



DOE/OE Transmission Reliability Program

Suite of Open-Source Applications and Models for Advanced Synchrophasor Analysis

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Project Team

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 - James O'Brien
- LBNL
 - Joe Eto
 - Ciaran Roberts
 - Emma Stewart
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- Partners
 - BPA
 - NERC
 - WECC
 - University of Wisconsin-Madison
(Bernie Lesieutre)



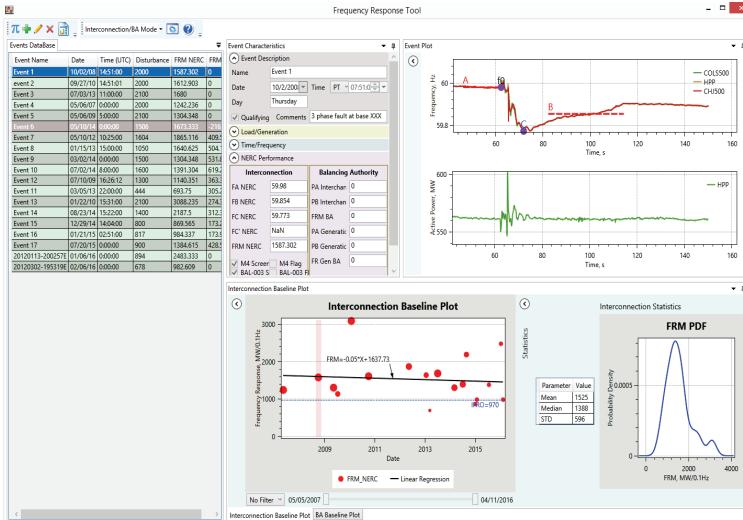
Overall project objective

- Develop and advance applications of phasor measurement units (PMUs) and synchrophasor data for power system planning, modeling, and analysis.
- Create building blocks and solutions for future and third-party applications.
- Address oscillation analysis, frequency response, model validation and calibration, load modeling, and other important power-grid-related issues.
- Enable adoption of PMU technology by a wider range of electrical utilities.

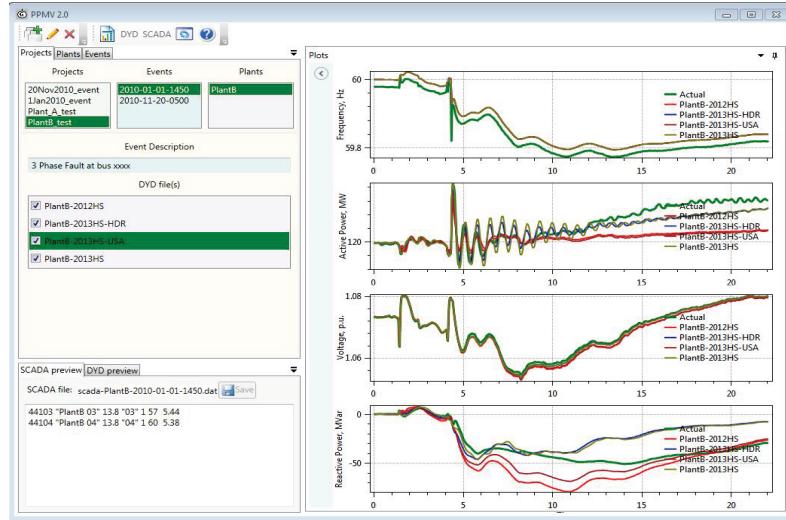


Applications built on the open source platform

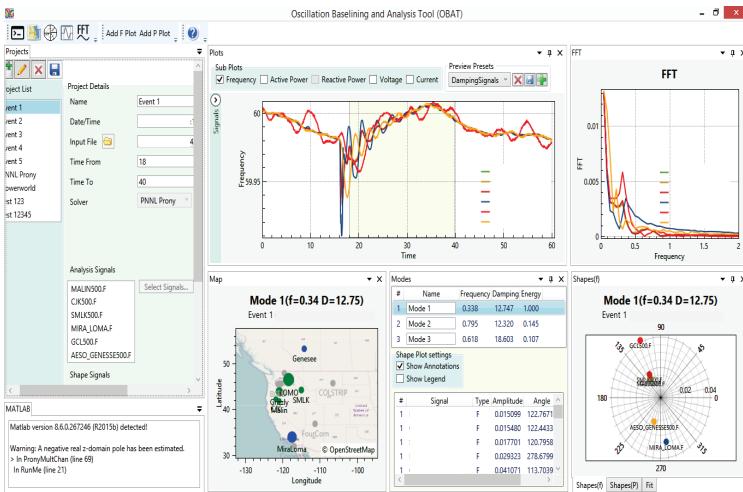
Frequency Response Analysis Tool (FRAT 2.0)



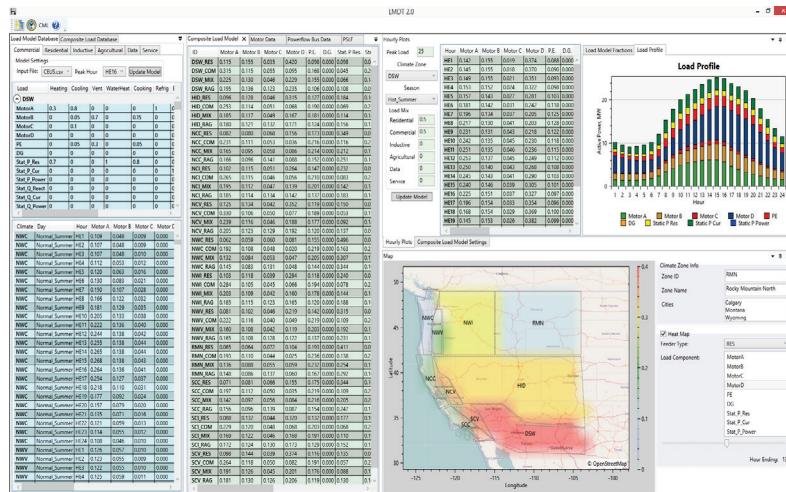
Power Plant Model Validation Tool (PPMV 2.0)



Oscillation Baselining and Analysis Tool (OBAT 1.0)

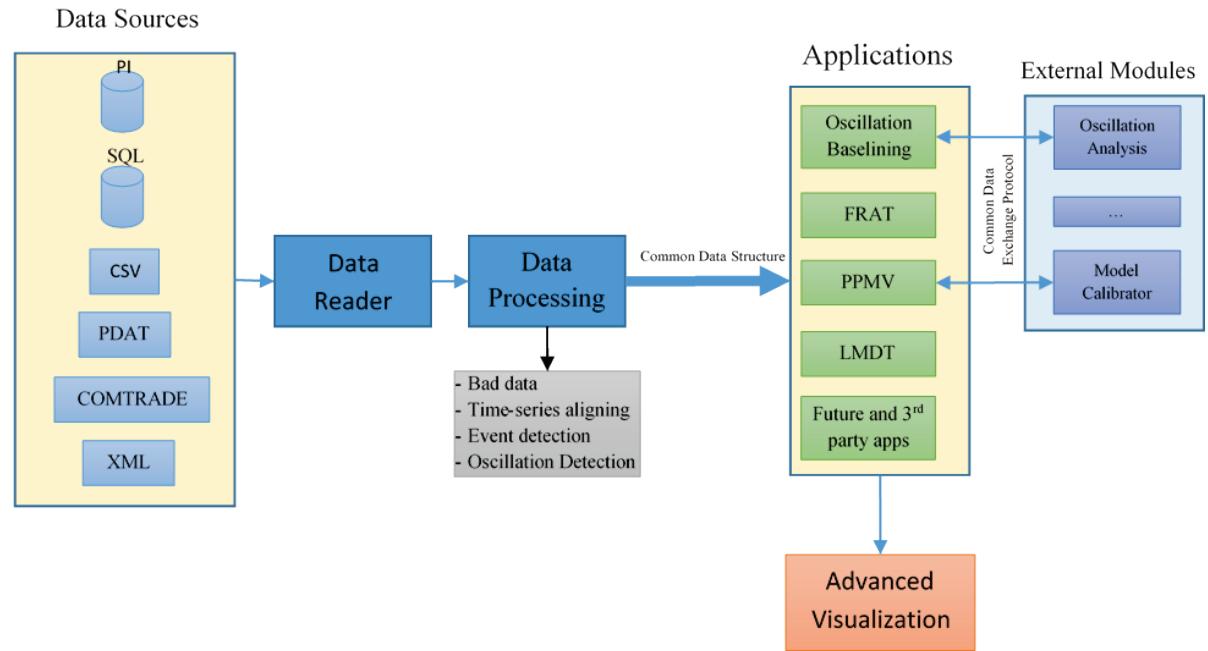


Load model Data Tool (LMDT 2.0)



