PhasorAnalytics-Commercial tool for disturbance based model validation and calibration

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October 23, 2018

GE Global Research
GE Grid Software Solutions
GE Energy Consulting
Powertech The Power of Trust. The Future of Energy.
MISO Midcontinent ISO
ISO new england
Peak Reliability
PG&E Pacific Gas & Electric

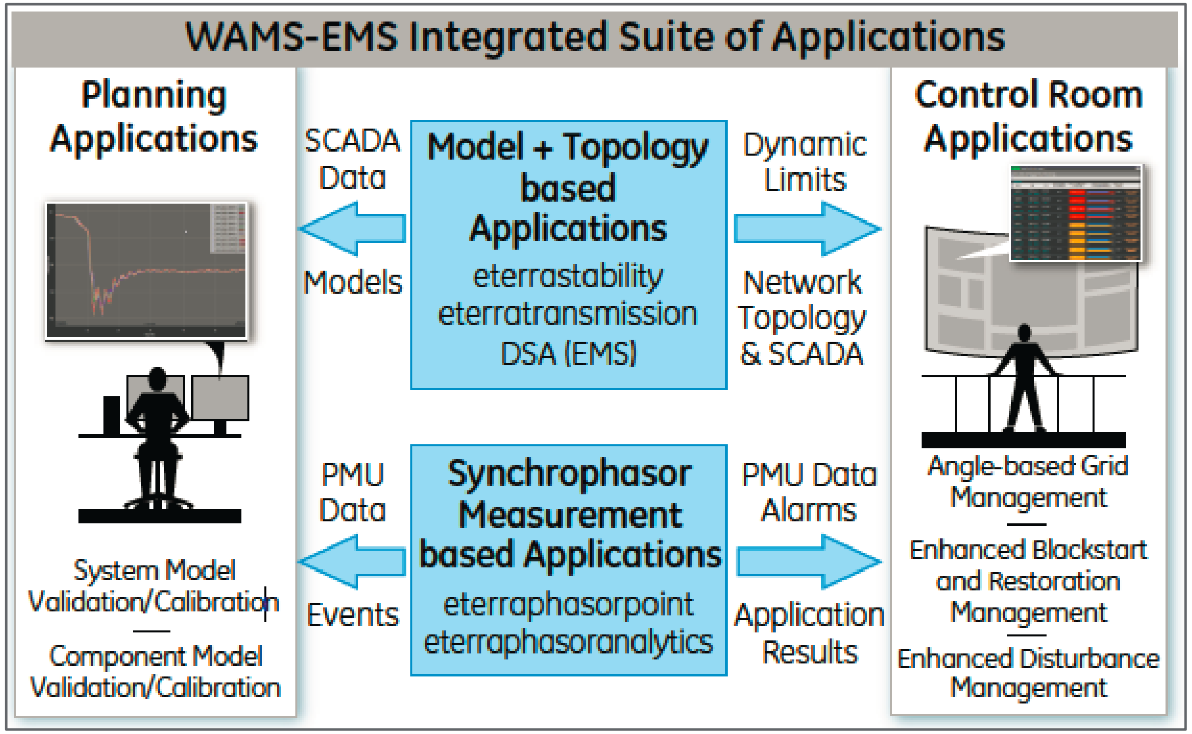
Project Overview

March, 2017 – June, 2019

- Develop and demonstrate multiple ***production-grade*** synchrophasor applications to enhance grid reliability and asset utilization through utilization of existing WAMS infrastructure along with EMS network applications available at control rooms

- Project includes field demonstrations at multiple utility locations

1. Model Validation/Calibration tool for improving models to meet emerging NERC requirements
2. Angle-based grid management tool for improved transmission asset utilization applied to voltage stability limited systems
3. Demonstration of Operator guidance tool for enhanced blackstart/restoration and disturbance management



Team Chart

U.S. DEPARTMENT OF ENERGY

Carol Painter: DOE Project Officer
Phil Overholt: DOE program mgr.
Jeff Dagle: Technical advisor from PNNL

GE Global Research

Honggang Wang: PI. PMP, reports, site visit review
Alex Santos: Contract manager
Na Jing: Financial Analyst

Developers

GE Grid Software Solutions

Lead FAT and field demos, Develop model cal., AGM and operator guidance software tools; Model val./cal. platform integration of PSLF & TSAT with WAMS product

Manu Parashar
Director-SW engineering
Anil Jampala
Principal Power Systems
Saugata Biswas
AGM/EDM/EIM Design
Krish Srinivasan
Model Cal Integration
Russ Frizzell-Carlton
Model Cal Integration
Vijay Sukhavasi
AGM/EDM/EIM integration

GE Global Research

Development of model calibration techniques, angle-based grid management, factory acceptance testing

Honggang Wang
Phil hart
Mustafa Dokucu
Jovan Bebic
Chaitanya Baone
Anup Menon
Naresh Acharya
Yan Pan

GE Energy Consulting

Model validation/ calibration platform integration of PSLF with WAMS product

Haris Ribic
Juan Sanchez-Gasca
Brian Thomas
Develop APIs to enable Communication between WAMS product and PSLF

Powertech
The Power of Trust. The Future of Energy.

