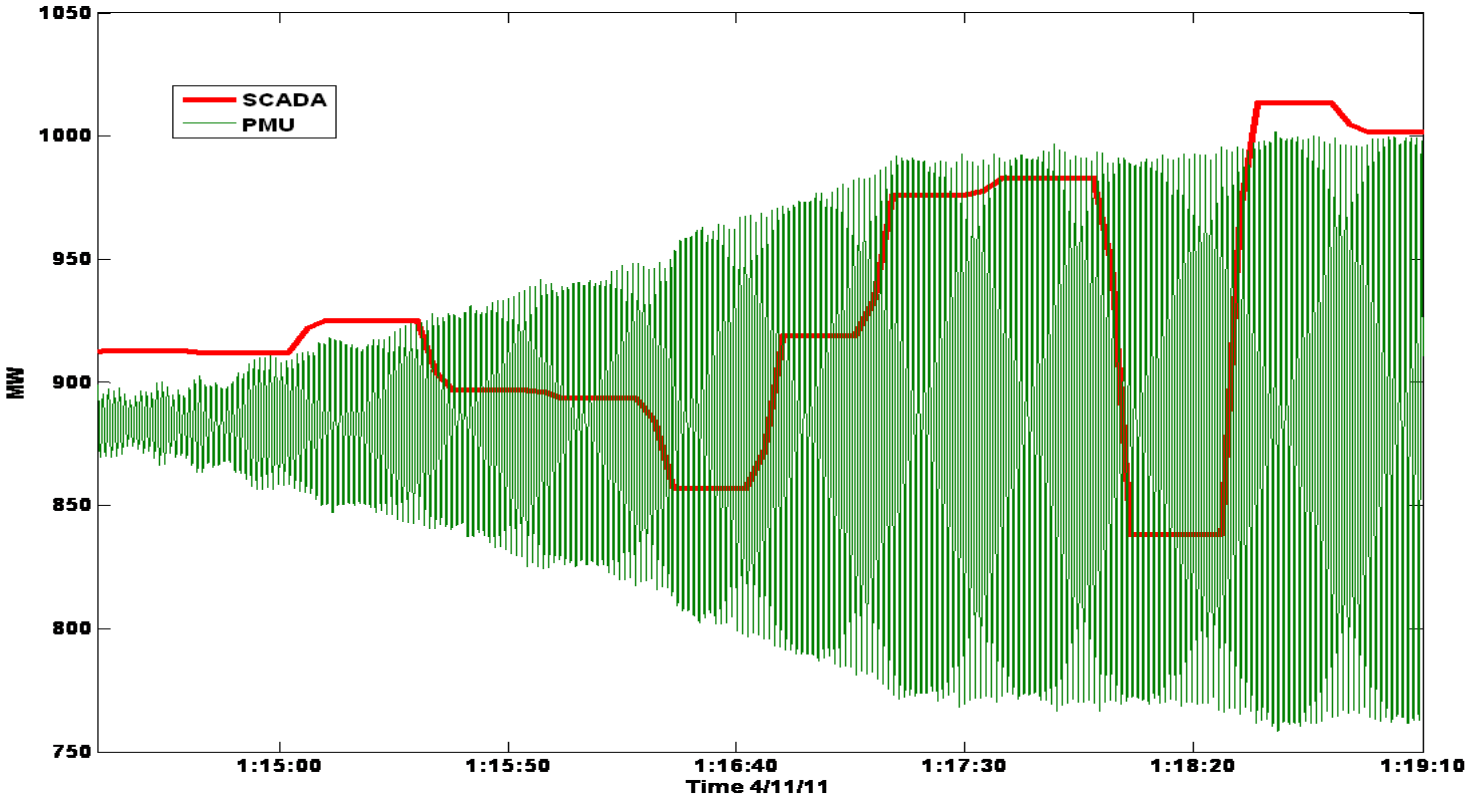
All Synchrophasors referenced to the same time