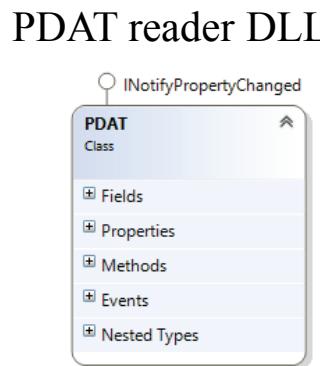
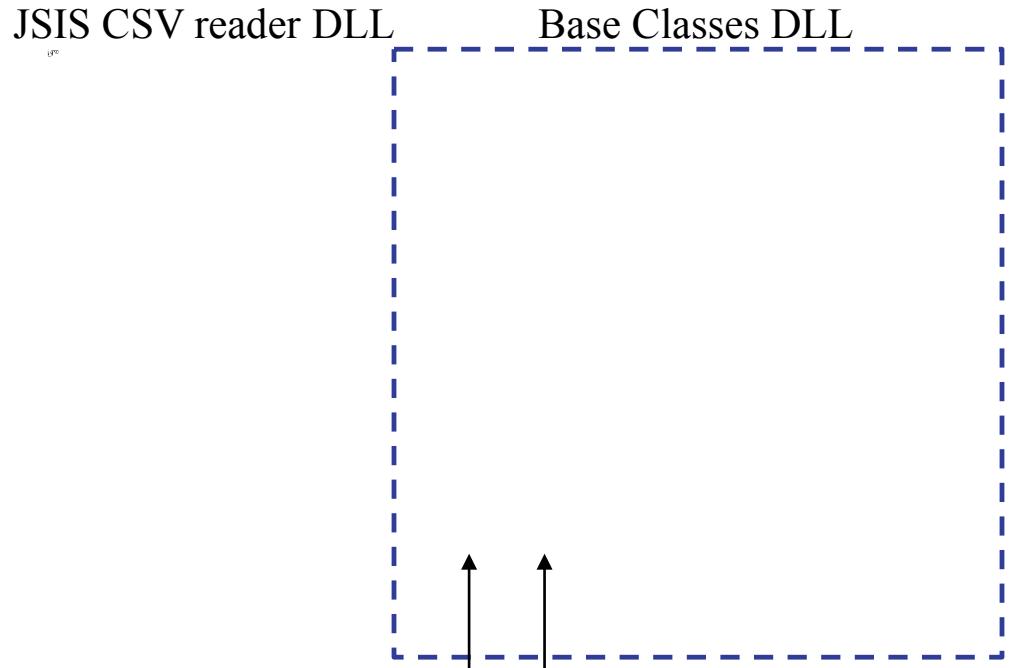
Open Source Framework

- Based on Open Source Components:
 - Extended WPF Toolkit™
 - OxyPlot
 - Math.NET
- Building blocks for future and 3rd party applications.
- Common data structure and data exchange protocols.
- Support external modules/solvers:
 - Oscillation Analysis
 - Model Calibration



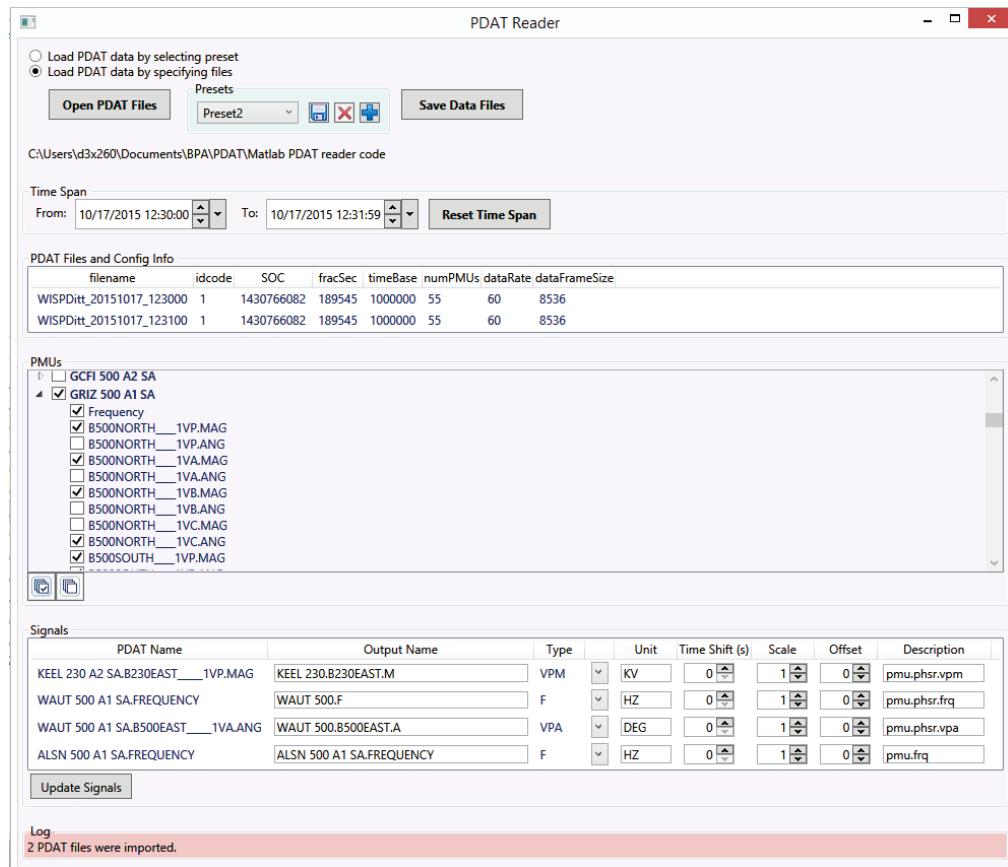
Data readers

- Available:
 - PI database reader
 - JSIS CSV reader
 - PDAT reader
 - COMTRADE reader
- Under development:
 - Event detection
 - Data validation



