Power Plant Model Validation and Performance Monitoring

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NASPI Workshop

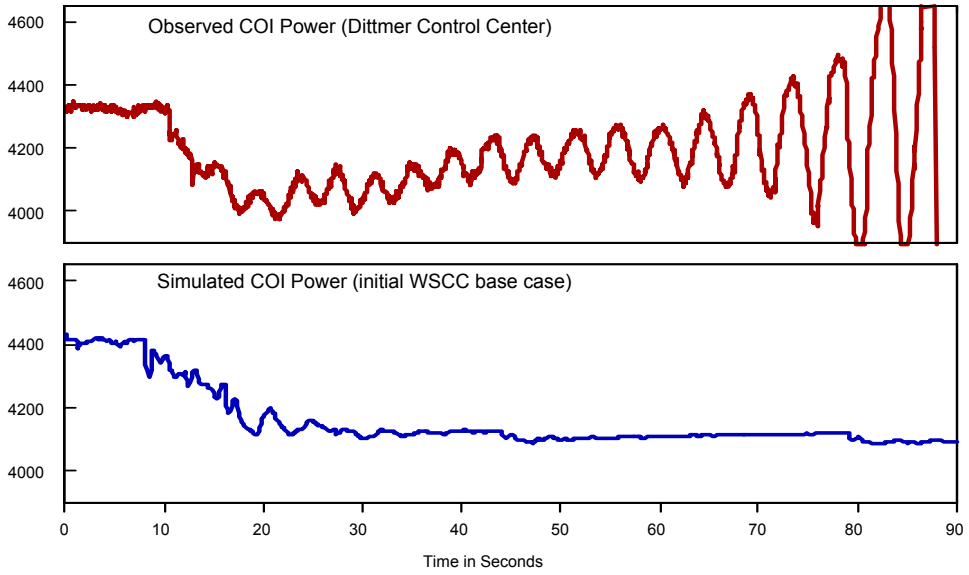
October 2103

Power System Models

- Accurate power system models are required for ***reliable*** and ***economic*** power grid operations

- Failure of models to predict system behavior
- 7.4M customers lost power due to the outage
- Major interties were de-rated temporarily by 33%
- WSCC BOT required all generators >20 MVA be tested for model validation

August 10, 1996



Power Plant Model Verification Requirements

- 1996 – generator baseline testing for model verification is required in WSCC
  - Benefits of WECC generator testing program are indisputable:
    - Vast majority of models needed revisions
    - Structural model errors were detected
    - Errors in control settings were identified and corrected
  - Need to sustain the model validation was apparent
- 2006 – WECC formalized its Generating Unit Model Validation Policy
  - Baseline Model Development
  - Periodic Model Validation

Reliability Standards

- 2007 – NERC started the development of model verification standards
- 2013 – NERC approved
  - NERC MOD-025 - reactive power capabilities verification
  - NERC MOD-026 – generator and excitation control model verification
  - NERC MOD-027 – generator turbine control model verification
  - NERC PRC-019 – coordination of generator protection and controls
  - 2013 – NERC MOD-B effort to address FERC directives
  - Requires plant operator to provide accurate model data

Perspectives

- Generator Owner / Operator
  - Owns and operates generating unit
  - Has knowledge of their generating equipment
  - Responsible to provide accurate models to a transmission planner
- Transmission Planner
  - Uses models in system studies
  - Needs to verify that the models are usable
  - May want to have an independent way to verify model accuracy

Generator Owner

Generator Owner: Baseline Testing vs. Model Validation

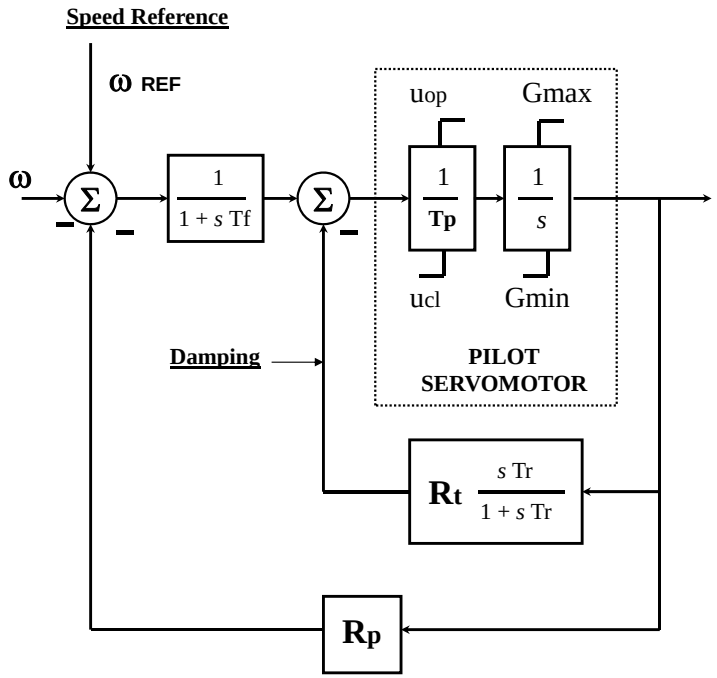
- Baseline model development
  - Needed to establish the correct model structure
  - Needed to create initial model data set

- Periodic model validation
  - Done to ensure that the models stay accurate and up-to-date **AFTER** a good model baseline is developed
  - Should not be a substitute for baseline model development

Baseline Model Development

Equipment

Model



- Needed to establish the correct model structure
- Inspection of equipment and control settings
- Some tests are required
- Disturbance monitoring can complement model development


EASY
EXIT


NOT

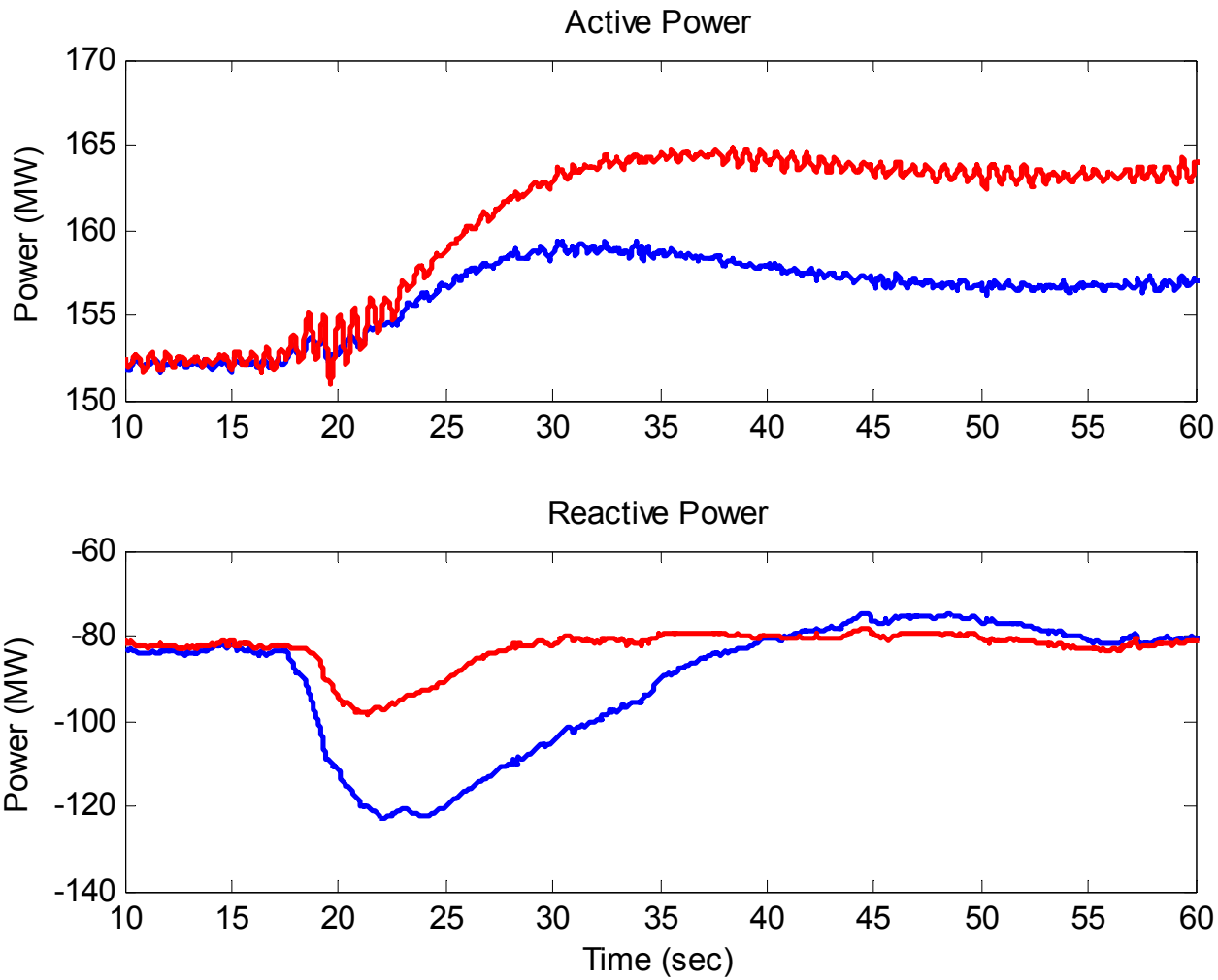
Generator Owner

- We recommend generator owners to require test and recording capabilities in new digital excitation systems and governors
  - Need to ensure recording has adequate bandwidth
- We strongly encourage generator owners to install disturbance monitors in a power plant
  - Stator three-phase voltages and currents
  - Field voltage and current
  - Governor valve position