- Simultaneous snapshots of the electric grid

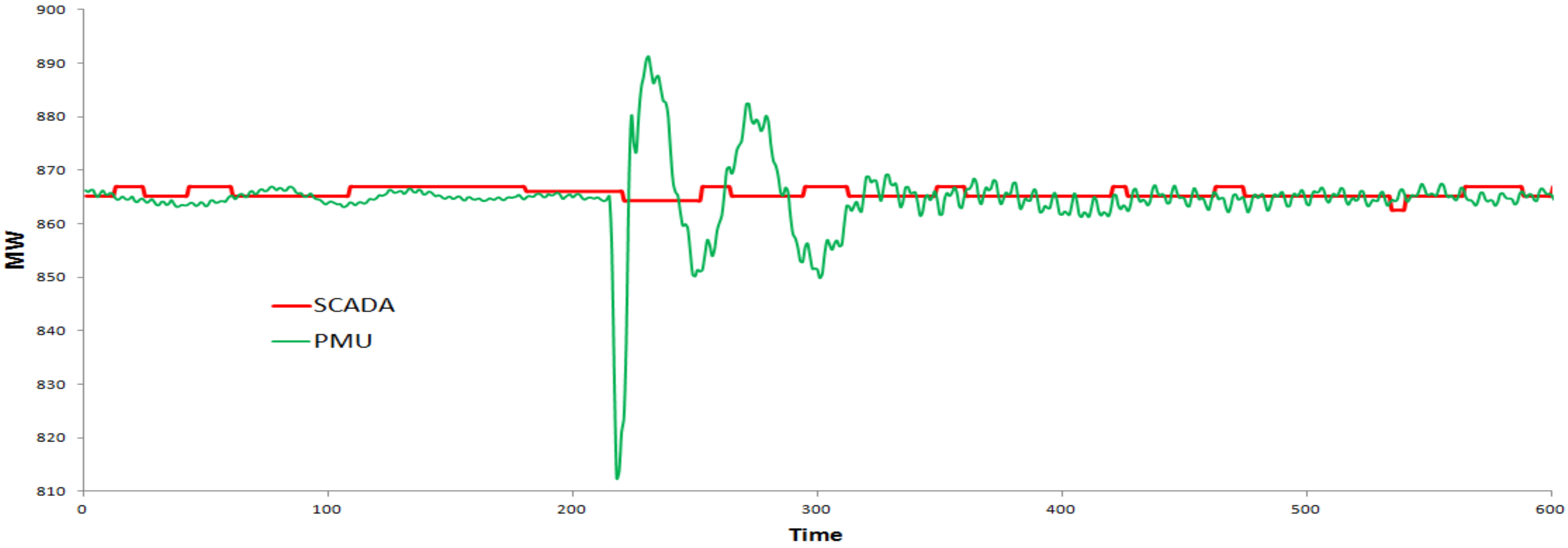
Higher Resolution Data (30 Synchrophasors/sec)

- Many more snapshots of the electric grid

New perspectives with PMUs



Three-phase Fault Near Power Station

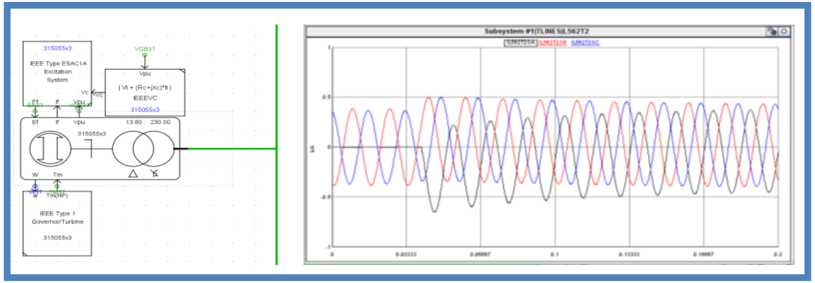


New Perspectives with PMUs

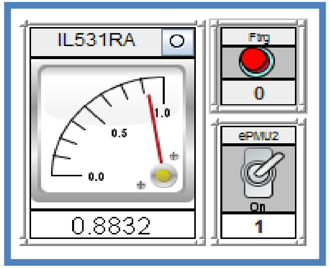
These events are great examples of the new information we will now get from PMUs. This data is crucial to addressing the ever increasing stress on power grids so that reliability and stability are maintained.

However, with this new data comes new challenges for power grid operators. How are they supposed to respond to these new events that we have never been able to see before?