Model validation/ calibration platform integration of TSAT with WAMS product, assist with AGM

George Zhang
Develop APIs to enable Communication between WAMS product and PSLF

Utility Partners

MISO
Midcontinent ISO

Provide cost share, test data and models, assist/host applications in QA environment, ***Field tests***

Keith Mitchell
Field demo for AGM and operator guidance.

PG&E Pacific Gas & Electric

Provide cost share, test data and models, assist/host applications in QA environment, ***Field tests***

Sherman Chen
Field demo for Model Validation/ Calibration tool.

ISO new england

Provide test data and models, feedback on developed Applications; ***Field tests***

Xiaochuan Luo
Frankie Zhang
Field demo for Model Validation/ Calibration tool.

Peak Reliability

Provide feedback on developed Applications

Hongming Zhang
Alex Ning
Technical advisor

Task 1: Disturbance based Model Validation & Calibration

Motivation

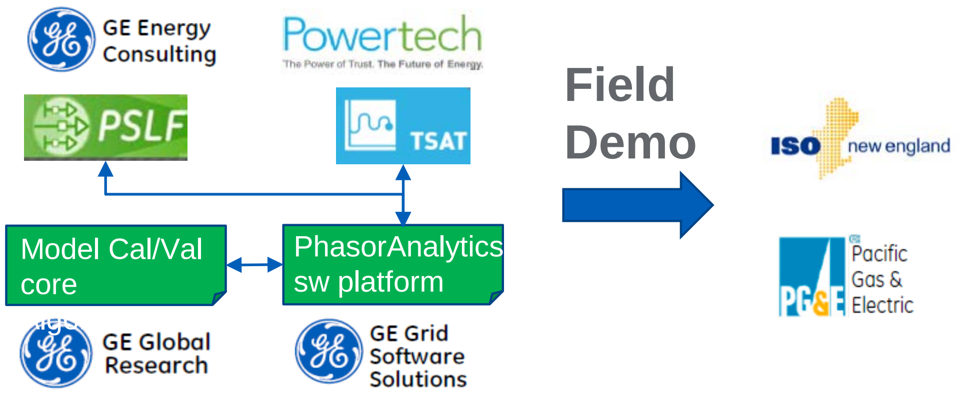
- Generic tool for generator owner to be compliant with NERC Requirement (MOD-026/033)

Objective

- Production-grade software solution which can work across multiple commercial dynamic simulation engines

Accomplishment

- Functional specification completed.
- Algorithm developed and tested with simulated data.
- Software platform integration with simulation tool PSLF completed.
- Paper titled “Synchrophasor Based Dynamic Model Validation Leveraging Multiple Events” presented at the 2018 IEEE Innovative Smart Grid Technologies (ISGT) Conference.
- Paper titled “Towards a Commercial-grade Tool for Disturbance-based Model Validation and Calibration” at 2018 IEEE PES General Meeting.



Multi-team Collaboration

PhasorAnalytics User Interface

Task 2: Angle-based Grid Management for Voltage Stability Assessment

Motivation

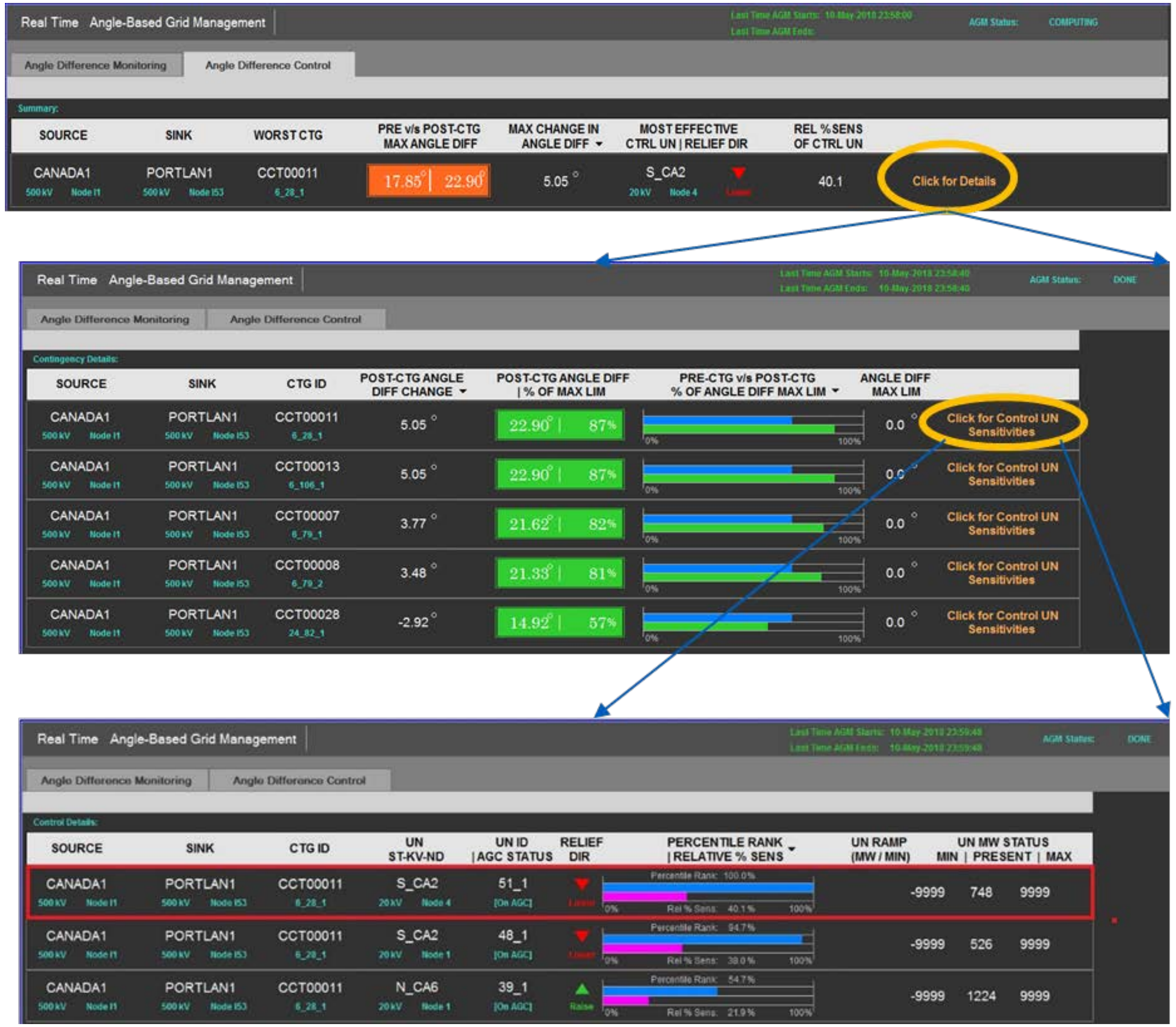
- To enhance the real time visibility and grid asset utilization