Contact: Shawn Patterson, USBR

Transmission Planner

The same power plant tested by two consultants



Consultant A

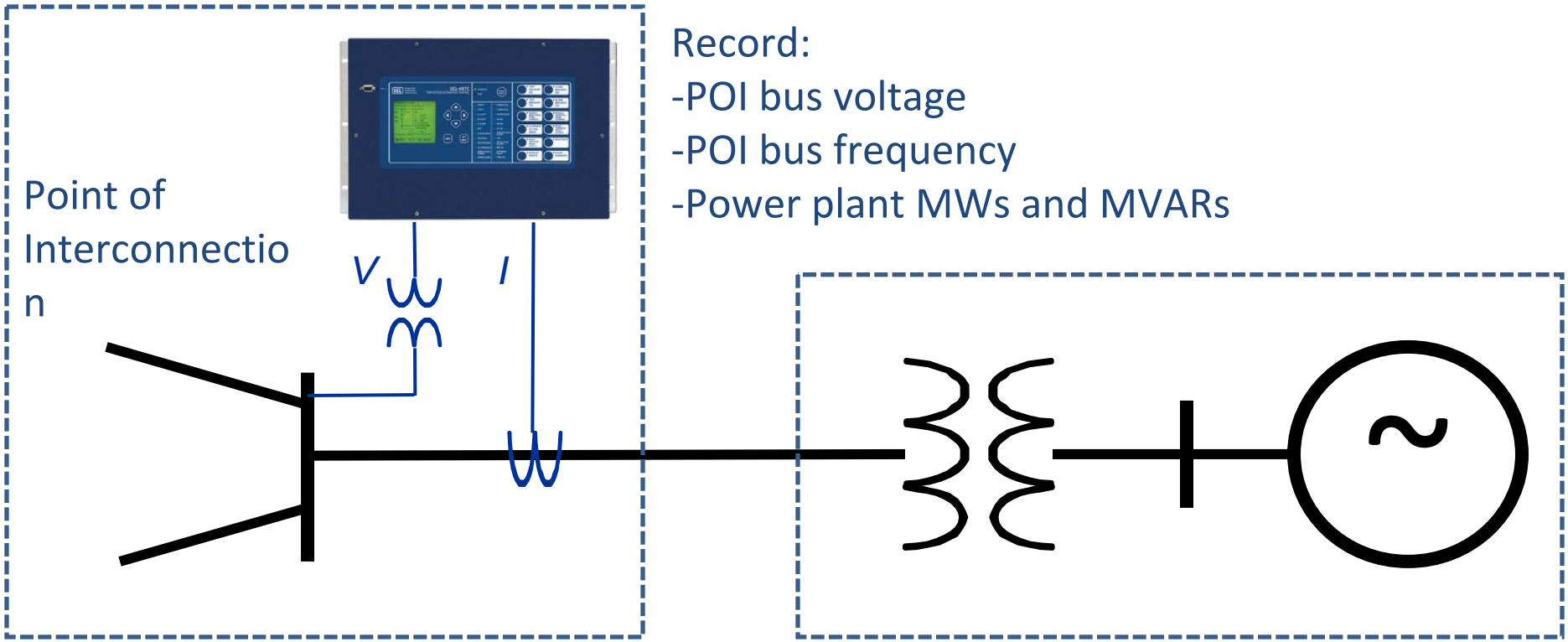
Consultant B

Which data is correct ?

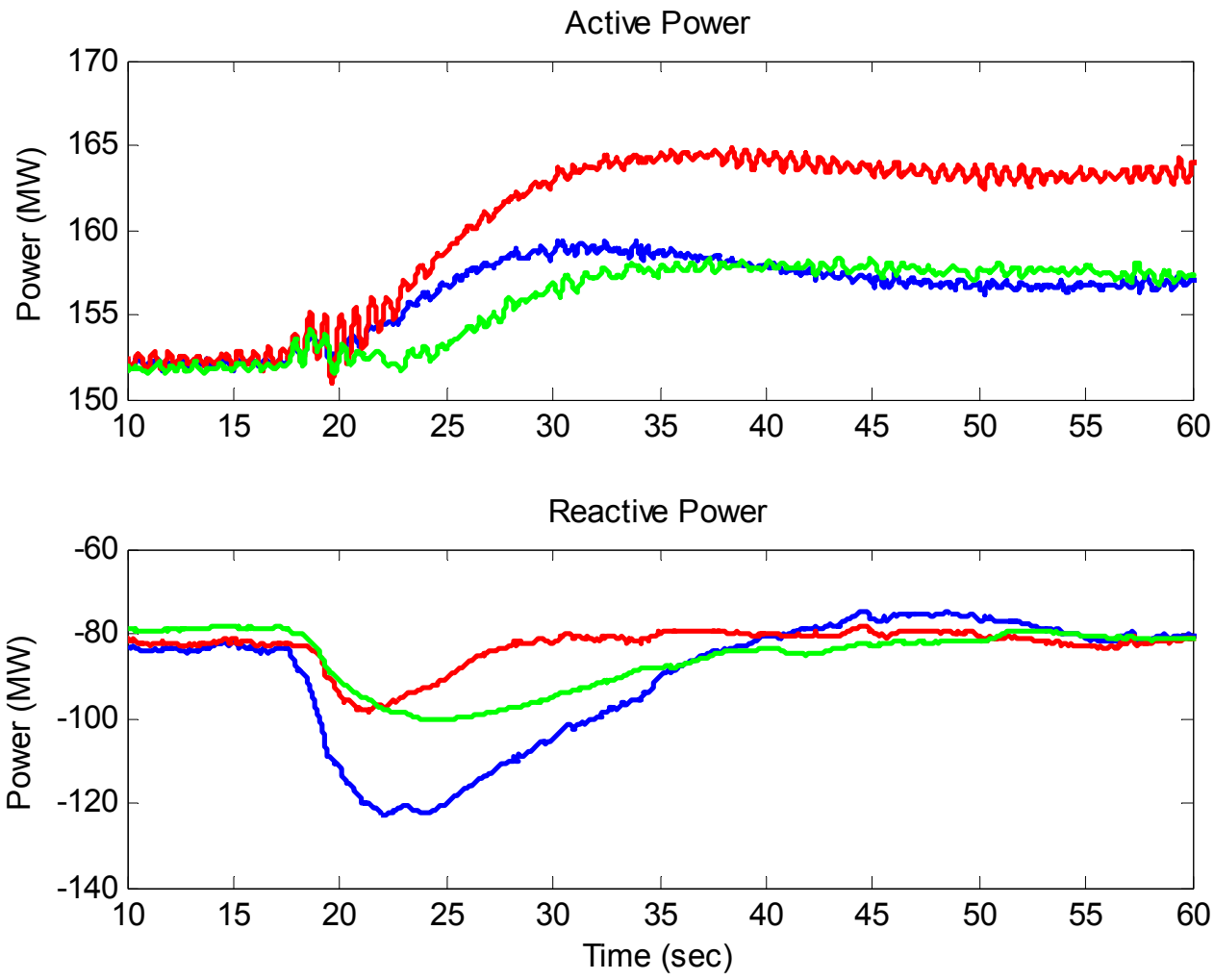
You do not know unless you have an independent way of verifying

Using PMU Data for Model Validation

- BPA has installed PMUs at power plant POIs
- BPA developed Power Plant Model Validation (PPMV) application using PMU data



Turned out neither consultant was right



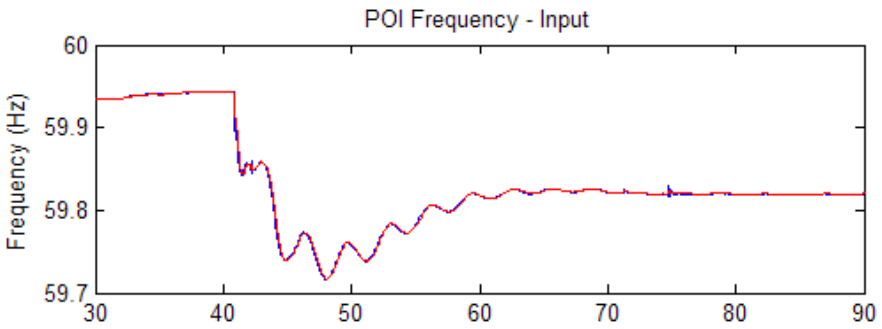
Consultant A

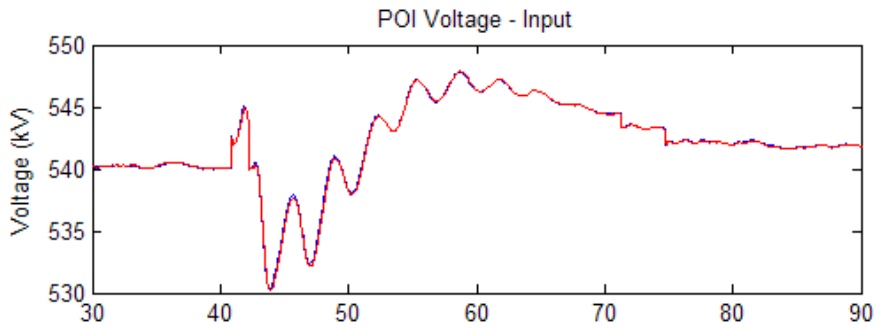
Consultant B

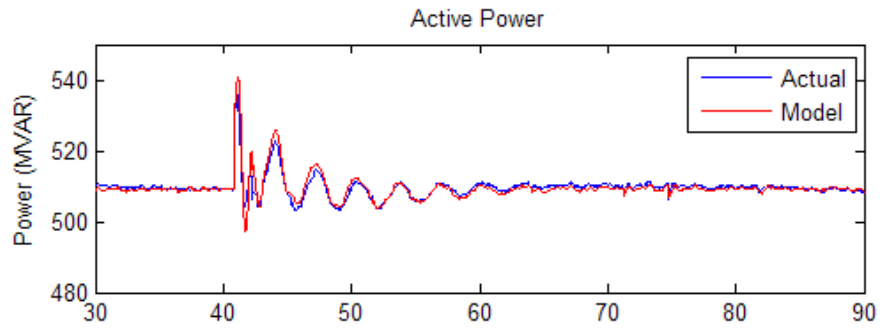
Reality

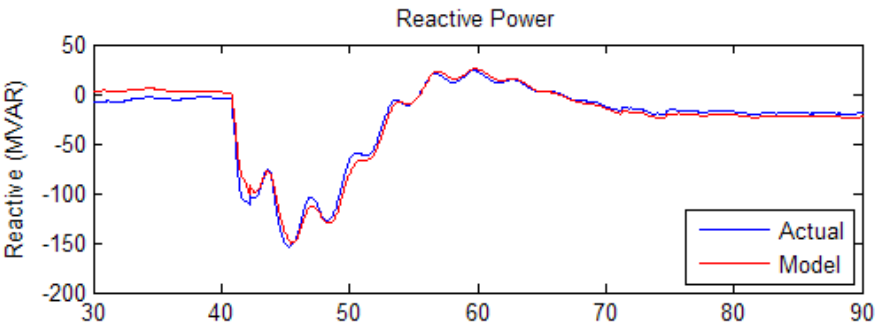
Power Plant Model Validation

- What a good models looks like:







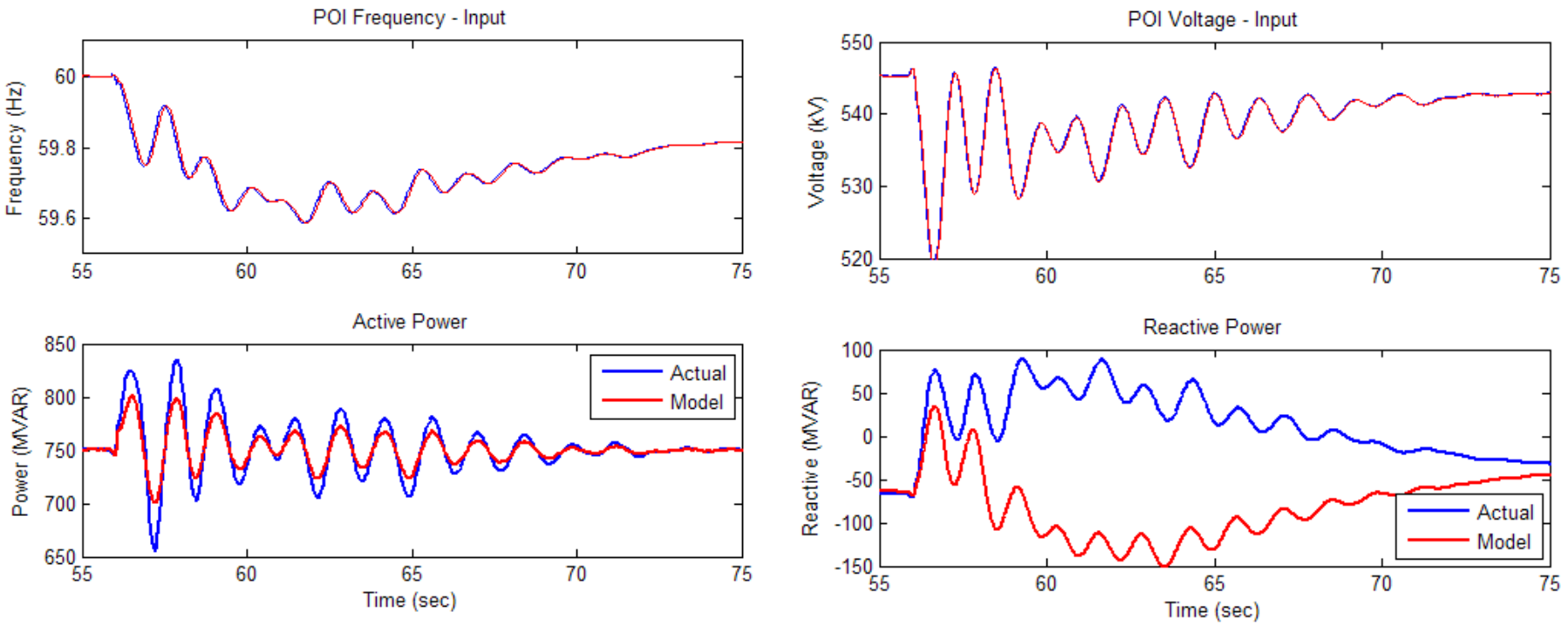


Voltage and frequency are inputs
Active and reactive power are “measures of success”

Blue line = actual recording
Red line = model

Power Plant Model Validation

- What a bad model looks like:



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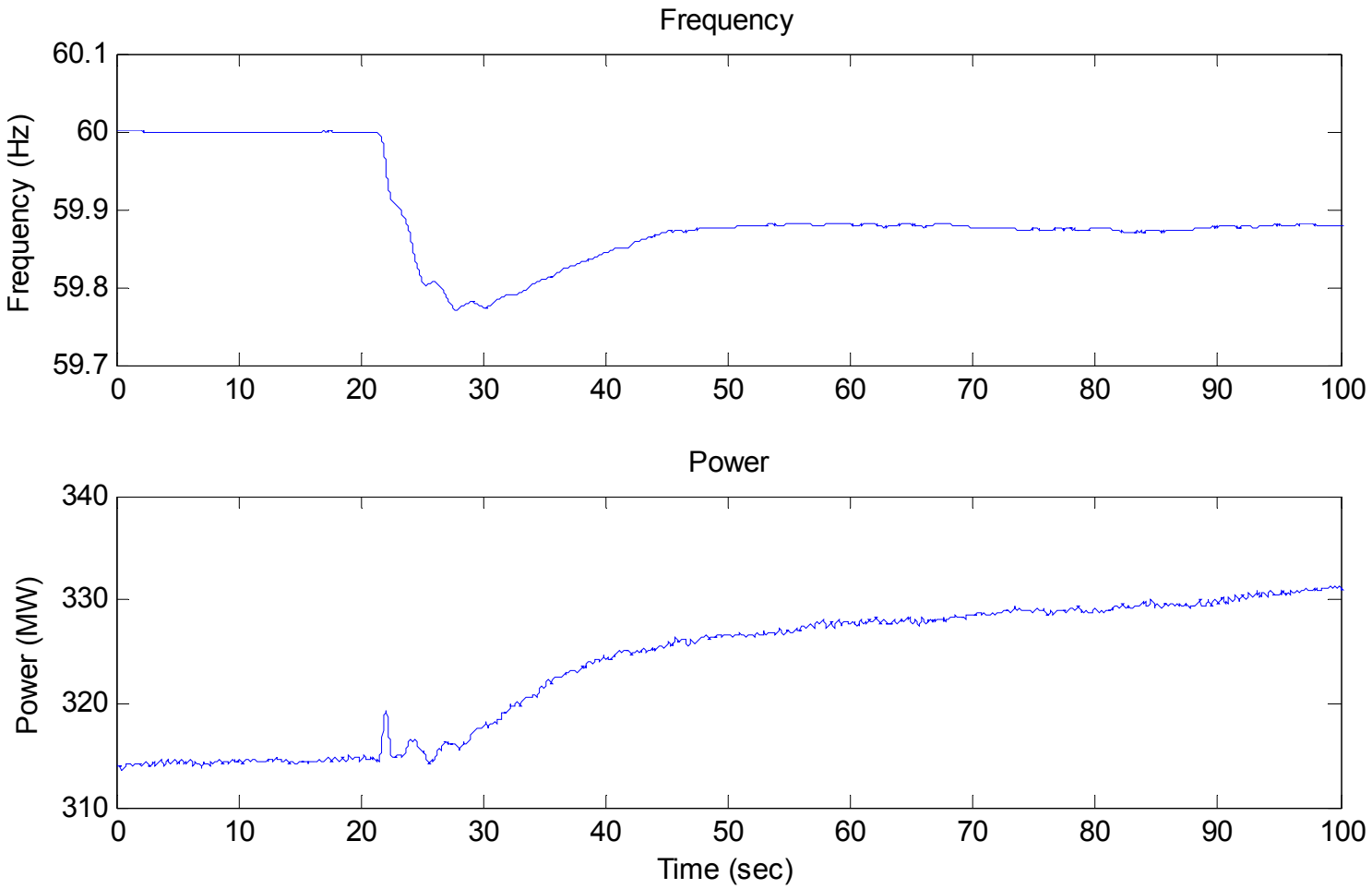
BPA Experience with Disturbance-Based Model Validation

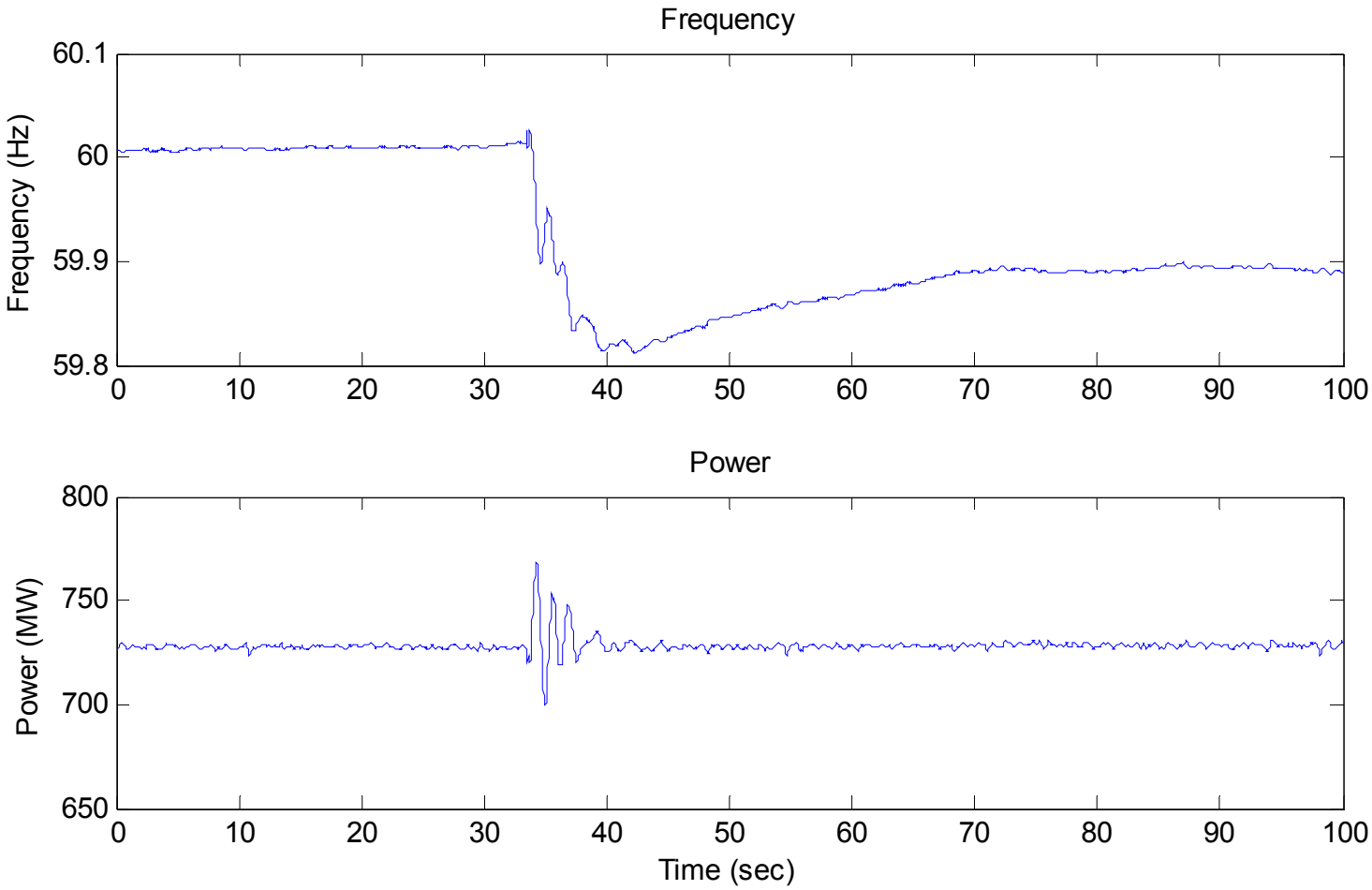
- Most common model issues:
  - Power System Stabilizer models
  - Turbine control mode of operation / governor models
  - Generator inertia
  - Deficiencies in model structure
- Other reasons for model mismatch
  - Automatic Generation Controls
  - UEL
- "Clinical" experience:
  - Plants with modern digital systems have good models that stay accurate over time
  - Plants with legacy analog controls have most errors and tend to change in time