RTDS Operator Training Simulator

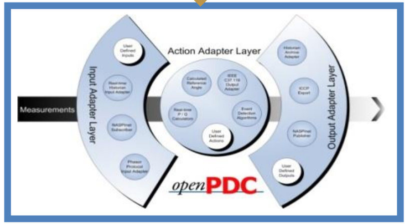


Electromechanical & Electromagnetic Dynamics

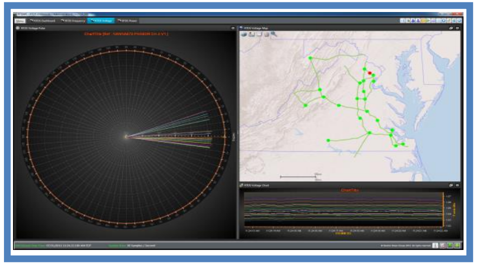


Operator-In-Loop
Runtime Controls

Closed-Loop
Relay/PMU Interface



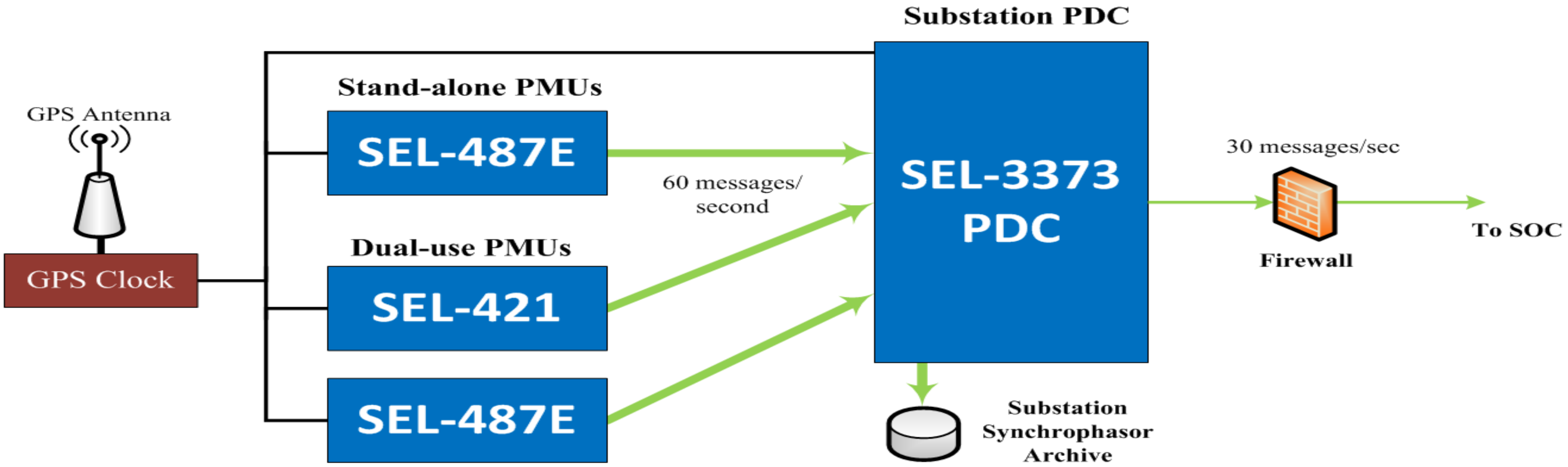
Virtual PMUs Streaming Data



Visualization Software

Synchrophasor Substation Architecture

- Independent from SCADA Systems
- **Capture all three phases**
- PMUs made CIP CCAs
- Back-up Archive



Substation Standards for Synchrophasors & PMUs

Four Substation Standards for Synchrophasors & PMUs

1. Transmission Line Relays
   - Add satellite coaxial cable, Ethernet connection, PMU Settings
2. Transmission Transformer Relays
   - Add satellite coaxial cable, Ethernet connection, PMU Settings
3. Stand-alone PMU Panel
   - Install if Lines/Transformer don’t have PMU-capable relays (and aren’t being upgraded in near future)
   - Install if other voltages/currents/digitals in the station are needed (ex: cap banks, FACTs)
4. Substation PDC
   - Install one per control house (sufficient at this time, as one PDC can handle ~40 PMUs)
   - Install PDC on a Communication Panel or a

     Stand-alone PMU Panel

Future Substation PMU Standards

Non-CIP PMUs

- Non-relay devices
  - Digital Fault Recorders
  - Meters
- Distribution Substations
  - Feeder-level relays
  - DG point-of-interconnection PQ meters and relays

Blackstart PMUs

- Along all cranking paths
- PMU-based synchroscope for connection of cranking paths

INTRODUCTION TO openECA PLATFORM

Objective

- To develop an open source software platform that enables the production use and facilitates the development of analytics that use high-fidelity synchrophasor data.