Objective

- Production-grade software solution for Fast Voltage Stability Assessment (FVSA) based on Voltage Angle-based information

Accomplishment

- Fast Voltage Stability Assessment (FVSA) functional specification completed.
- FVSA algorithm developed and tested with simulated data.
- FVSA software platform integration completed.
- FVSA software application factory acceptance testing completed.
- Presented “PMU Measurement-Model Based Voltage Security Monitoring Application” at the April 2018 NASPI Meeting and North America User Group Meeting in June 2018.



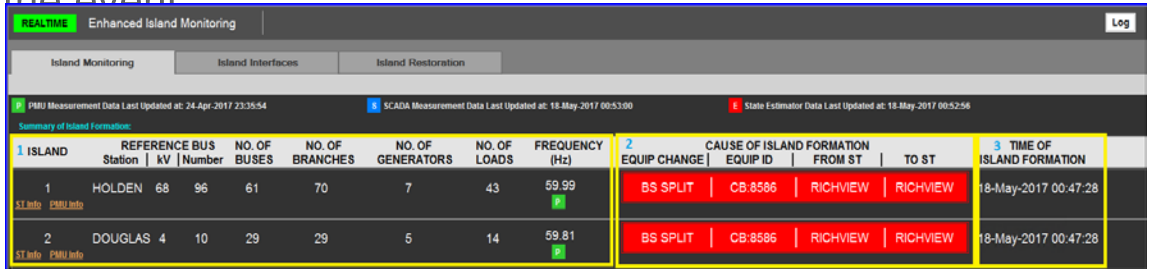
Task 3: Operator Guidance Tool

- Augment existing synchrophasor applications with detailed root cause assessment, what-if capabilities, and recommendations during islanding and other disturbance conditions.
- Demonstrate Enhanced Island Monitoring and Enhanced Disturbance Management at MISO.
  - Enhanced Island Monitoring (EIM) provides the exact cause and location of the islanding event, island size, island composition, information about circuit breaker(s) that can be closed by the operators to resynchronize the formed island from the main grid.
  - Enhanced Disturbance Management (EDM) provides time of occurrence of a disturbance event, event spread (wide area or local), event type and MW change during the event.

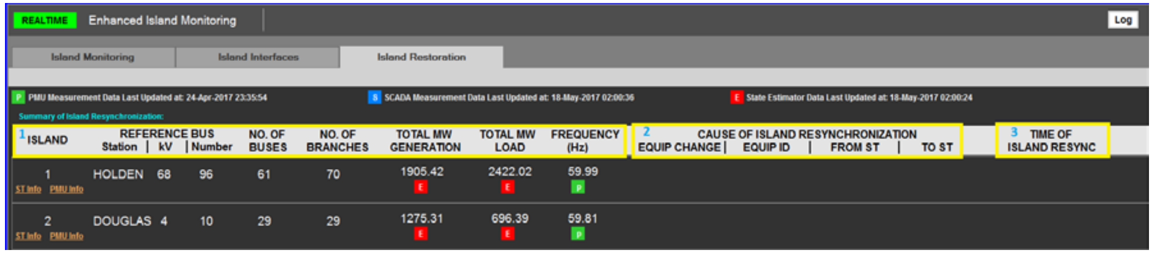
Accomplishment

- Enhanced Island Management and Enhanced Disturbance Management tested with simulated data.
- Operator guidance field test plan document for deployment at MISO completed.