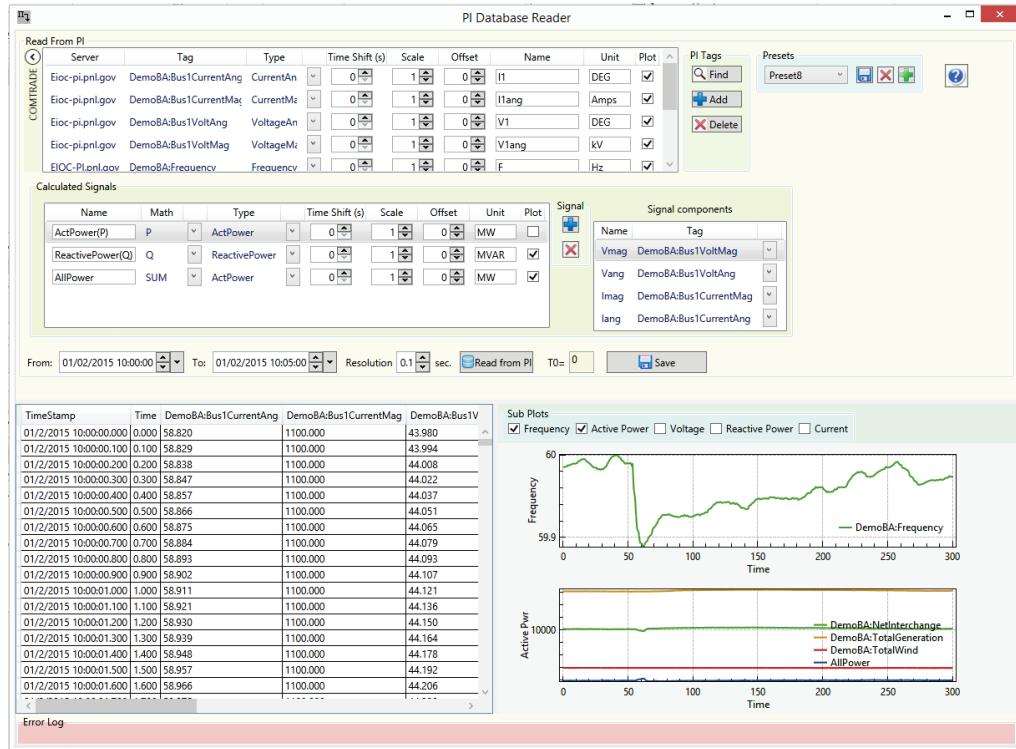
PDAT reader

- Read information from PDAT files.
 - PDAT format developed by BPA.
 - Based on IEEE Std. C37.118.2-2011.
 - Binary files.
 - Each file contains 1 minute of data.
 - PNNL receives PMU data stream from Bonneville Power Administration.
- User friendly GUI.
- Export data to CSV and COMTRADE.
- Configurable presets:
 - PMU/signal names
 - Time shift
 - Scale
 - Offset



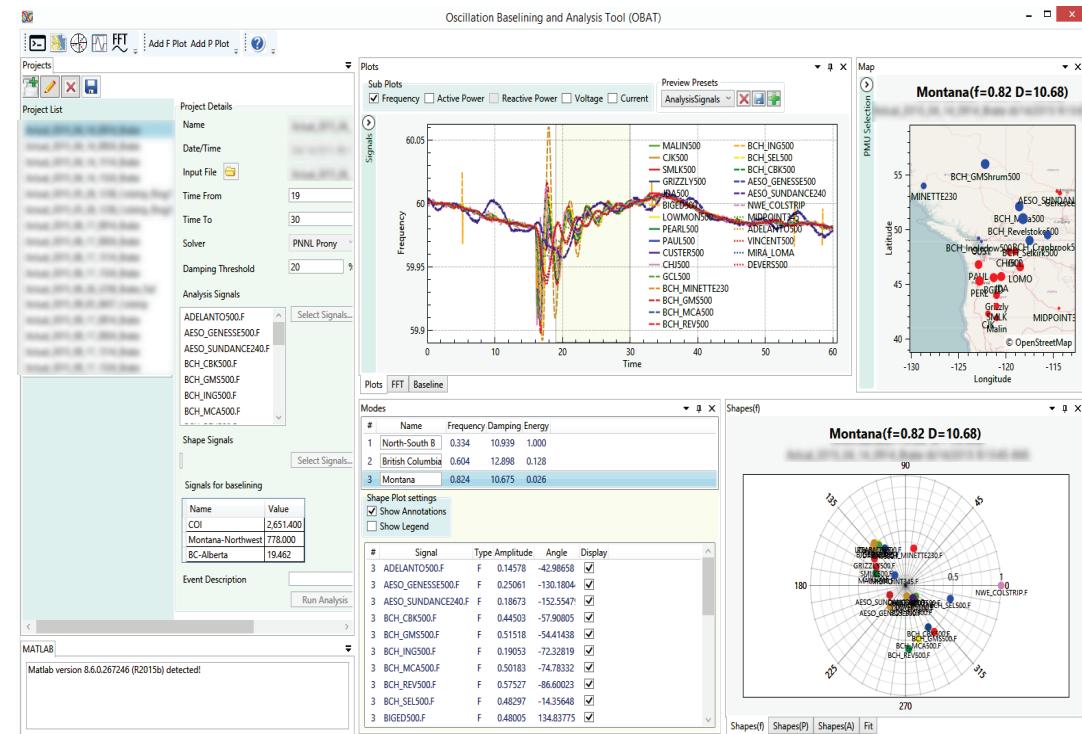
OSIsoft PI database

- New version includes multiple improvements.
- Read information from OSIsoft PI database server.
- Time series alignment.
- Configurable presets:
 - PI tag
 - Time shift
 - Scale
 - Offset
- Support simple math operations:
 - Sum of several signals.
 - P and Q calculation.