Frequency Responsive Plant



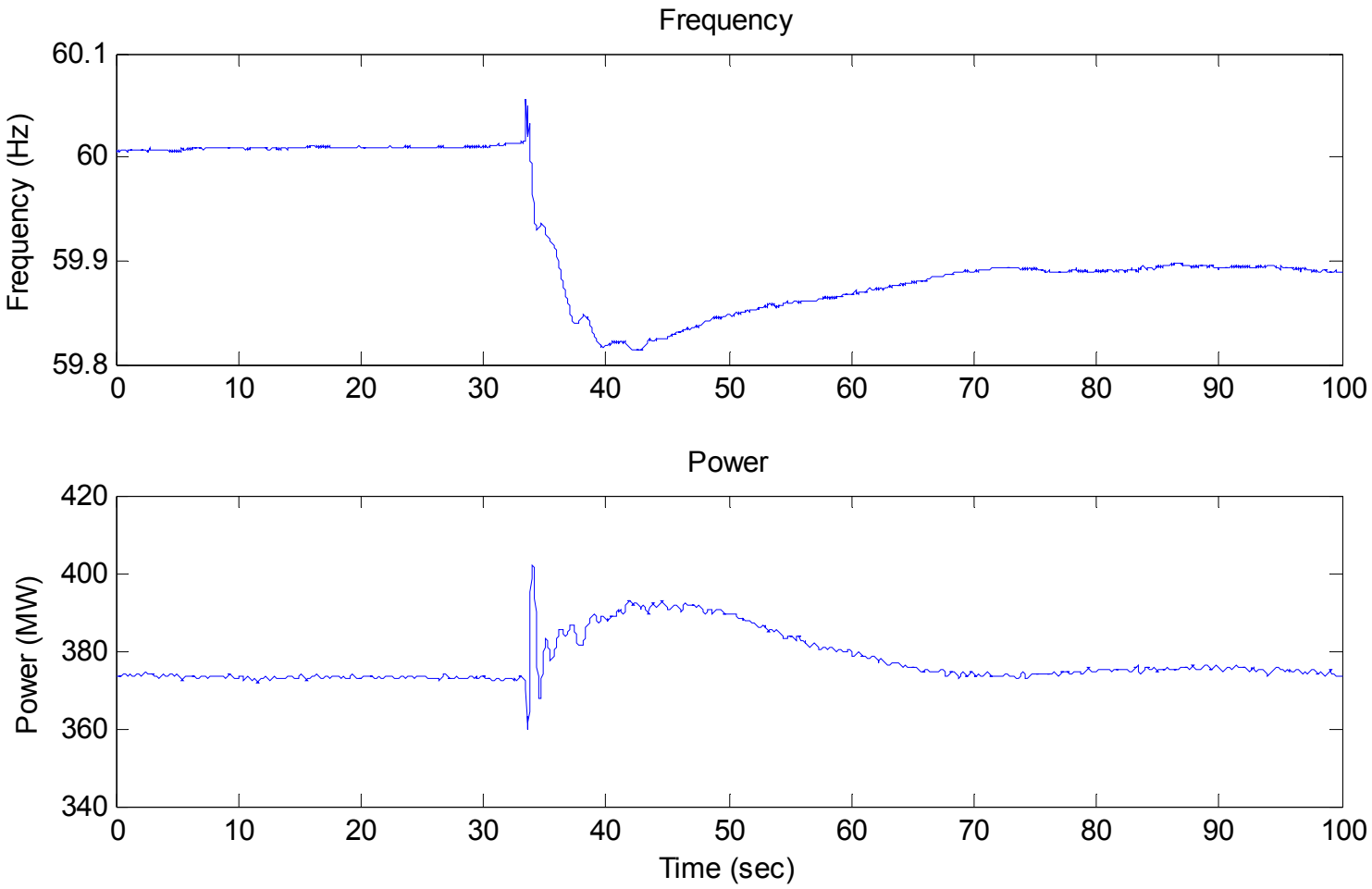
Provides sustained frequency response

“Baseloaded” Generating Unit



Does not respond to system frequency

Plant under Load Control

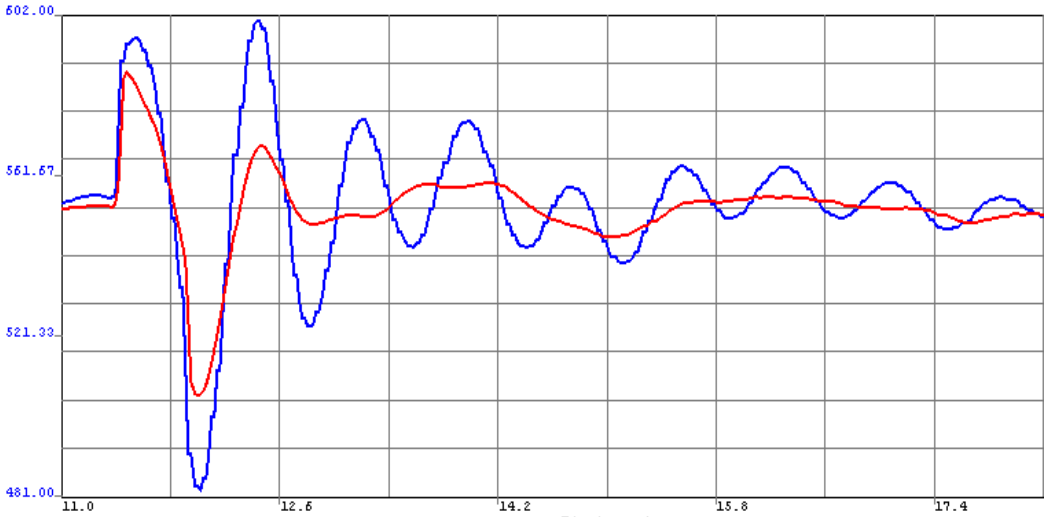


Provides initial response, but returns to the MW set-point

Generator Performance Monitoring

Performance Monitoring and Detecting Generator Control Failures

- Once a good baseline is developed, PMU is used for "clinical" assessment of power plant performance



Blue line = actual response

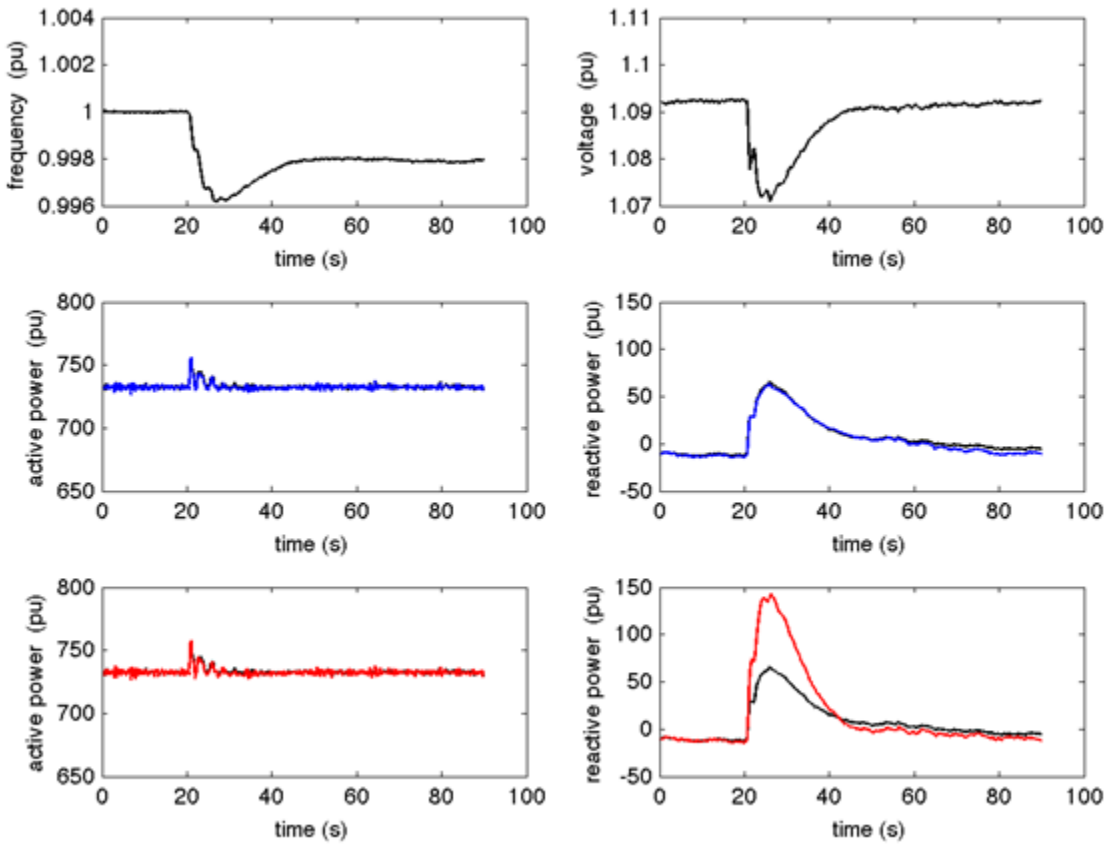
Red line = expected response

- Controller status at the generator was indicating normal state
- PMU disturbance data indicated actual response very different from what was expected
- Power plant was contacted, controls inspected, found internal failure