- Project Members:

- 2-Year Scheduled Project

<u>October 2015 – September 2017</u>

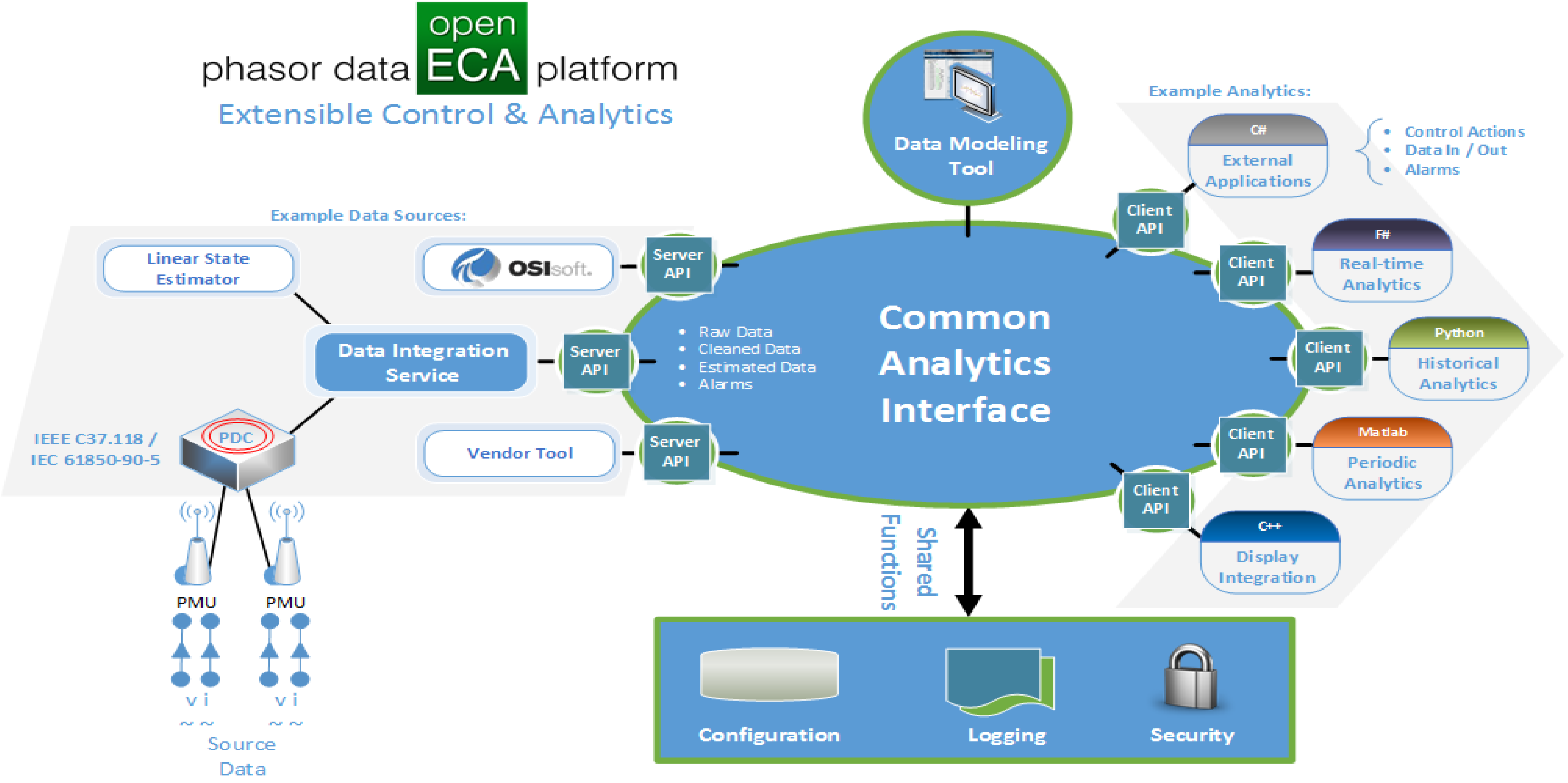
  - Alpha Version – March 2017
  - Demonstration Begins – August 2017
  - Version 1.0 released – September 2017