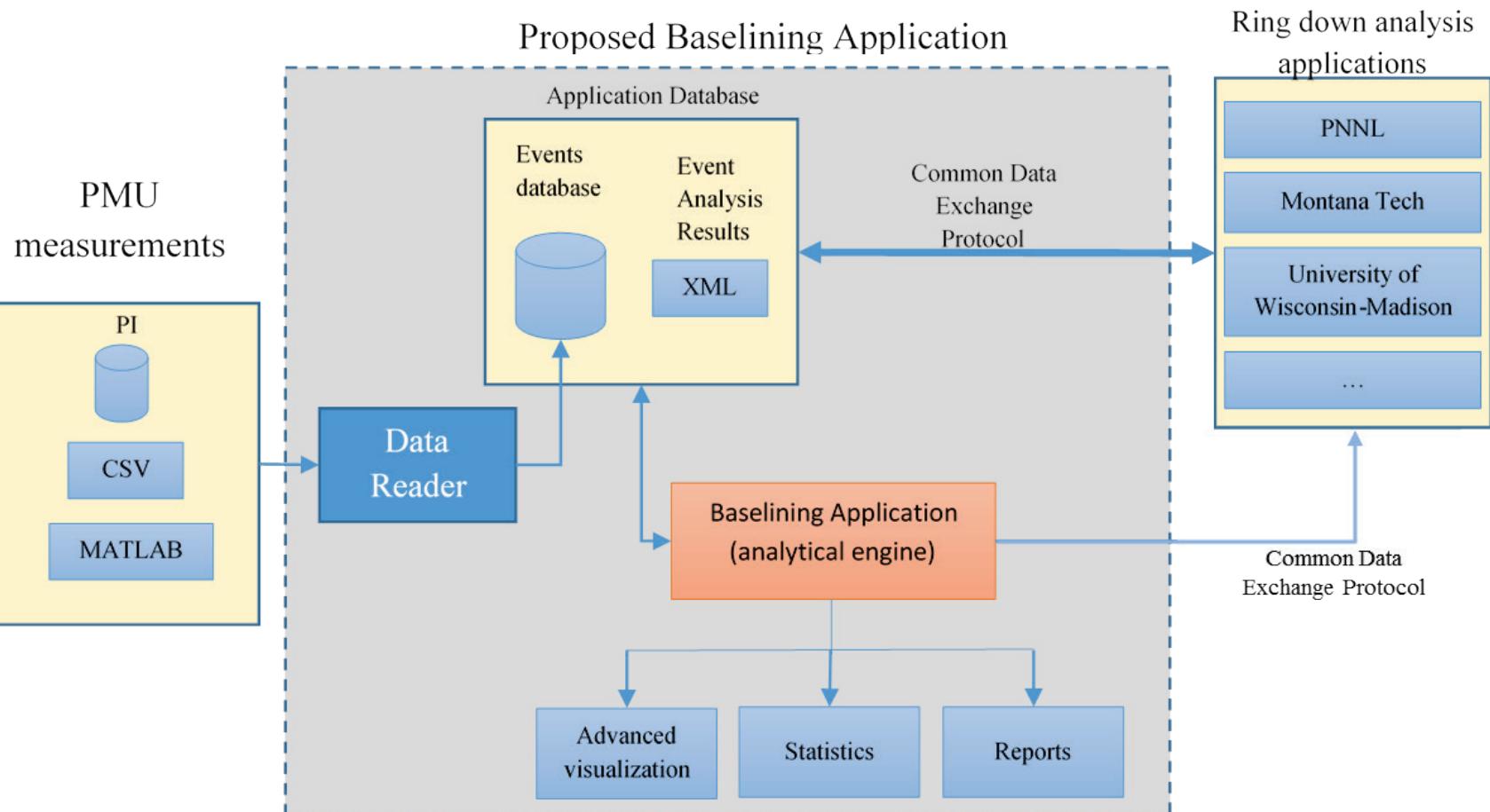


Oscillation Baselining and Analysis Tool

- Standalone Windows application.
- Released under an open source license on 05/01/2017.
- Based on the open platform for engineering application.
- Interaction with external MATLAB analytical modules for oscillation analysis through COM interface.
- Three analytical methods have been implemented:
 - VARPRO (provided by Bernie Lesieurte)
 - Prony
 - Matrix pencil
- Connectivity to different data sources.
- Database of events.
- Event baselining.
- Advanced visualization.
- Automatic reporting.

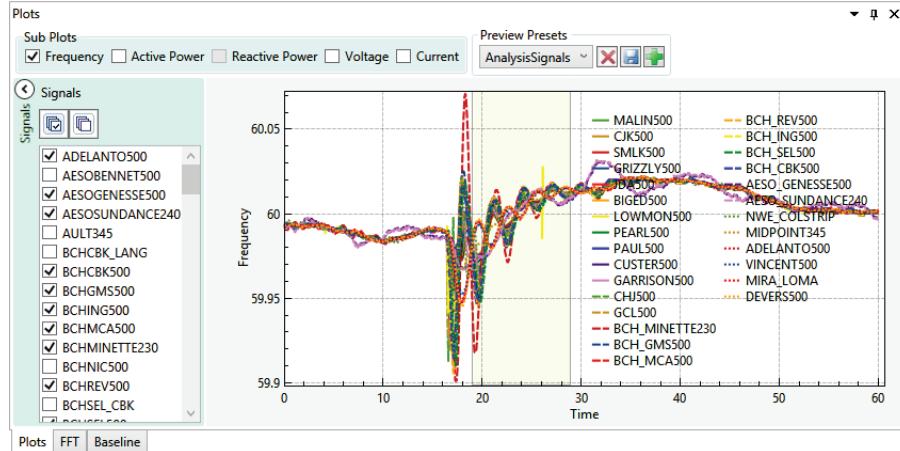


OBAT Conceptual Design

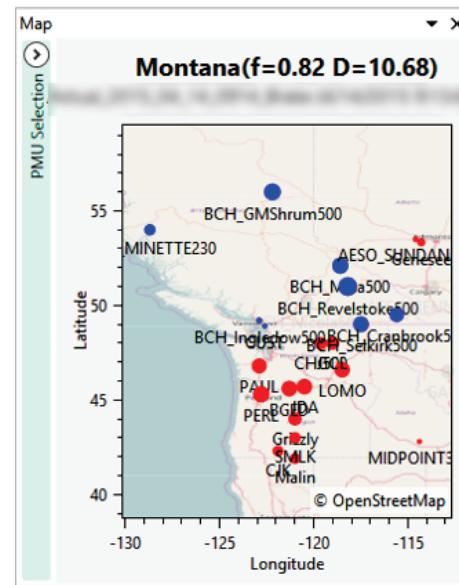


OBAT - visualization

Event plot



Map

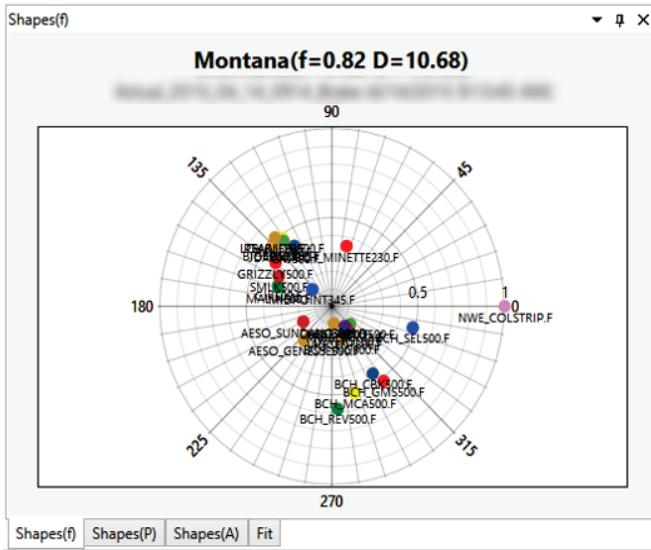


XML based configuration

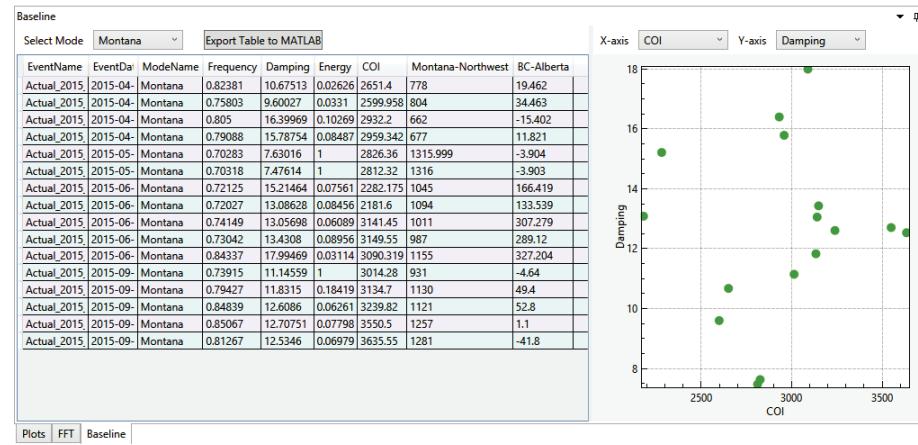
```

<Event Name="Event2">
  <Tstart>5</Tstart>
  <Tend>45</Tend>
  <InputFile>Event2.csv</InputFile>
  <Solver>VARPRO</Solver>
  <Signals>
    <Signal>A</Signal>
    <Signal>B</Signal>
    <Signal>C</Signal>
  </Signals>
  <Modes>
    <Mode>
      <ID>1</ID>
      <Name>Mode 1</Name>
      <Frequency>0.37802</Frequency>
      <Damping>1.03616</Damping>
    </Mode>
    <ModeShapes>
      <Signal Name="A">
        <Amplitude>0.00389</Amplitude>
        <Angle>66.38118</Angle>
      </Signal>
      <Signal Name="B">
        <Amplitude>0.03919</Amplitude>
        <Angle>66.41947</Angle>
      </Signal>
      <Signal Name="C">
        <Amplitude>0.00419</Amplitude>
        <Angle>67.69662</Angle>
      </Signal>
    </ModeShapes>
  </Mode>
  <Mode>
    <ID>2</ID>
    <Name>Mode 2</Name>
    <Frequency>0.06316</Frequency>
    <Damping>3.0263</Damping>
  </Mode>
  <ModeShapes>
    <Signal Name="A">
      <Amplitude>0.01537</Amplitude>
      <Angle>199.65433</Angle>
    </Signal>
    <Signal Name="B">
      <Amplitude>0.01537</Amplitude>
      <Angle>199.6545</Angle>
    </Signal>
    <Signal Name="C">
      <Amplitude>0.01531</Amplitude>
      <Angle>199.61553</Angle>
    </Signal>
  </ModeShapes>
</Event>
```