Performance Monitoring
Event 1

PSS ON

PSS OFF

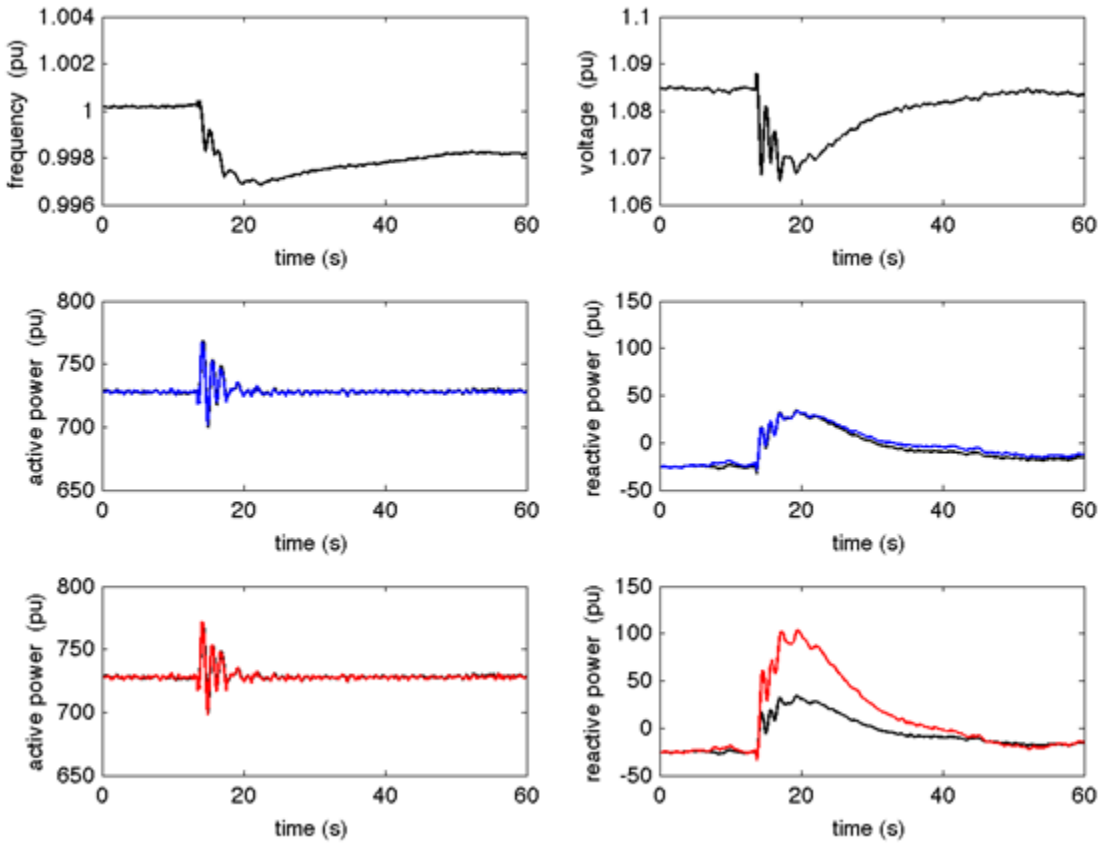


Actual PMU recording, Simulation with PSS ON, Simulation with PSS OFF

Performance Monitoring
Event 3

PSS ON

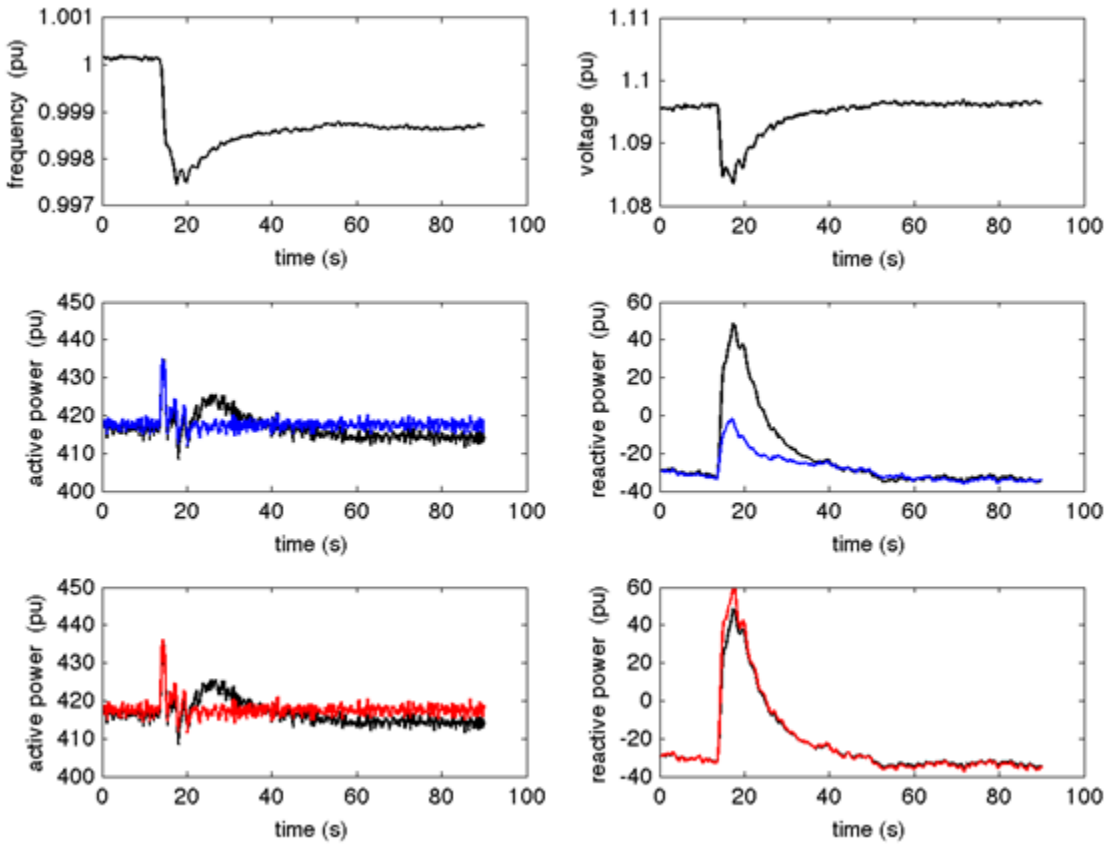
PSS OFF



Performance Monitoring
Event 4

PSS ON

PSS OFF

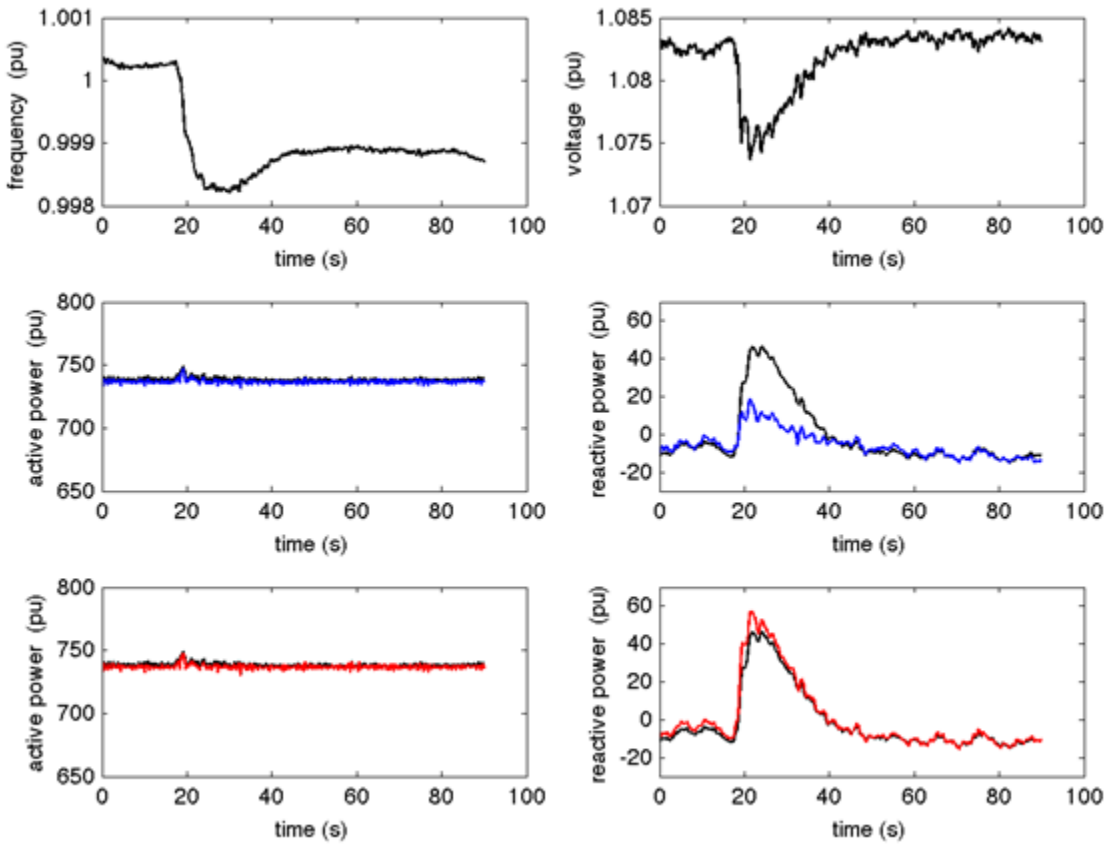


PSS failed sometime between event 3 and event 4

Performance Monitoring
Event 7

PSS ON

PSS OFF



Benefits of PMU-based Model Validation

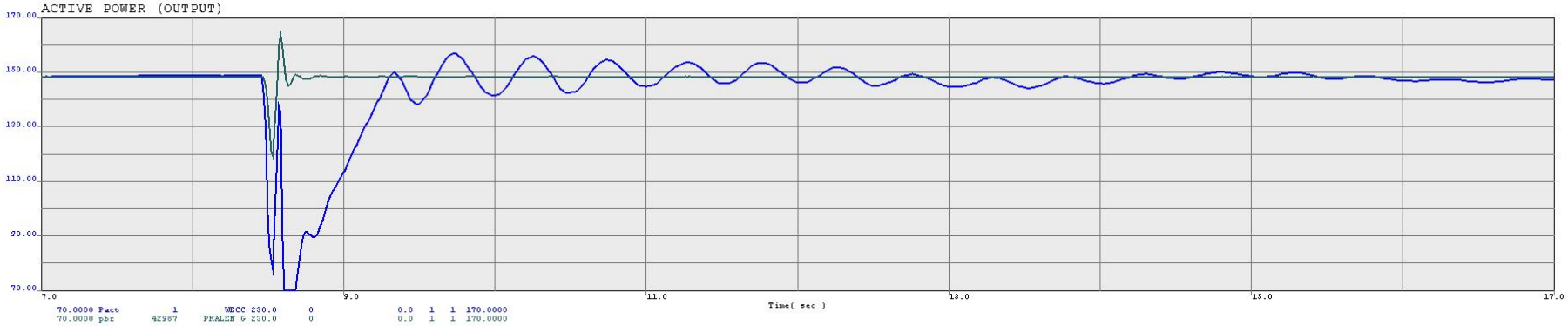
- Disturbance recordings can complement the baseline model development (e.g. TransAlta – BPA work at Centralia)
- PMU-based model validation is an acceptable method for GOs to comply with NERC MOD-026,-027
  - assuming a correct baseline model is developed
- PMU-based model validation can be used by TPs to independently verify that the models provided by GOs are accurate
  - BPA experience suggests that 60 to 70% of models did not match disturbance recordings even after the baseline test was performed
  - TPs need independent method of model verification – it is difficult to police traffic if you do not have a speed radar
- PMU-based model validation allows more frequent model verification and detection of control failures (e.g. Grand Coulee and Colstrip) than once every 10 years (per NERC) or 5 years (per WECC)