openECA

open and Extensible Control & Analytics platform for synchrophasor data

Motivation

- Allows analytic developer to focus on development of new techniques and tools and not on learning how to build information interfaces
- Lowers cost of addition of new production analytic tools
- Improves availability of phasor data with greater visibility of phasor data quality
- Complements current phasor data architecture and supports integration with other data sources such as SCADA


phasor data
open
ECA
platform
Extensible Control & Analytics
Data Modeling Tool
Example Analytics:
C#
External Applications
Control Actions
Data In / Out
Alarms
Example Data Sources:
Linear State Estimator
OSIsoft.
Server API
Client API
F#
Real-time Analytics
Data Integration Service
Server API
Raw Data
Cleaned Data
Estimated Data
Alarms
Common Analytics Interface
Client API
Python
Historical Analytics
IEEE C37.118 / IEC 61850-90-5
PDC
Vendor Tool
Server API
Client API
Matlab
Periodic Analytics
Client API
C++
Display Integration
Shared Functions
PMU
PMU
v i
v i
Source Data
Configuration
Logging
Security

Various Analytics

- Local Voltage Controller
- Regional Voltage Controller
- PMU Synchroscope
- Real-Time Line Parameters Calculation
- Topology Estimation
- Transmission Line Parameters Estimation
- CT/PT Calibration
- Oscillation Detection
- Oscillation Mode Meter
- Synchronous Machine Parameter Estimation
- Acceleration Trend Relay Improvement