Mode shape

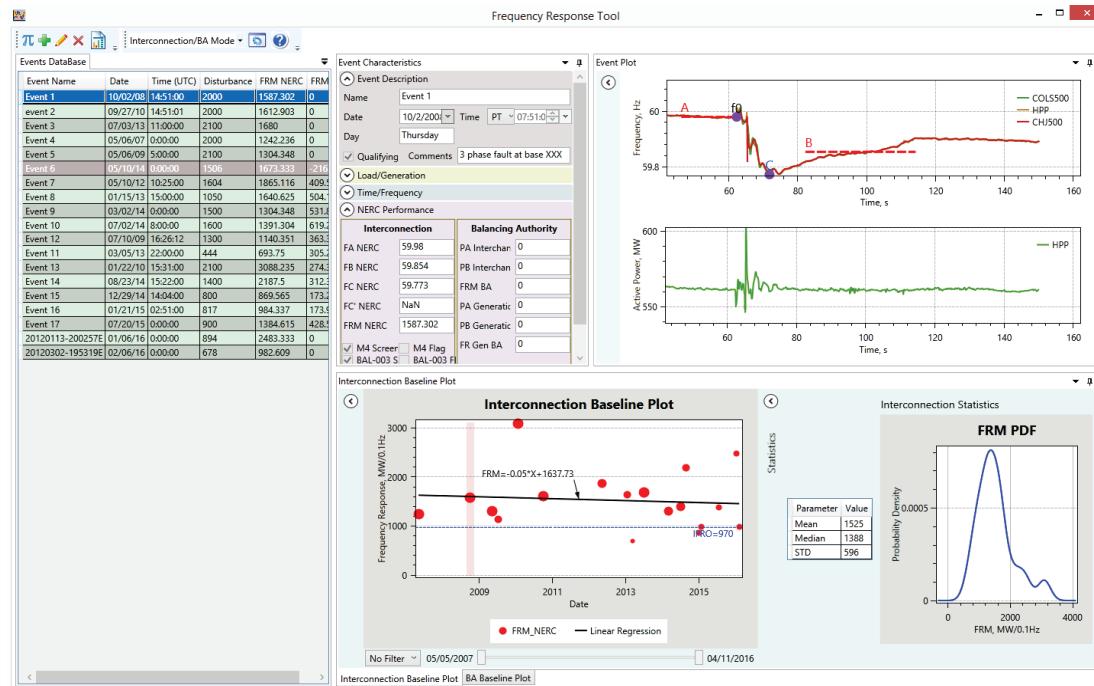


Baselining



Frequency Response Analysis Tool

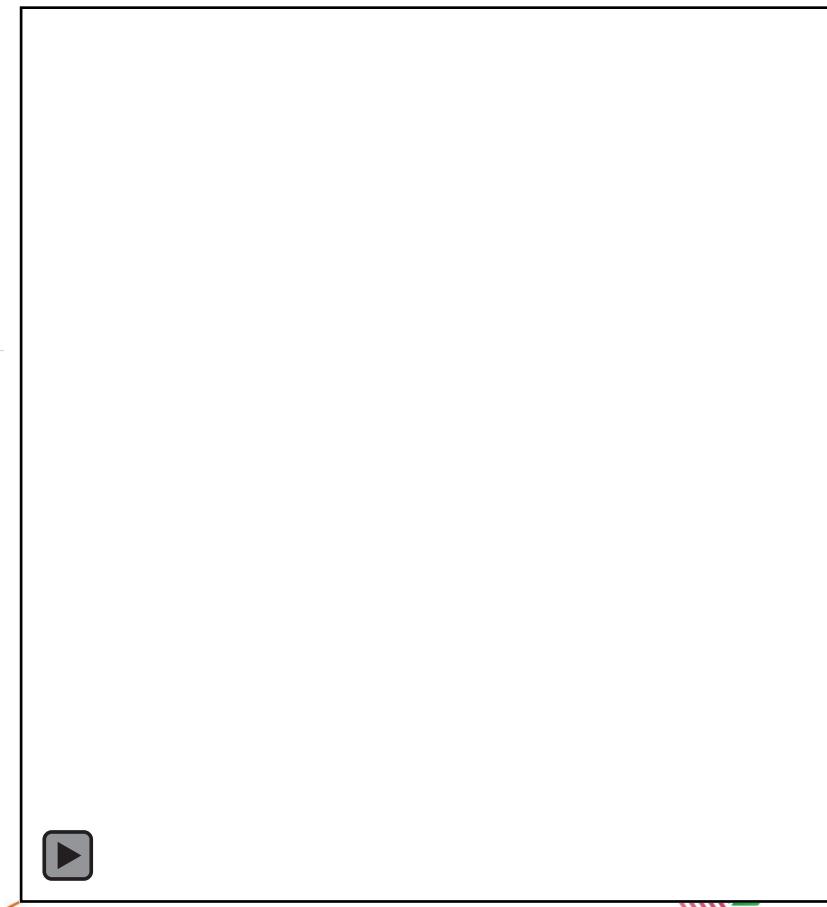
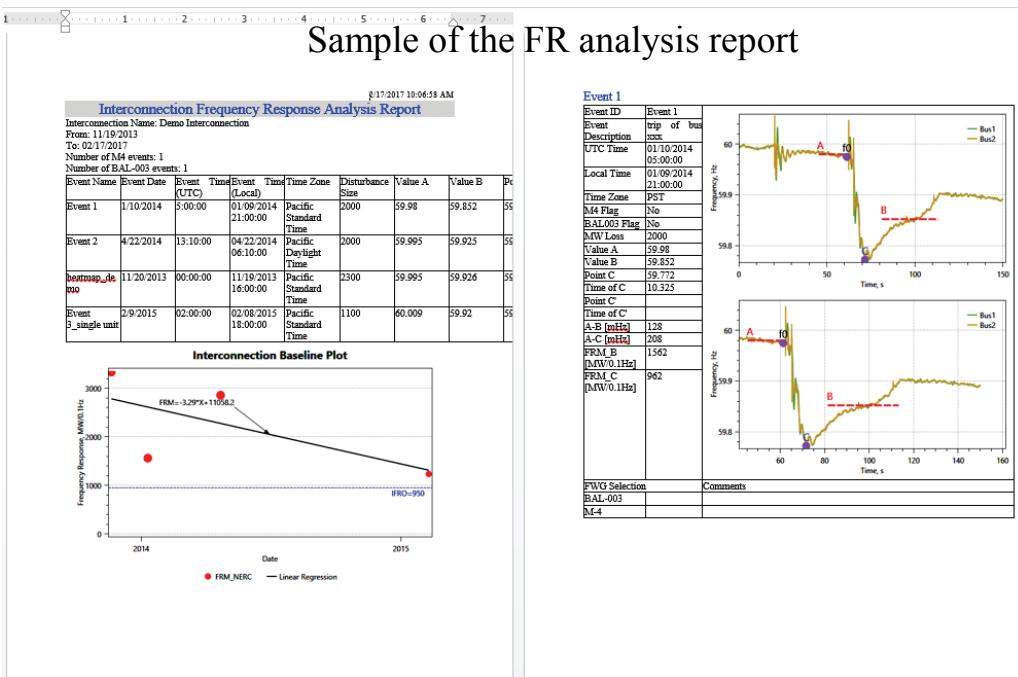
- Developed under NERC and BPA guidance.
- Frequency response monitoring:
 - Interconnection
 - Balancing Authority
 - Power Plant
- Calculates NERC FRM using PMU and SCADA measurements according to BAL-003 standard.
- Compliance reporting.
- Baseline frequency response for interconnection and BA.
- Supporting different data formats (csv, xml, OSIsoft PI, COMTRADE).
- Statistical Analysis.
- Advanced visualization.