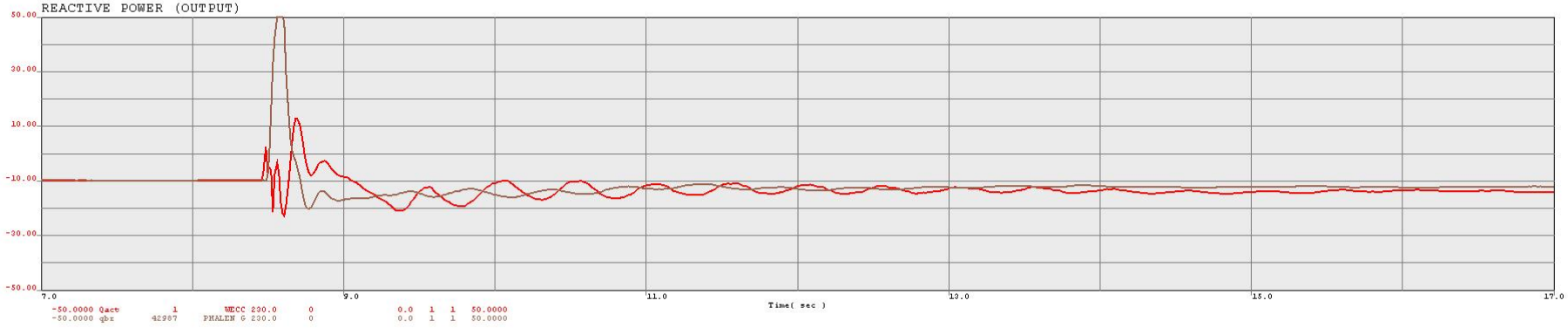
Wind Power Plants

Wind Power Plant Model Validation

- BPA, Idaho Power installed several PMUs at wind power plants
- BPA is collaborating with EPRI, NREL, Enernex, UVIG, Sandia on wind power plant model validation
- Initial results suggest more model development work is needed before models can be used in dynamic simulations