PMU SYNCHROSCOPE

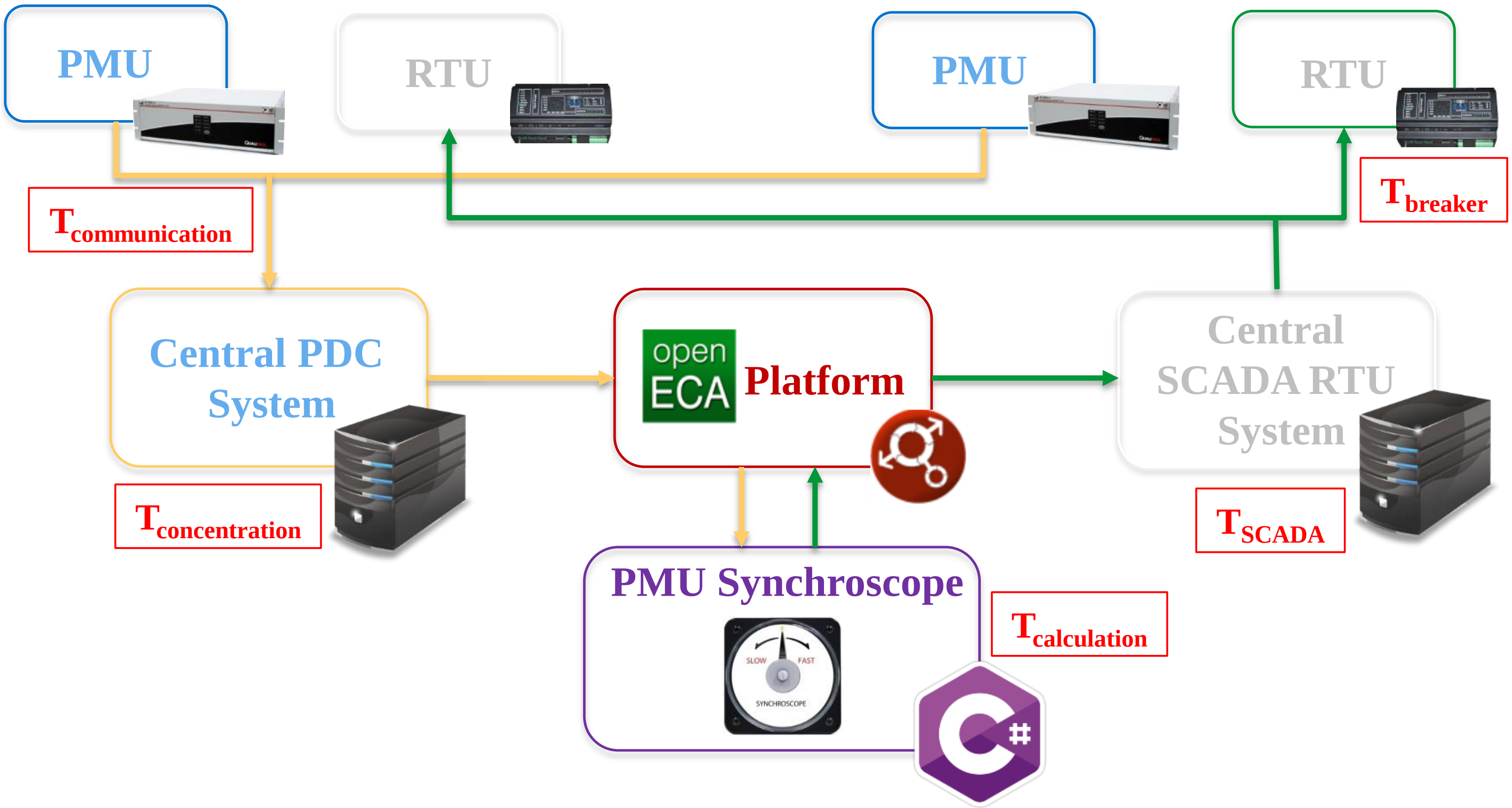
Quick Recap to PMU Synchroscope

- A synchroscope is a physical device that assists with the synchronization of generators or islands with the grid.

- The synchronization process is mainly monitored and operated at the substation level which might not control or even predict the after-effects of synchronization.

- But with advent of time synchronized phasor measurements synchroscope functionality can now be enabled at a remote centralized control platform.

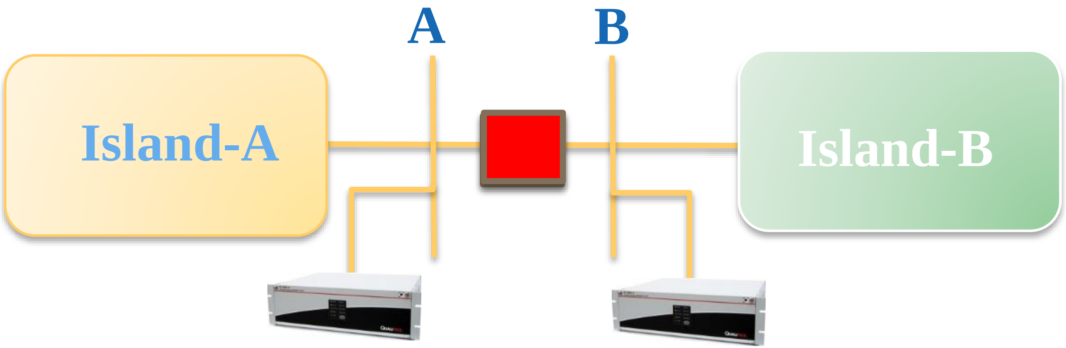
Introduction



Concept of Advanced Angle

- **Cumulative Delays are calculated depending upon network configuration and traffic of the path adopted.**

$$Adv.Ang = \left\{\frac{(Slip)cyc}{sec}\right\}\left\{\frac{sec}{60\ cyc}\right\}\left\{\frac{360}{cyc}\right\}\{(Cumulative\ Delay)cyc\}$$



Goals

Proper Depiction: The analytic would be tested whether it successfully represents the real time measurements in the form of phasors along with accurate rotation of incoming phasor proportional to frequency slip with respect to reference phasor.

Annunciation Display: It would be verified if Proper alarms are raised for meeting the criteria for successful synchronization along with checklist for the same.

Compatibility with openECA: The analytic would be tested to check streaming in of data as well as providing synchronizing breaker close/open command back to the openECA platform.