FRAT 2.2

- LBNL prepared a review of international practices for managing frequency response.
- Multiple improvements and modifications based on NERC guidance.
- New visualization capabilities:
 - Animated heat map
 - Path flows
- New reporting capabilities based on NERC feedback.

Animated video created using FRAT
(Illustrative example, synthetic data).

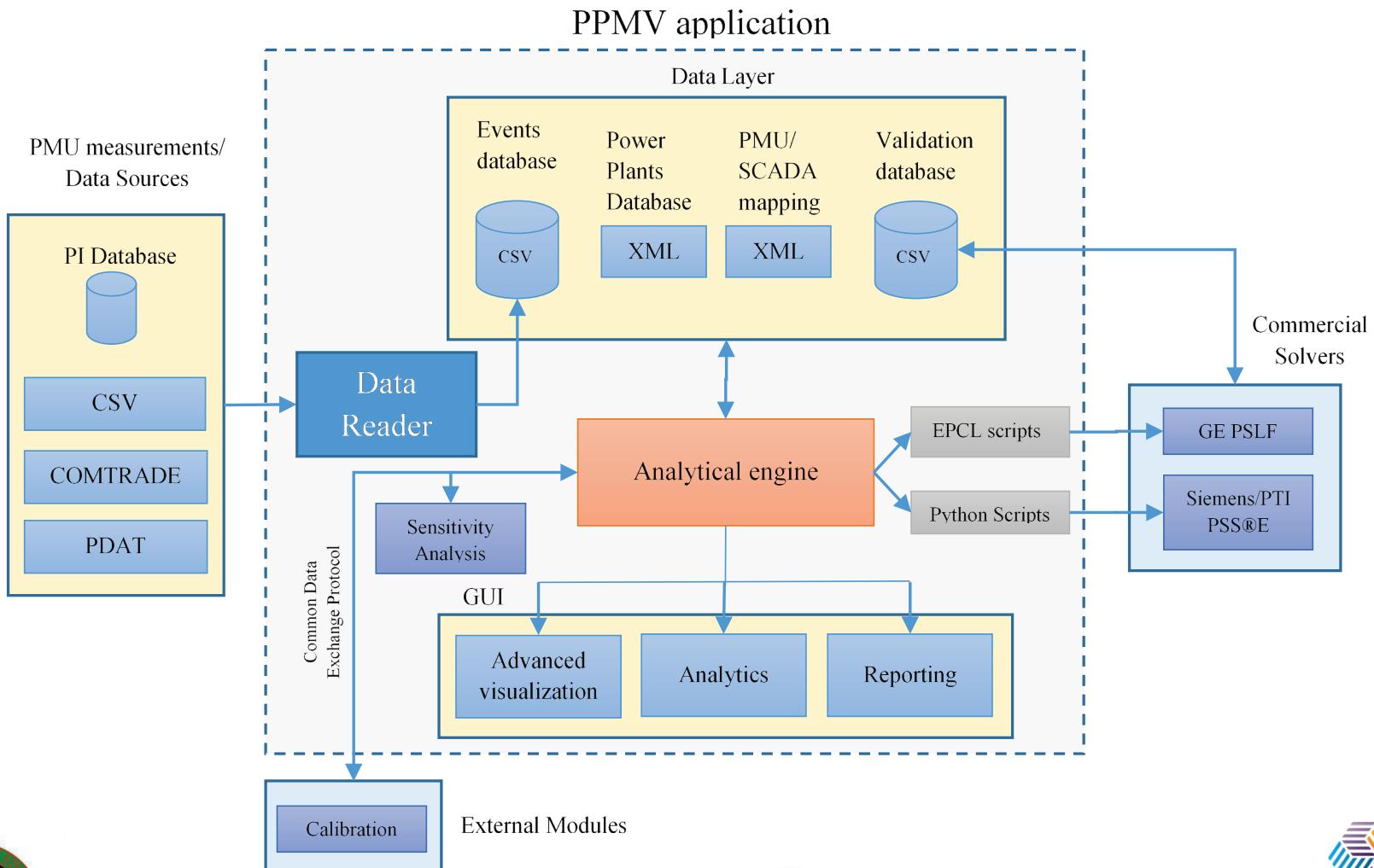


Power Plant Model Validation Tool

- Supports GE PSLF and Siemens/PTI PSS®E Play-In function for generator model validation.
- Maintains the database of model validation studies (projects).
- Maintains the database of the historic events.
- Maintains the database of the power plants.
- Advanced visualization capabilities.
- Automatically generates reports.
- Performs sensitivity analysis
- Supports interface to external model calibration modules.