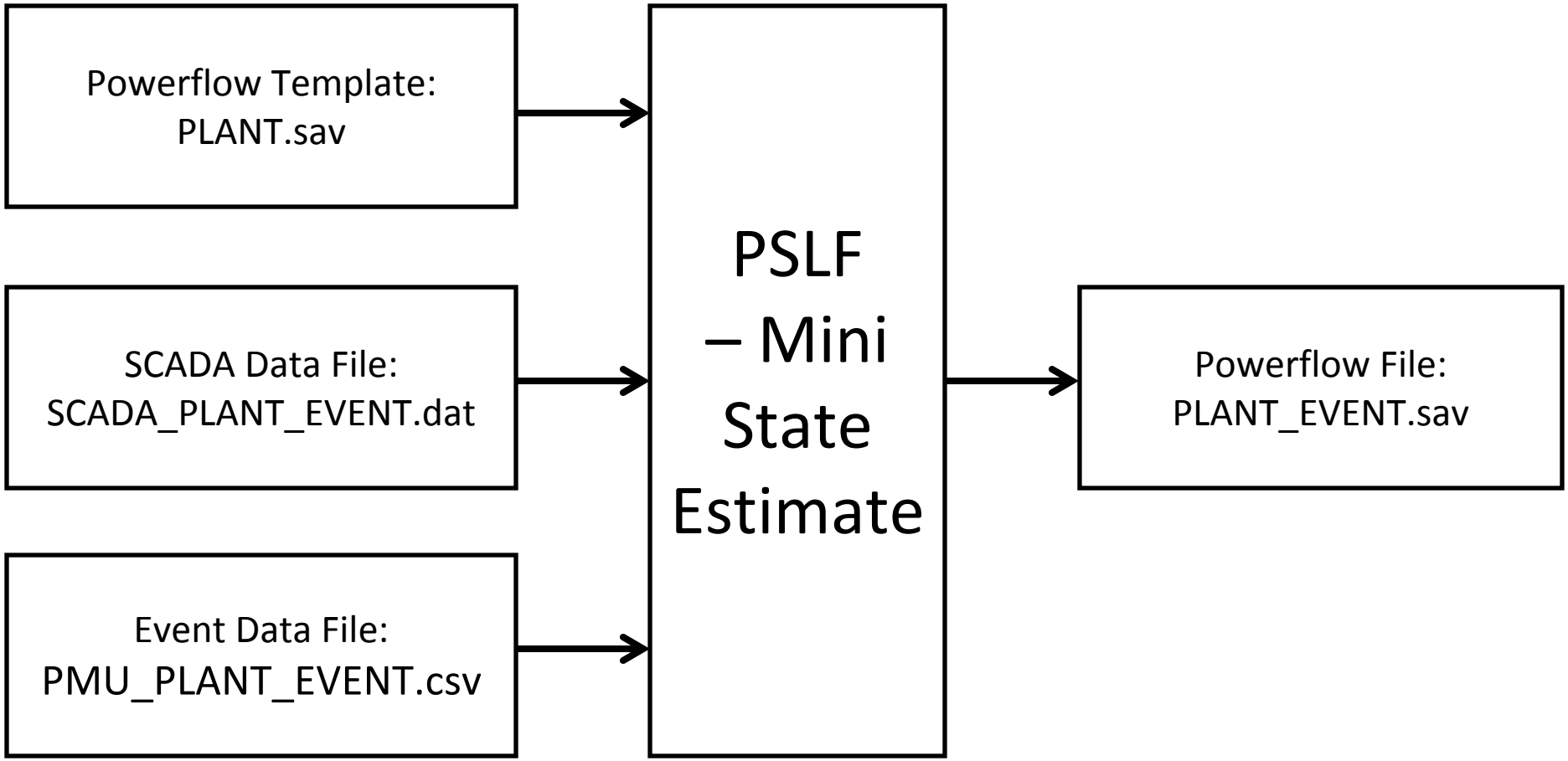
Wind Power Plant Model Validation





Demonstration

PPMVa_SetBaseCase_v1a.p

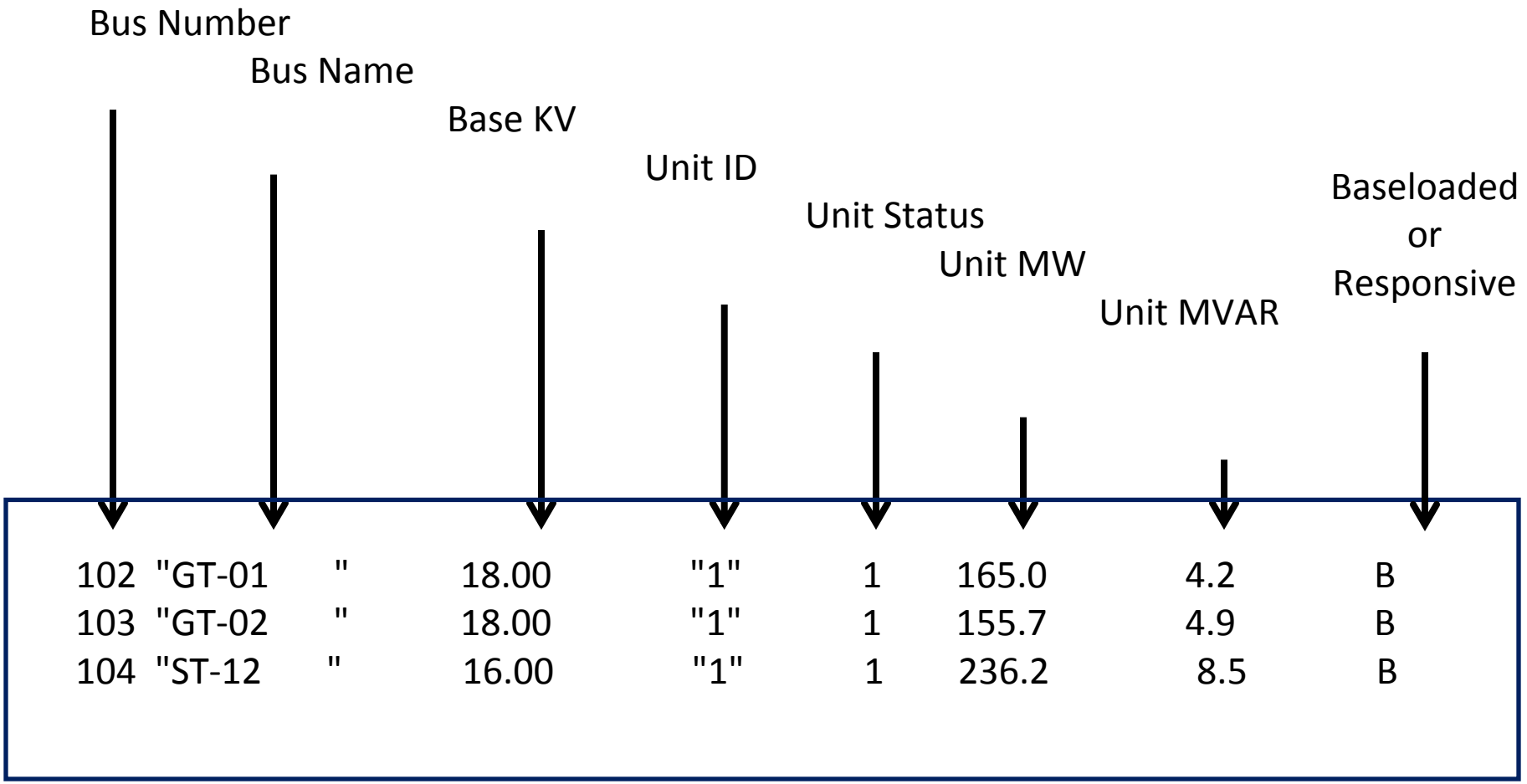


Set up a power flow with initial conditions

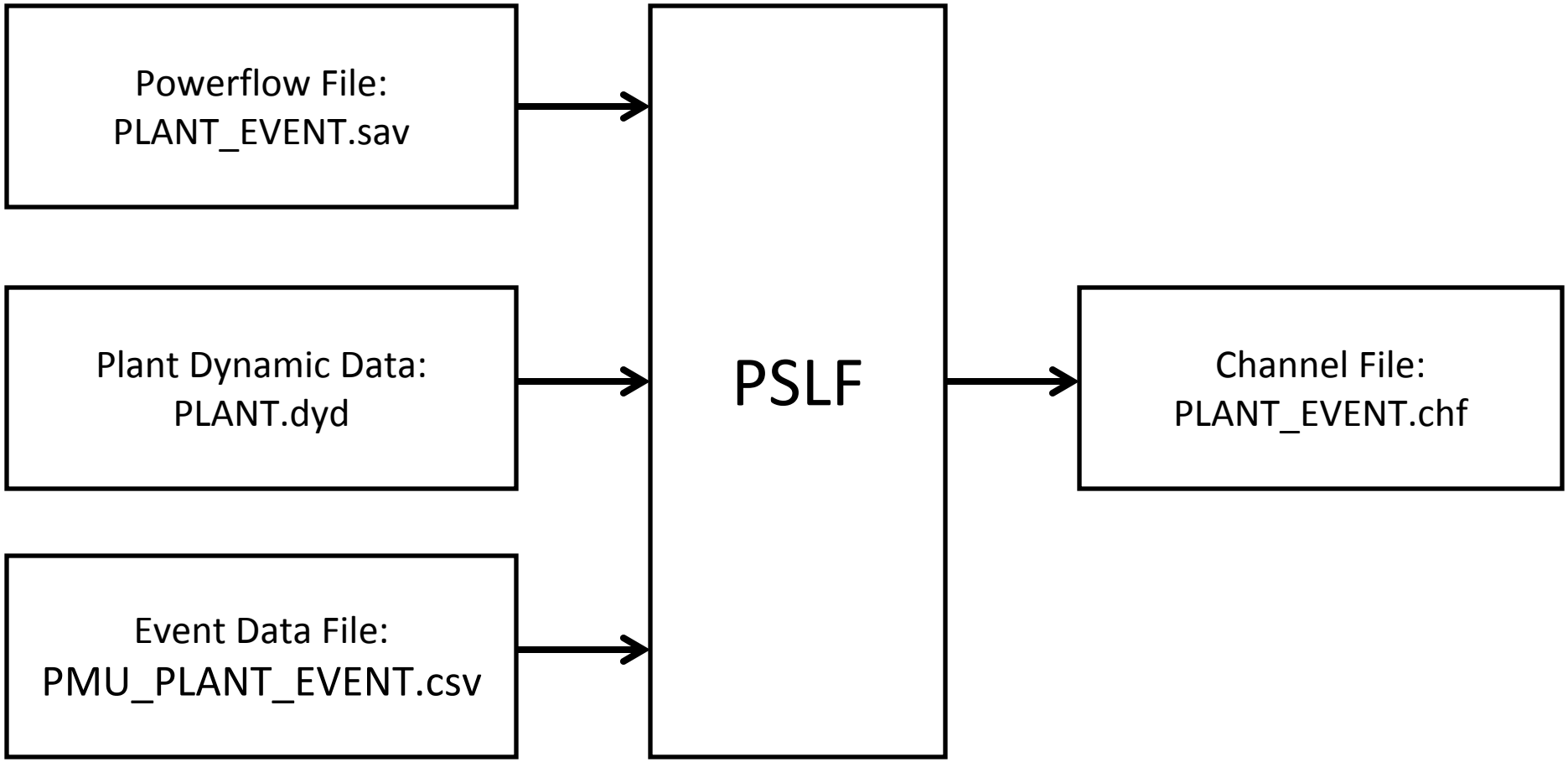
PMU Data File

5
Time Vact Fact Pact Qact //Head
1 **500** **60** 1 1 // Scale
0 0 0 0 0 // Offset
0 0 0 0 0 // Tf
0 0.8 0.99 0 -200 // min
160 1.2 1.01 1000 200 // max
1 1 1 1 1 // Plot
0,**542.696899**,**59.987999**,561.183899,-38.693913
0.033333,**542.686523**,**59.988998**,561.175293,-38.754639
…..

SCADA Data File



PPMVa_RunValidation_v1a.p



Run power plant model validation

PLOT Graphics GAS-2010-09-27-1450.chf

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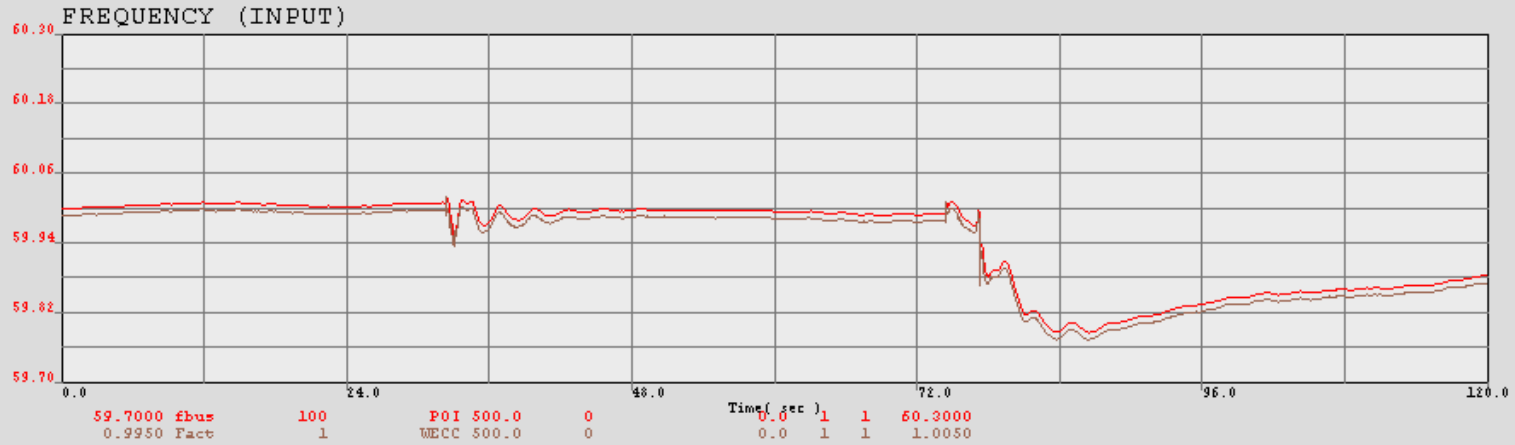

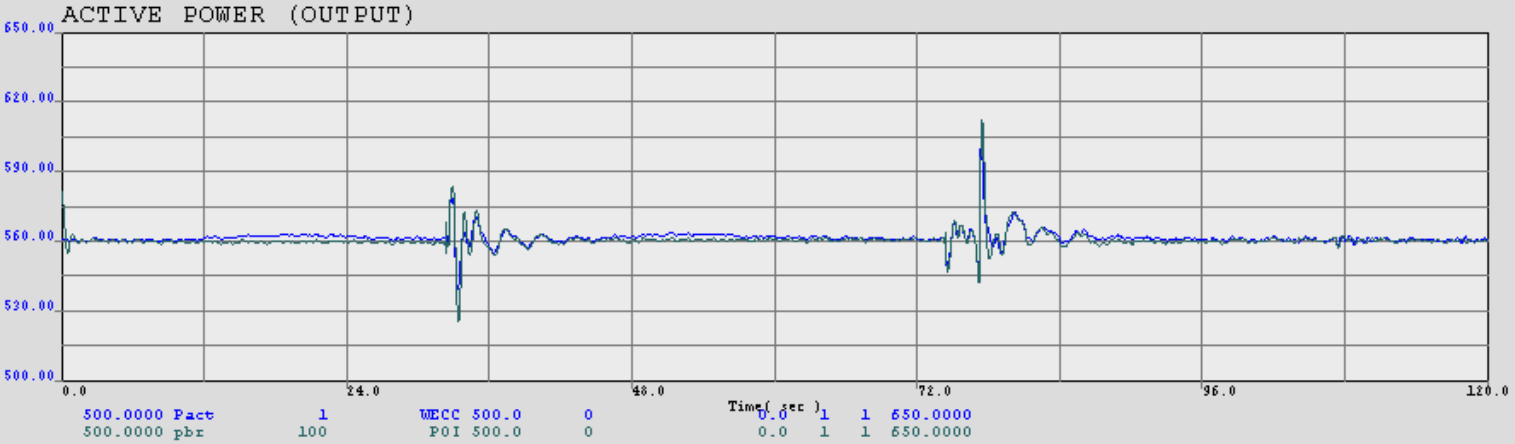

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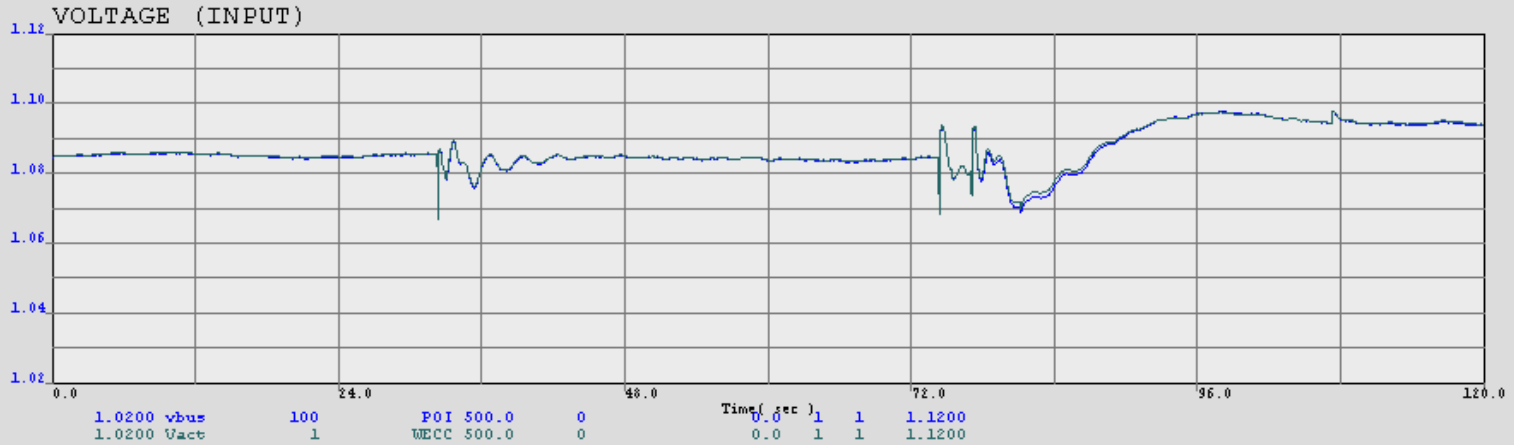
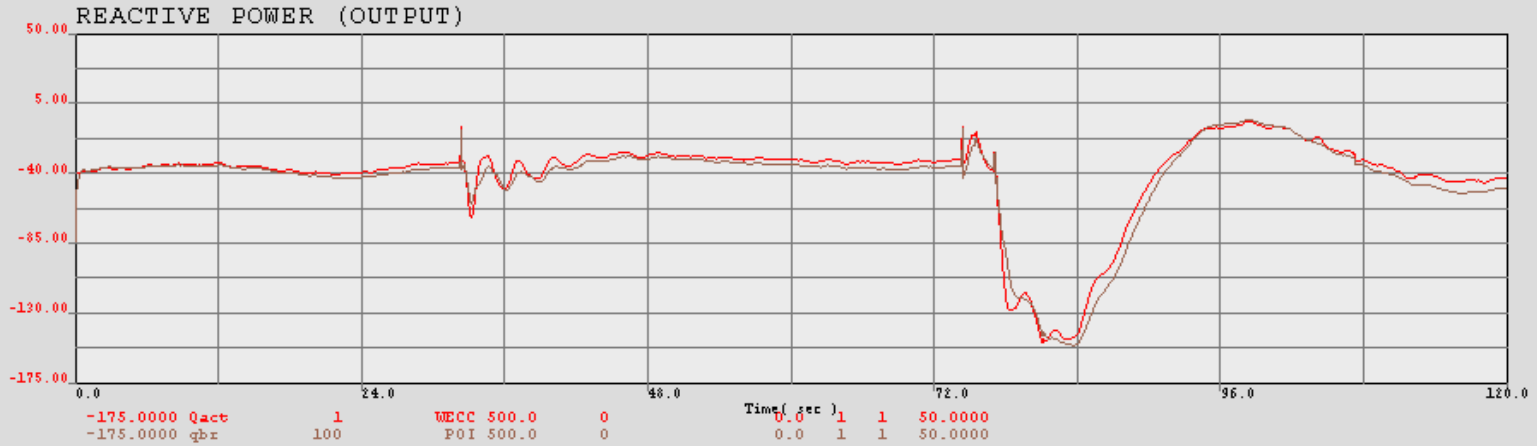