EIM Display for Monitoring



EIM Display for Restoration / Resynchronization



Upcoming Milestone & Field Tests

2018 Q4

Milestone	Milestone Description	Due	Category
M10A	Dynamic model calibration algorithm tested with realistic data in target platform with PSLF	12/19/2018	Development
M22	Model Validation & calibration FAT using PSLF	12/19/2018	FAT/Field Demo
M30	Operator Guidance FAT	12/19/2018	FAT/Field Demo

2019 Q1

Milestone	Milestone Description	Revised	Category
M6B	Model calibration software platform with TSAT	3/19/2019	Development
M10B	Dynamic model calibration algorithm tested with realistic data in target platform with TSAT	3/19/2019	Development
M24	Model Validation & calibration FAT using TSAT	3/19/2019	FAT/Field Demo
M23	Model Validation field tests	3/19/2019	FAT/Field Demo
M28	AGM field test	3/19/2019	FAT/Field Demo
M31	Operator Guidance field test	3/19/2019	FAT/Field Demo

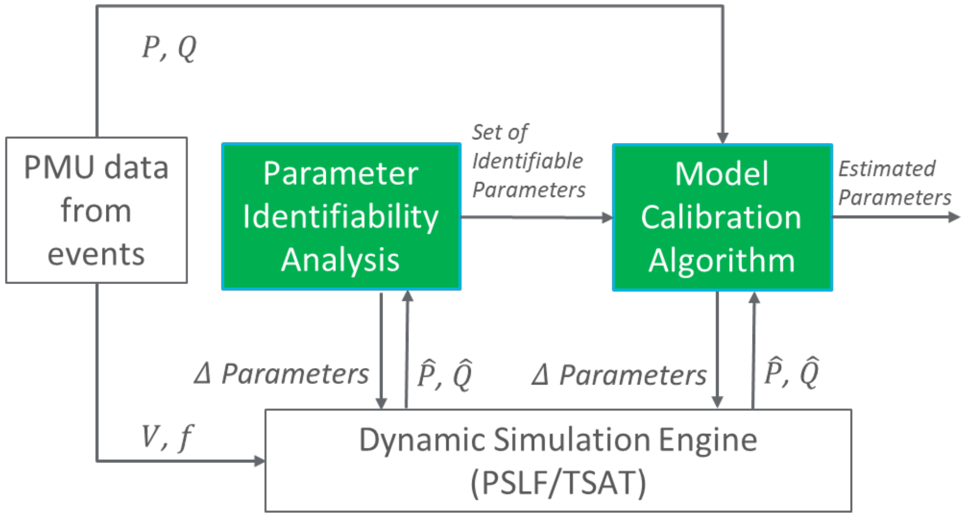
2019 Q2

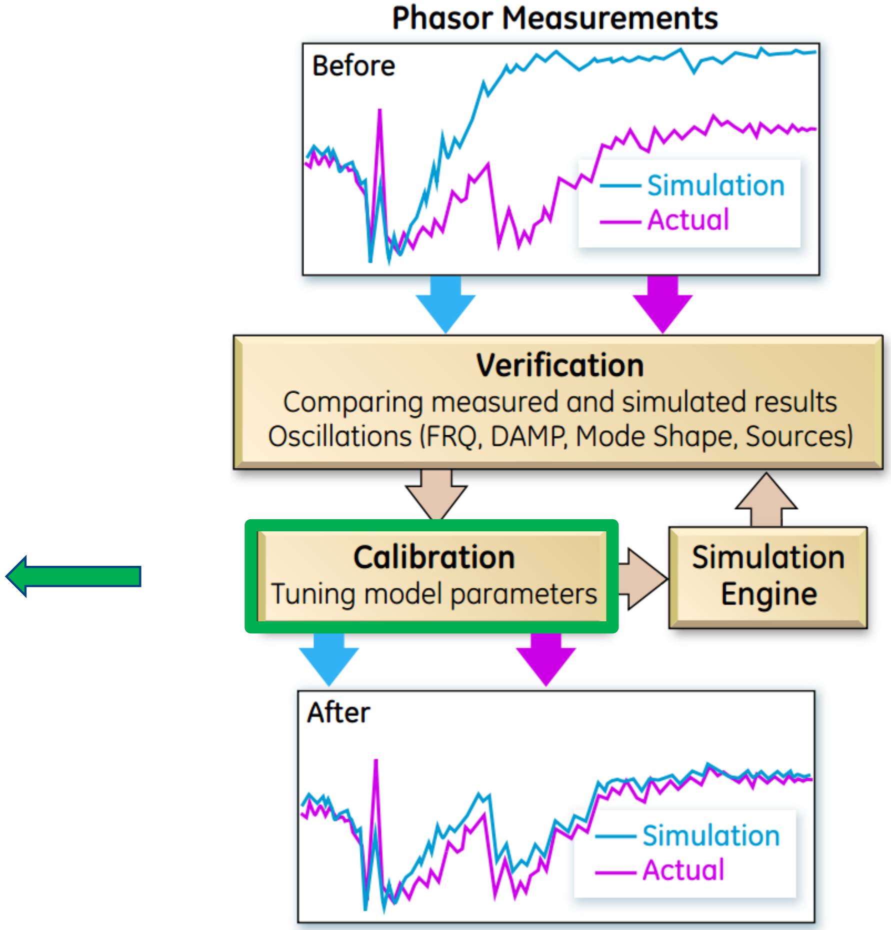
Milestone	Milestone Description	Revised	Category
M25	Model Calibration field tests	6/19/2019	FAT/Field Demo