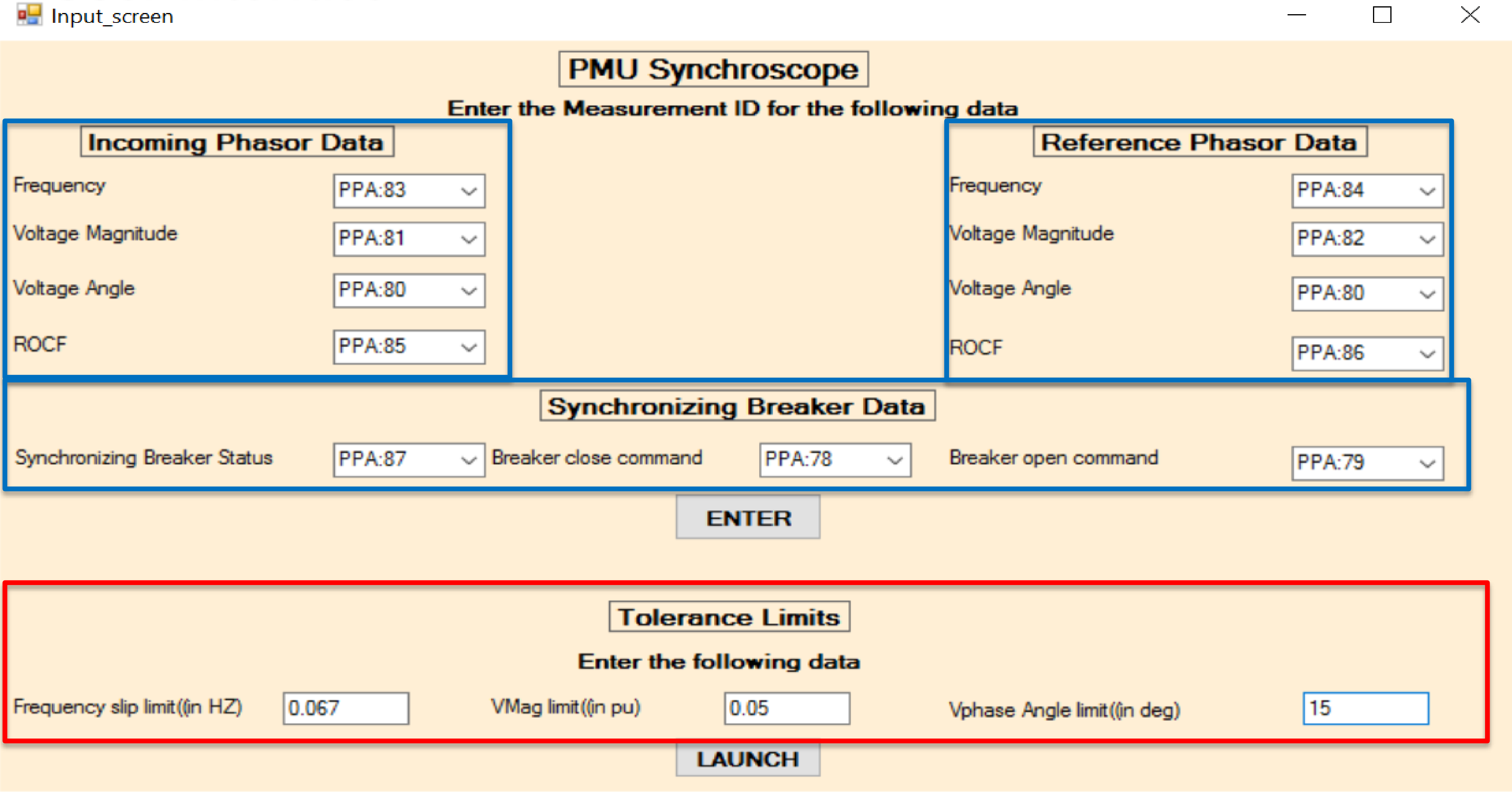
Implementation

- As openECA is an open source project, the PMU Synchroscope installer package built using openECA software can be downloaded and deployed at the user's system.