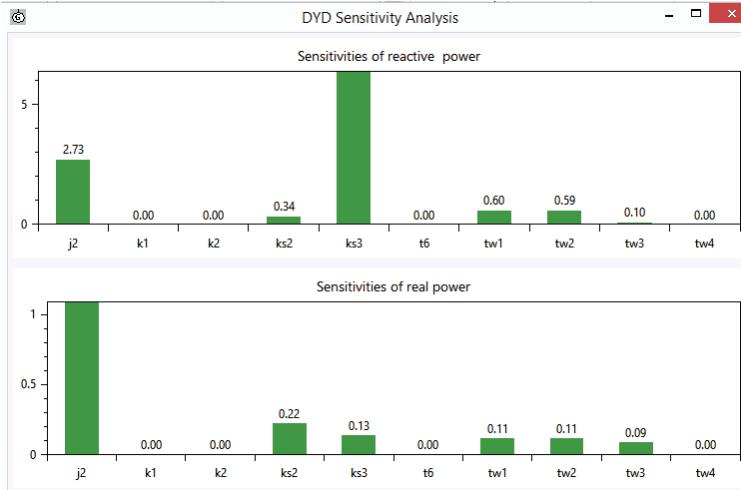


PPMV Tool Conceptual Design



New features in PPMV 2.2

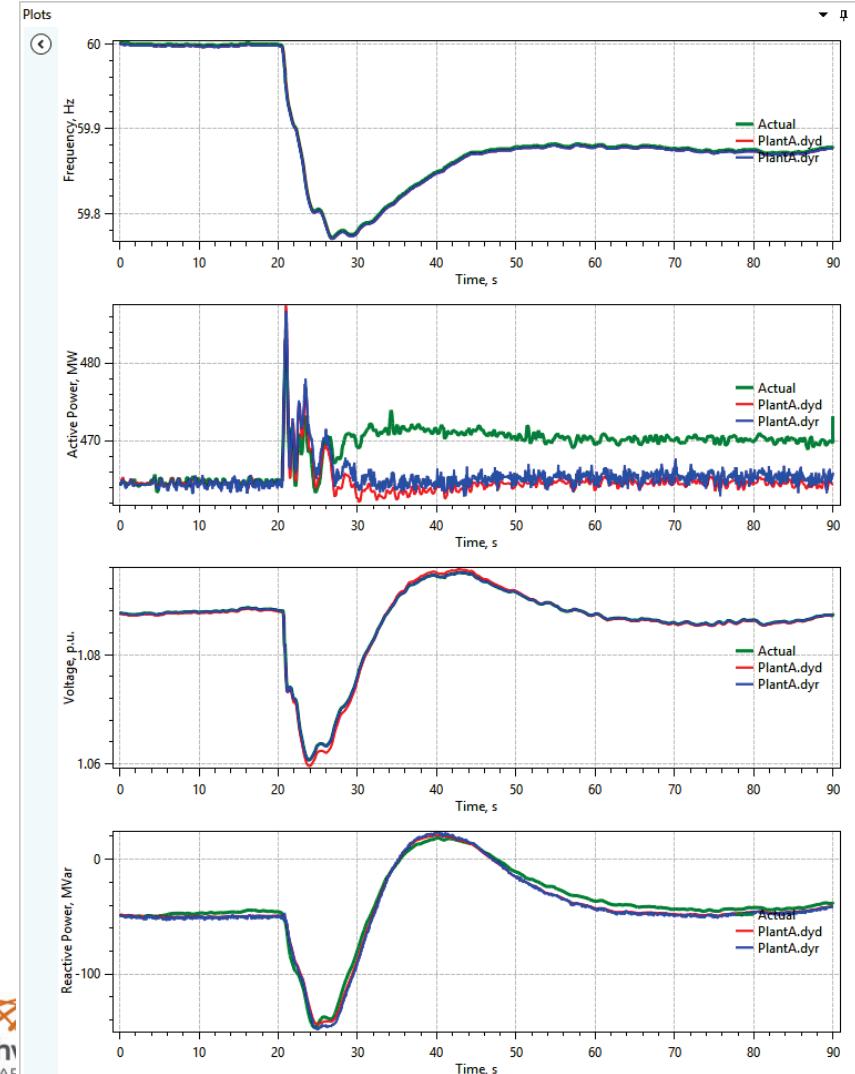
Sensitivity Analysis



Python scripts for PSS®E

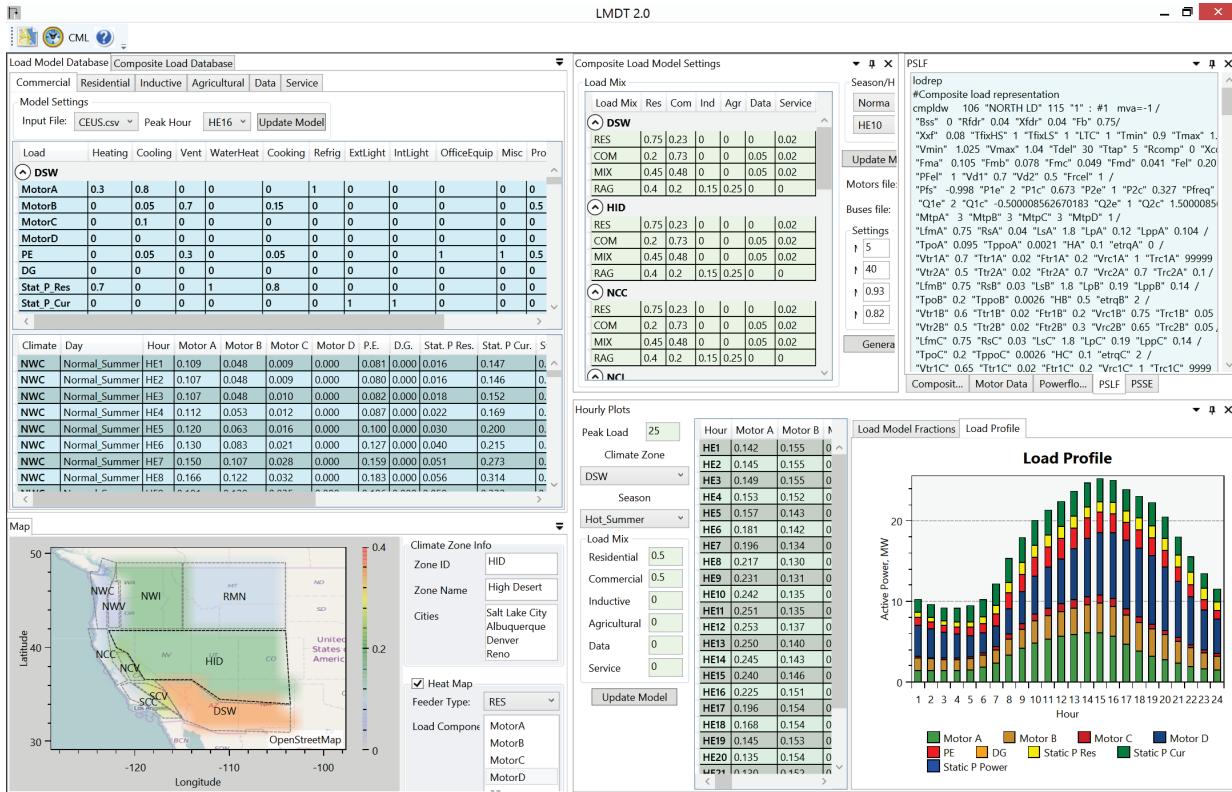
```
PlayIn.py
1 ######
2 #
3 # PSS/E PMU-Based Model Verification Script
4 #
5 # Authors: Ryan D. Quint, NERC, ryan.quint@nerc.net
6 # Pavel Etingov, PNNL, pavel.etingov@pnnl.gov
7 #
8 ######
9 def RunPlayIn(P):
10     print P.Path
11     import os,sys,csv
12     _PSSBINPATH = 'C:\Program Files (x86)\PTI\PSSE33\PSSBIN'
13     sys.path.append(_PSSBINPATH)
14     os.environ['PATH'] = _PSSBINPATH + ';' + os.environ[
15         'PATH']
16
17     import dyntools, psspy, redirect
18     _i=psspy.getdefaultint()
19     _f=psspy.getdefaultreal()
20     _s=psspy.getdefaultchar()
21     redirect.psse2py()
22     psspy.psseinit(150000)
23
24     Input Data
25     Case = P.Path+'/' +P.Plant+'/' +P.Event+'/' +P.Raw+'-' +P.
26     Event+'.'raw'
27     plbfile = P.Path+'/' +P.Plant+'/' +P.Event+'/' +'AN.plb'
28     SCADAfile=P.Path+'/' +P.Plant+'/' +P.Event+'/' +'scada'+
'-' +P.Raw+'-' +P.Event+'.'dat'
    dyrfile = P.Path+'/' +P.Plant+'/' +P.DYR+'.'dyr'
    OutFile=P.Path+'/' +P.Plant+'/' +'00-OUT/plot-' +P.Raw+'-' +P.
```

Comparison PSLF and PSS®E model validation results



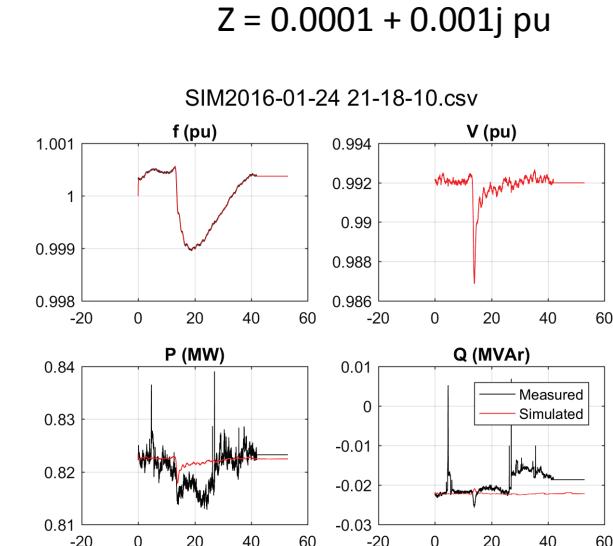
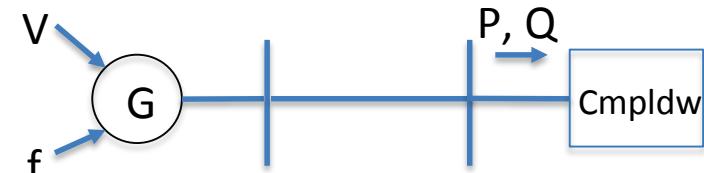
Load Model Data Tool

- Fully redesigned GUI.
- Advanced functionality.
- New visualization capabilities.
- Database of load models for different climate zones.
- Configurable presets for each climate zone.
- Generating .dyd and .dyr dynamic records.