PhasorAnalytics Model Calibration Algorithm Development

Two Stage Approach for Model Calibration

1. Design Considerations
   - **Production-grade** software tool
   - **Generic** for wide variety of models (PSLF, TSAT and PTI PSS/E)
   - **Minimal data flow change** on existing tools
   - Account for **non-linearity** in models
   - Quality of solution with **reasonable speed**
   - Account for **multiple different events**
   - Avoid tuning parameters that may already be at their true values





Stage I-Parameter Identifiability

- Jacobian matrix, $A =$

Parameters →

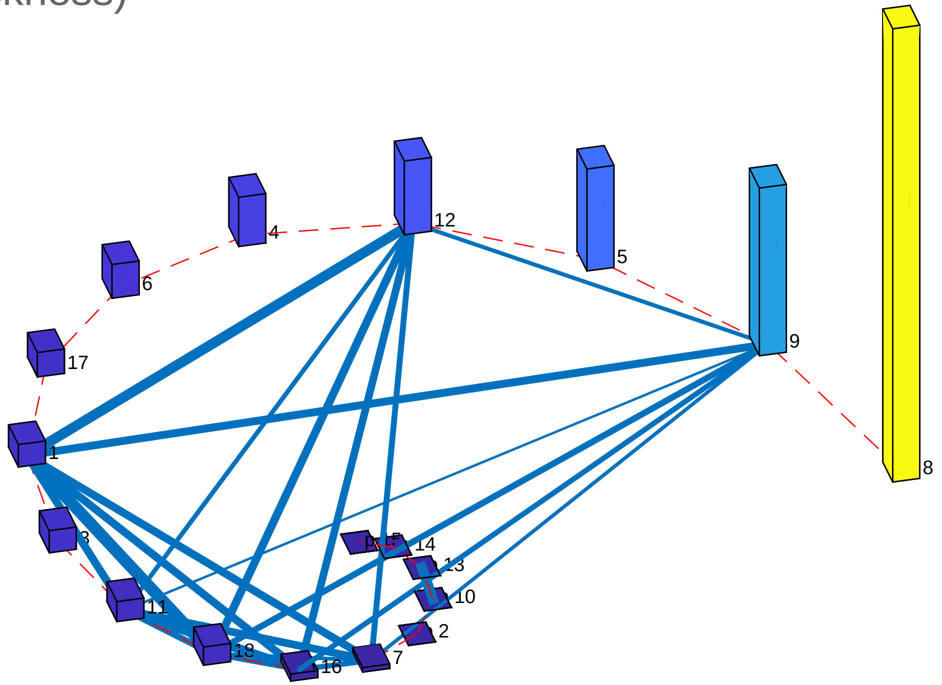
Time series ↓

$$
\begin{bmatrix}
\frac{\partial P(t_1)}{\partial \theta_1} & \frac{\partial P(t_1)}{\partial \theta_2} & \cdots & \frac{\partial P(t_1)}{\partial \theta_k} \\
\frac{\partial P(t_2)}{\partial \theta_1} & \frac{\partial P(t_2)}{\partial \theta_2} & \cdots & \frac{\partial P(t_2)}{\partial \theta_k} \\
 & \vdots & & \\
\frac{\partial P(t_N)}{\partial \theta_1} & \frac{\partial P(t_N)}{\partial \theta_2} & \cdots & \frac{\partial P(t_N)}{\partial \theta_k} \\
\frac{\partial Q(t_1)}{\partial \theta_1} & \frac{\partial Q(t_1)}{\partial \theta_2} & \cdots & \frac{\partial Q(t_1)}{\partial \theta_k} \\
\frac{\partial Q(t_2)}{\partial \theta_1} & \frac{\partial Q(t_2)}{\partial \theta_2} & \cdots & \frac{\partial Q(t_2)}{\partial \theta_k} \\
 & \vdots & & \\
\frac{\partial Q(t_N)}{\partial \theta_1} & \frac{\partial Q(t_N)}{\partial \theta_2} & \cdots & \frac{\partial Q(t_N)}{\partial \theta_k}
\end{bmatrix}
$$

- Rank deficiency of A can result from:
  (1) very small entries in columns of A
  (2) columns of A being nearly linearly dependent

Causing failure to identify parameters uniquely

- Sensitivity **magnitude**: reduces in counter-clockwise direction
- Sensitivity **dependency**: represented by connecting lines (thickness)