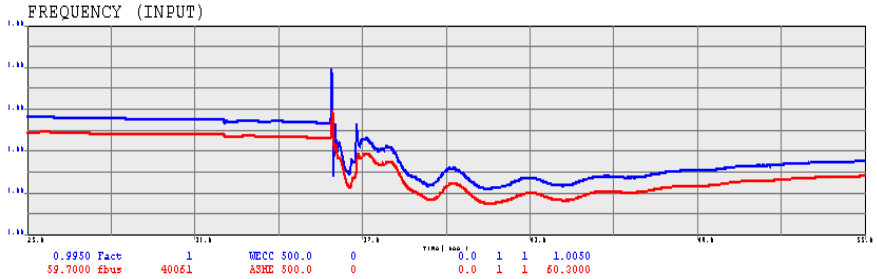


Model Calibration

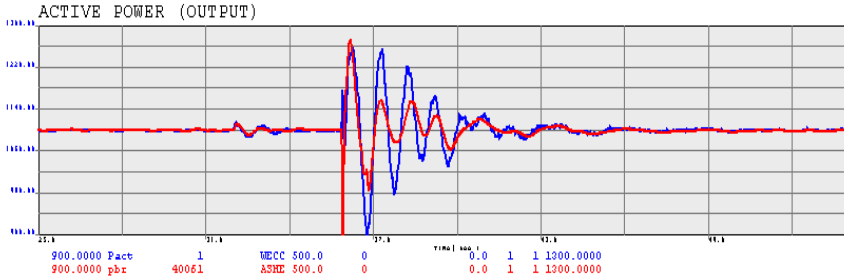
Model Calibration

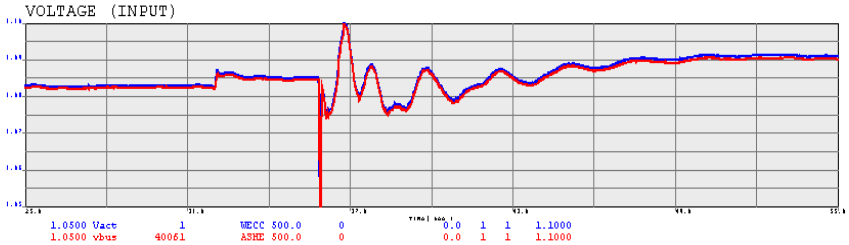
- Initially, BPA use of the PMU data has been limited to validating dynamic models of power plants:
  - used for pass / fail checking
  - no model adjustments are made should the model be wrong

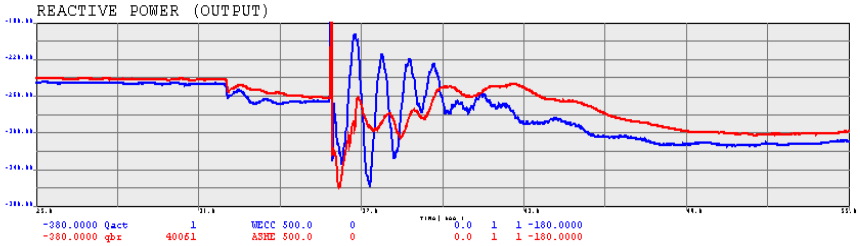
Model (in)Validation



Simulations done using a model from WECC dynamic data base







Blue = actual

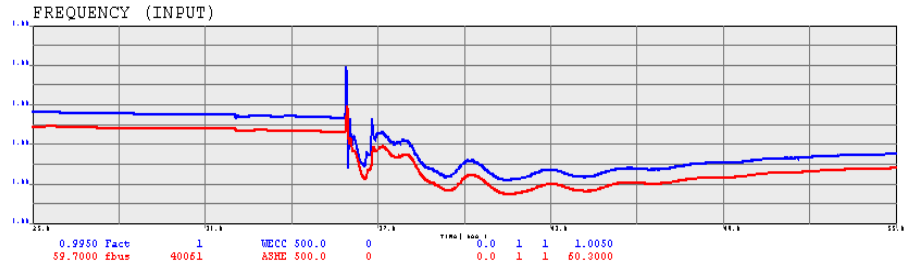
Red = simulated

Model Calibration

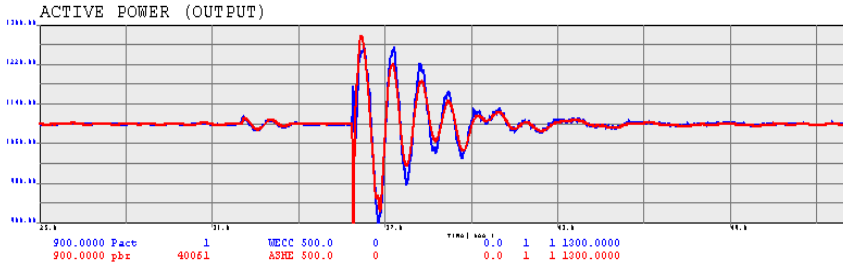
- DOE is funding several researchers to do work on power plant model calibration using PMU data
  - PNNL (Kalman filter)
  - Sakis Meliopolis, Georgia Tech (super-calibrator)
  - Bernard Lesieutre, University of Wisconsin (pattern matching)
  - Wei-Jen Lee, University of Texas (particle swarm optimization and non-linear optimization)
- EPRI is also working on PMU-based model calibration

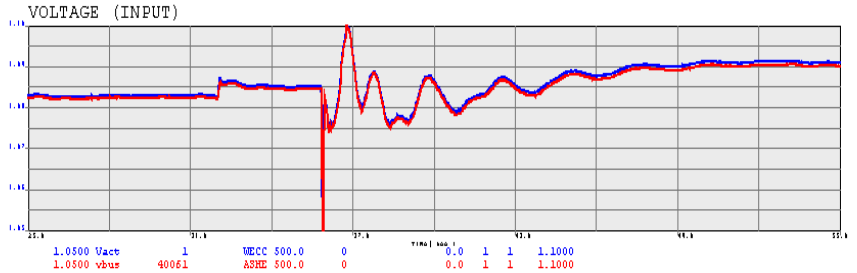
- BPA has worked with Bernie Lesieutre to perform model calibration for CGS and Colstrip

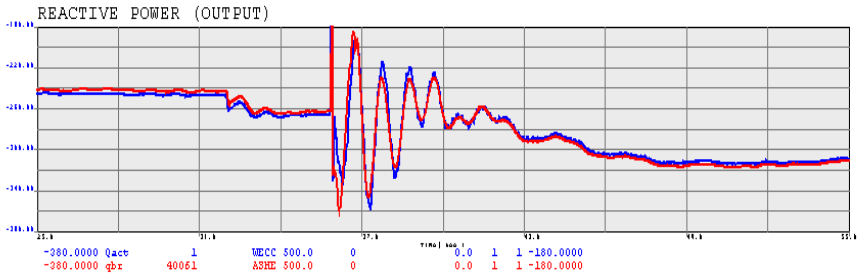
Model Calibration



Simulations done using a calibrated model







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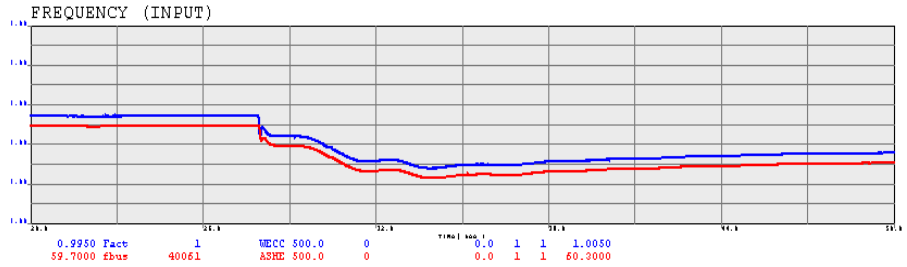
Model Calibration



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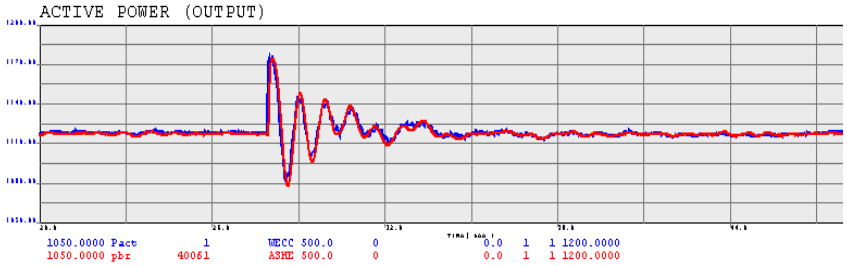

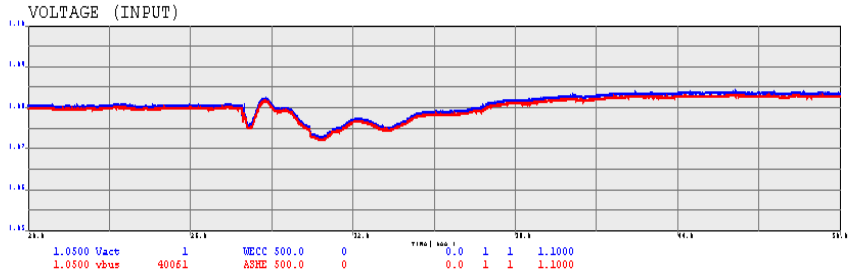

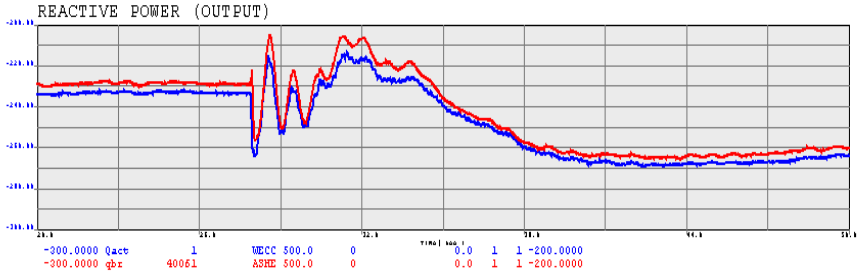

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Contact Information

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