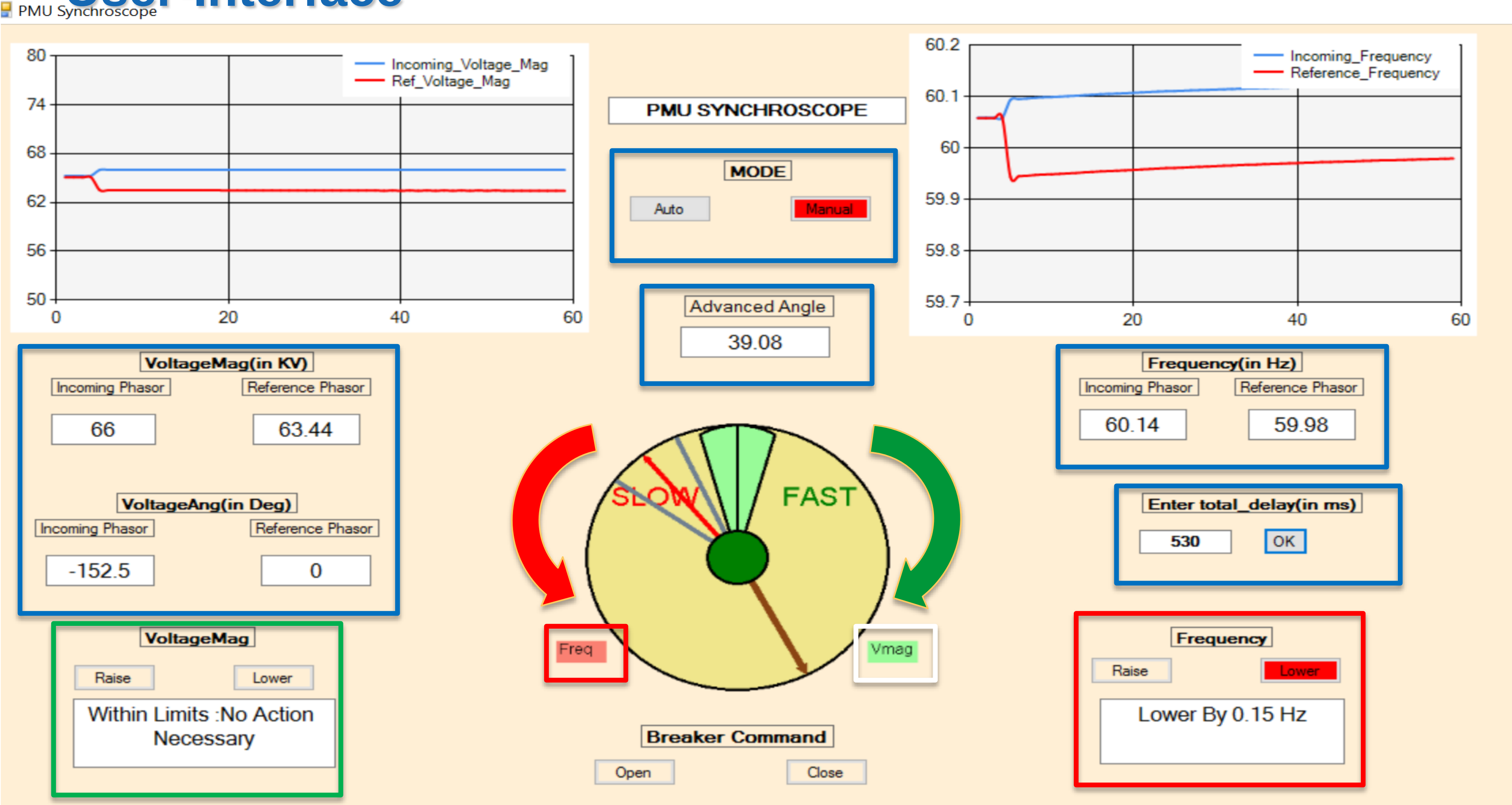
- The Analytic was tested with RTDS generated data using predefined system models available which consisted of two islands.

- The 3 phase RMS value of the bus voltages, bus frequencies, ROCOF measurements, breaker status and instantaneous voltage difference for phase A, before and after synchronization are retrieved from RTDS simulation.

User-Interface



User-Interface



Conclusion

- **The Synchroscope designed thus has the capability of synchronizing two buses from a remote centralized location.**

- **The downstream and upstream delays would vary from one system to the other and thus the advanced angle would be calculated separately.**

- **Testing to be further done using OPAL-RT ePHASORSIM simulator in order to improve the application so that after synchronization transients can be minimized.**

Related Links

- https://github.com/GridProtectionAlliance/openECA
- https://www.github.com/kdjones/linear-state-estimator
- https://www.github.com/kdjones/openlse
- http://www.opal-rt.com/systems-ephasorsim