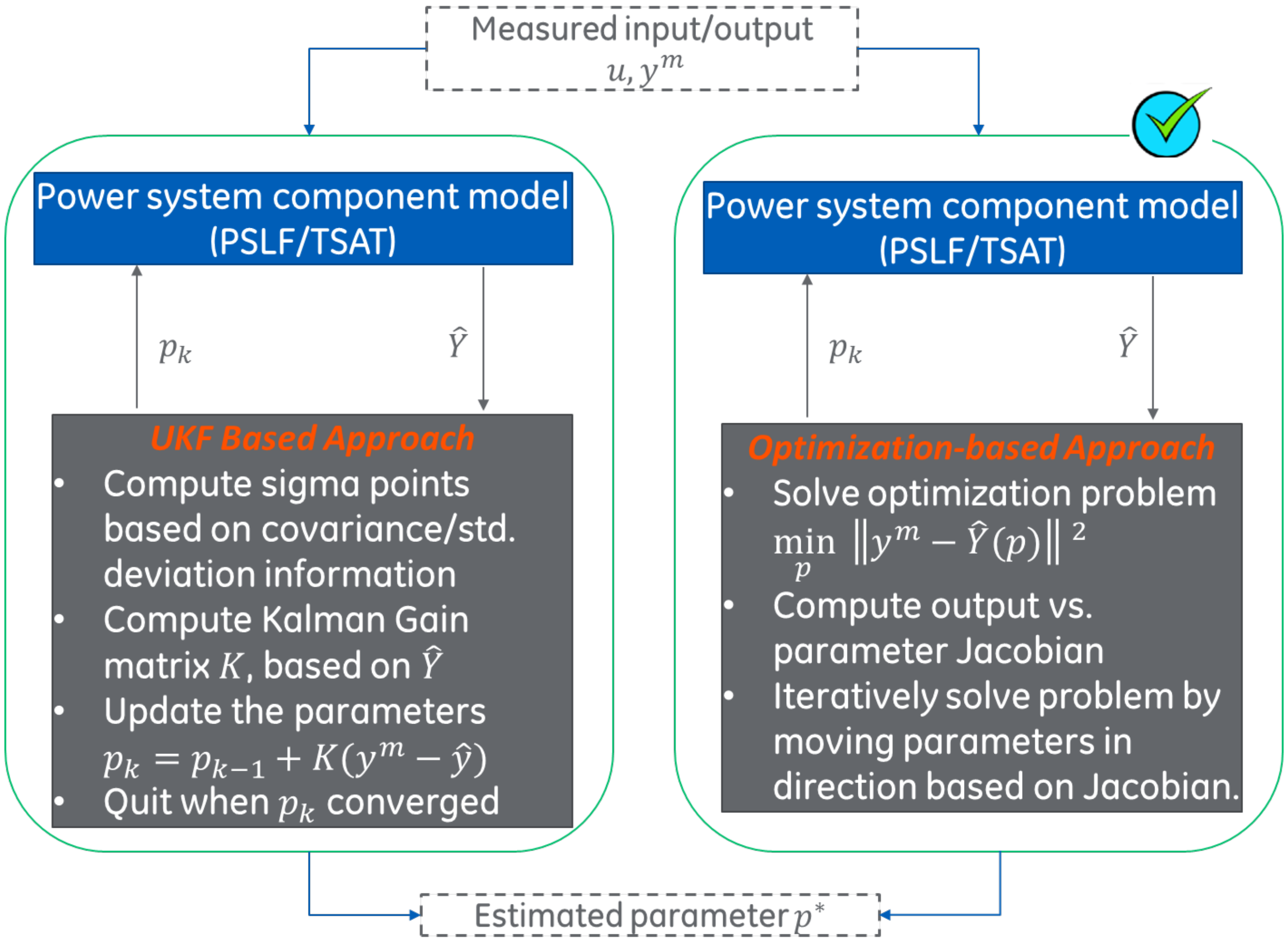


A = USV^T

$$\mathbf{M}_{sen} = \sum_{i=1}^{N_p} \sigma_i^2 \mathbf{v}_i^2 .$$

Identifiability provides data-driven sensitivity insight for user.

Stage II-Parameter Estimation



NLS Optimization approach is selected:

- Flexibility for customization
- Handling non-gaussian noise

Algorithm Improvement:

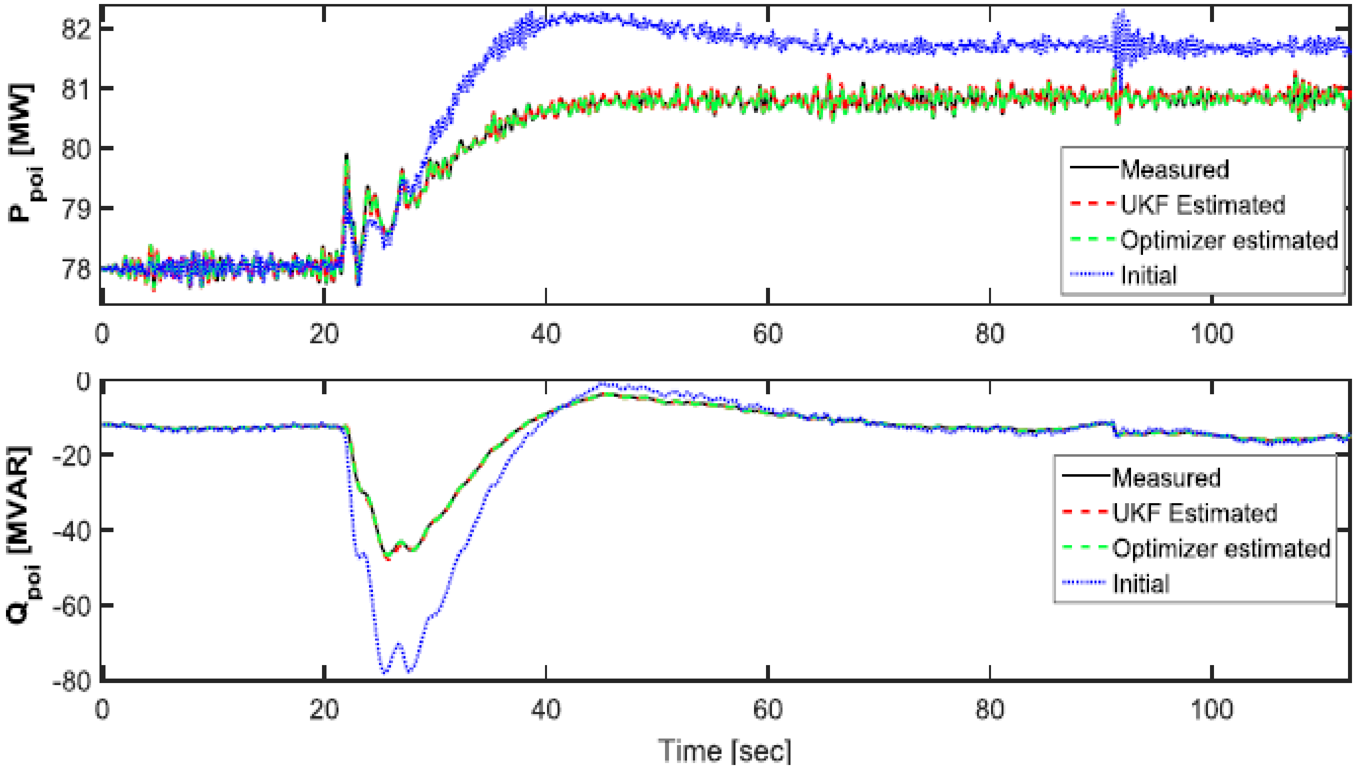
- Faster execution.
- Robustness during abnormality.
- Sequential parameter estimation for real-world sequential events.

Example Result: Hydro Power Plant Model Calibration

PMU data based dynamic model calibration for a Hydro power plant using NERC data set and GE PSLF simulation engine

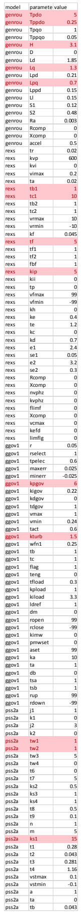
Parameter name	True	UKF	Optimization	Corrupt
'tpdo '	5.5	6.34	5.78	4.30
'h '	5.5	5.07	5.28	4.00
'lpd '	0.25	0.22	0.26	0.25
'tc'	0.9	0.50	0.94	2.10
'tb'	3.85	2.35	3.70	2.50
'ka'	125	103.13	124.05	50.00
'rperm'	0.065	0.06	0.07	0.05
'tr'	2.4	2.42	2.40	1.20
'tr'	0.012	0.01	0.01	0.01
'ks'	20	20.36	20.01	35.00
RMS ERROR:				
Perror	**0**	**0.0037**	**0.0009**	**0.8108**
Qerror	**0**	**0.0413**	**0.0001**	**64.4184**

Legend
Within ± 5% of true value
Within ± 20% of true value
Within ± 50% of true value
Beyond ± 50% of true value