Composite Load Model Validation

- LBNL collected micro PMU data for multiple events.
- PNNL set up a simple two-bus system to compare simulated PQ of composite load model and measured PQ in response to played-in voltage and frequency.
- Developed EPCL code to run play-in events in batch mode.
 - Pre-process original play-in event data file.
 - Extract initial bus voltage and load PQ measurements from play-in data file.
 - Adjust and re-solve power flow raw file.
 - Run dynamic simulations with played-in voltages and frequencies at the load terminal.



Climate Zone: DSW
Season: Winter day
Hour = 21



Major accomplishments

- Industry-grade, open-source power system analytical tools and software modules have been developed.
 - Power Plant Model Validation Tool (*new version*)
 - Frequency Response Analysis Tool (*new version*)
 - Oscillation Baseline and Analysis Tool
 - Load model data tool (*new version*)
 - Data readers (JSIS CSV, COMTRADE, PDAT, OSIsoft PI)
 - Outcomes of the project were leveraged by the BPA TI projects(e.g., Archive walker application).
- All tools are based on the common open platform and data formats.
- Developed tools have been used by many organizations and electrical utilities including: NERC, WECC, BPA, PG&E, SCE, SPP, BC Hydro, PacifiCorp, CAISO, SRP, and many more.



Deliverables

Significant Milestones	Date
Prototype of the Oscillation Analysis and Baseline Tool (OBAT)	12/15/2016
PPMV 2.2 (with Siemens/PTI PSSE support)	3/15/2017
FRAT 2.2	5/1/2017
OBAT version 1.0 released under an open source license	5/1/2017
LMDT 2.1	5/1/2017
Release the open source framework for PMU analysis	9/30/2017



Publications/Presentations

- Tools presented at multiple events, including IEEE conferences, NASPI meetings, NERC and WECC working groups, webinars to electrical utilities.
- Selected list of presentations:
 - Etingov P, "PPMV tool presentation" at the NASPI Technical Workshop - Model Verification Tools, 2016, Seattle
 - Diao R ,Huang R ,Li Y ,Etingov P, Huang Z ,Li X ,Wang S, "Calibration of Stability Model Parameters using EnKF", NASPI Work Group Meeting, Seattle, 2016
 - Etingov P, Tuffner F, Follum J, O'Brien J, Kosterev D ,Matthews G, Lesieutre B. "Oscillation Baselineing and Analysis Tool", NASPI Work Group Meeting, Seattle, 2016
 - Yang S ,Etingov P., Kosterev D, Leitschuh N , Vanzandt V. "BPA Experience with Synchrophasors: From Wide-Area Measurements to Wide-Area Control", panel presentation at IEEE Innovative Smart Grid Technologies Conference (ISGT 2017), Washington DC, 2017
 - Etingov P. "Composite load model parameters generation using LMDT tool", WECC MVWG workshop on the load modeling, Portland, 2016
 - Etingov P., Liu Y., Zhang Y. "Load Model Data Tool Development" , WECC MVWG, Portland, 2017
 - Etingov P. "PPMV 2.0 presentation" , WECC MVWG, Portland, 2017
 - Etingov P. "Power Plant Model Validation", WECC JSIS, Portland, 2017
 - Jim Follum, Frank Tuffner and Pavel Etingov, "Oscillation analysis and baselining", WECC JSIS, Portland 2017
 - Etingov P. "Oscillation baselining and analysis tool", NERC SMS, Atlanta, 2016
 - Etingov P. "Power Plant Model Validation Tool", NERC SMS, Atlanta, 2016
 - Etingov P. "Update on Oscillation baselining and analysis tool", NERC SMS, Little Rock, 2017
 - Etingov P. "Update Power Plant Model Validation Tool", NERC SMS, Little Rock, 2017
 - Etingov P. "Update on the PPMV tool development", WECC MVWG, Westminster, 2016
 - Etingov P. "Update on the LMDT tool development", WECC MVWG, Westminster, 2016



Publications related to the project

- Published one journal paper and two conference papers:
 - Quint R. D., Etingov P. V., Zhou D and D. N. Kosterev, "Frequency response analysis using automated tools and synchronized measurements," 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, 2016, pp. 1-5.
 - Follum J. and J. W. Pierre, "Detection of Periodic Forced Oscillations in Power Systems," in IEEE Transactions on Power Systems, vol. 31, no. 3, pp. 2423-2433, May 2016.
 - Follum J. and Tuffner F., "A multi-channel method for detecting periodic forced oscillations in power systems," 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, 2016, pp. 1-5.
- Submitted one journal paper and two conference paper:
 - Li Y, Diao R, Huang R, Etingov P., Li X., Huang Z ,Wang S ,Sanchez-Gasca J ,Thomas B, "An Innovative Software Tool Suite for Power Plant Model Validation and Parameter Calibration using PMU Measurements", 2017 IEEE Power and Energy Society General Meeting (PESGM), Chicago, IL, 2017 (accepted).
 - Follum J, Tuffner F., "Applications of a new nonparametric estimator of Ambient Power System Spectra for Measurements Containing Forced Oscillations," 2017 IEEE Power and Energy Society General Meeting (PESGM), Chicago, IL, 2017, pp. 1-5 (accepted).
 - Huang R, Diao R, Li Y, Sanchez-Gasca J, Huang Z , Thomas B, Etingov P., Kincic S, Wang S, Fan R, Matthews G., Kosterev D.,Yang S., "Calibrating Parameters of Power System Stability Models using Advanced Ensemble Kalman Filter" IEEE Transaction on Power Systems (submitted).



On-line Resources

- FRAT
<https://svn.pnl.gov/FRTool>
- PPMV
<https://svn.pnl.gov/PPMV>
- LMDT
<https://svn.pnl.gov/LoadTool>
- OBAT
<https://svn.pnl.gov/OBAT>

The screenshot shows two parts of the PPMV project on a Trac web interface. The top part is the Trac homepage with links for 'Power Plant Model Validation Tool', 'System Requirements', 'PPMV tool folders structure', and 'License'. The bottom part is a screenshot of the PPMV application's graphical user interface (GUI). The GUI has a left sidebar with tabs for 'Projects', 'Events', and 'Plants'. Under 'Events', it lists '2010-01-01-1450' and '2010-11-20-0500'. Under 'Plants', it lists 'PlantB' and 'PlantA'. Below these are sections for 'Event Description' (3 Phase Fault at bus xxxx) and 'DYD file(s)' (checkboxes for 'PlantB-2012HS', 'PlantB-2013HS-HDR', 'PlantB-2013HS-USA', and 'PlantB-2013HS'). To the right is a 'Plots' section with two line graphs. The top graph shows 'Frequency, Hz' from 0 to 20 against time, with multiple lines labeled 'Actual', 'PlantB-2012HS', 'PlantB-2013HS-HDR', 'PlantB-2013HS-USA', and 'PlantB-2013HS'. The bottom graph shows 'Active Power, MW' from 0 to 120 against time, with similar lines. A legend on the right identifies the lines.



Future plans

- Continue enhancement of the open source tools and developing new software tools and modules.
- Transition from off-line to near-real time analysis functionality.
- Expanding analytical capabilities based on users feedback.
- Industry outreach, working closely with NERC, WECC, BPA and other electrical utilities to promote nationwide dissemination of the tools.

Project Portfolio and Synergy