Software Application Steps

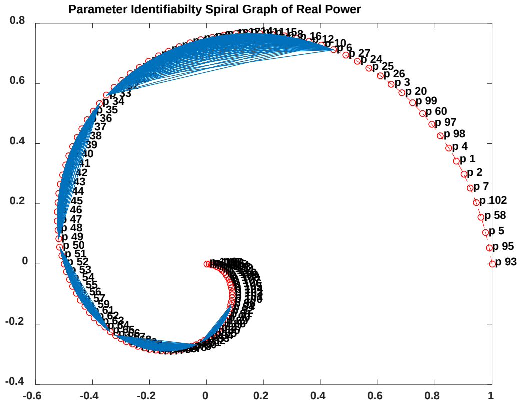
Raw Parameters



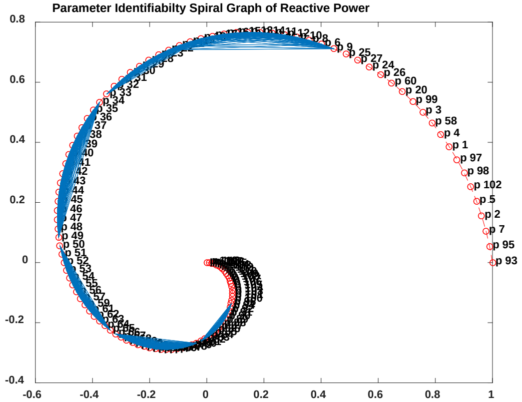
Red -> corrupt

Step I: Identifiability

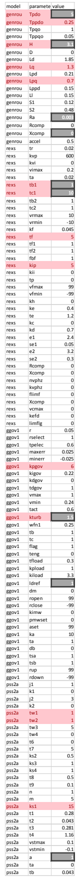
P



Q

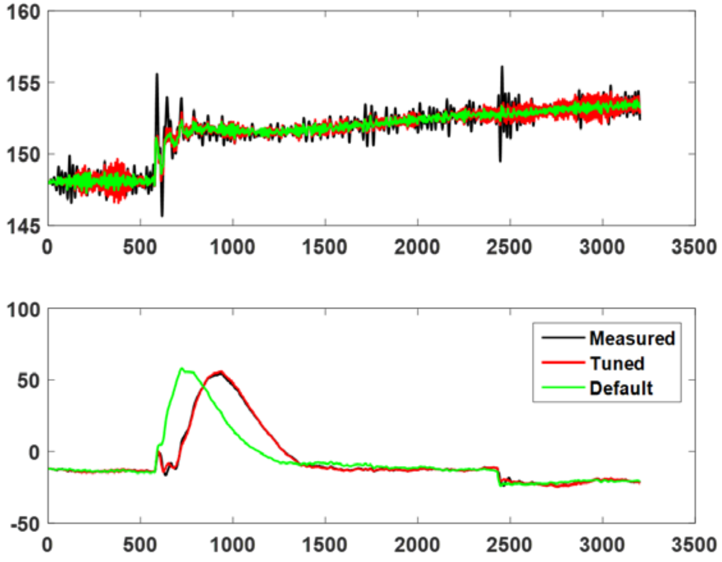


Down select parameters



Dark Grey -> to be identified

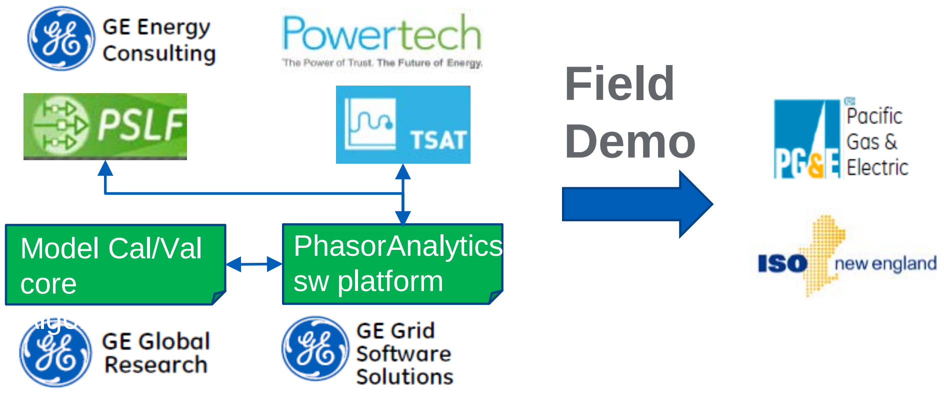
Step II: Parameter Estimation



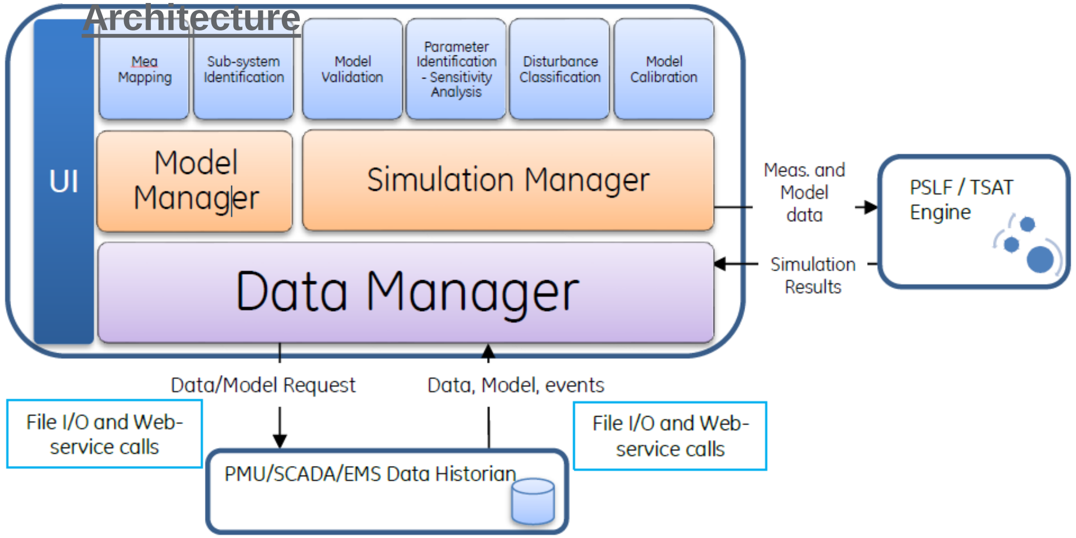
Product Integration (PhasorAnalytics)

Lesson Learned

- Compatibility: Matlab (prototype) vs. C# (application)
- Performance: multi-platform handshake time longer than expected
- Robustness: exception handling & measurement noise
- Customer voice: fast iteration with utility partners



GE PhasorAnalytics SW Architecture



PhasorAnalytics: Model Validation UI

GRC works closely with Biz team and utility partners for product integration & tests

Live Demo