Center for Commercialization of Electric Technologies (CCET)

Discovery Across Texas Project

Generator Parameter Validation

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1. Introduction

The Center for Commercialization of Electric Technologies (CCET) was awarded contract DE-OE0000194 by the Department of Energy to perform the Discovery Across Texas demonstration project. Electric Power Group, LLC (EPG) received a sub-award from CCET to provide professional services to perform, among other things, development of the Generator Parameter Validation (GPV) tool for Electric Reliability Council of Texas (ERCOT) use. The Generator Parameter Validation (GPV) tool is based on the research work done by Dr. Wei-Jen Lee et al from the University of Texas at Arlington [1][2]. EPG appreciates their contribution to the generator parameter validation process and for providing the program code which was used for the development of the GPV tool.

Power systems are complex networks with thousands of components. Computer simulations are used as the basis to simulate and study the power system's response to a variety of contingencies. Generators, loads, transmission lines and other power system components are represented as mathematical models in the computer simulation programs to predict network responses. Simulations, based on models of the network components, are used widely in both power system planning and operation, and play an important role in predicting the grid response and preparing for contingencies. Hence, having correct models is very essential. Checking and validating models is a must for maintaining grid reliability. Also, periodic validation of the models would be required to comply with North American Electric Reliability Corporation (NERC) reliability standards [3].

Generators are one of the most important components of the power systems. Having correct generator models is highly important. The traditional testing method of performing staged tests on generators, taking detailed recordings of the generator's response, and then comparing the measured and predicted responses, is very expensive, time-consuming and may risk damage to the equipment. Also, the units typically have to be taken out of service for testing.

GPV is the process of validating generator model parameters using Phasor Measurement Units (PMU) measured data. GPV uses recorded disturbance data measured at the output of a generator to validate and calibrate generator model parameters. Disturbances occur frequently on the network, and afford the opportunity to measure the response of the generator, if appropriate data recording capability is in place and operational. PMU data collected at the output of the generator provides the continuous high-speed monitoring capability needed to perform model validation. The GPV tool provides a means of validating the simulated results with the measured generator response from these occasional grid disturbances. If the model simulation results don't match the recorded data, the model parameters are likely to be incorrect and the model needs to be corrected. The correct model parameters are identified by the optimization process using advanced algorithms. The types of models that can be validated are generators, governors, exciters and stabilizers. This validation process can be done frequently, using data from normally occurring grid disturbances, without taking the generators offline. The GPV tool allows the user to perform the validation process with a user interface.

2. Executive Summary

Power systems are complex networks with thousands of components. Models are required to understand system behavior and are used widely in power system studies, planning and operation. They play an important role in predicting the grid response and planning for contingencies. Hence, having correct models is very essential. Checking and validating models is a must for maintaining grid reliability. Also, periodic validation of the models would be required to comply with North American Electric Reliability Corporation (NERC) reliability standards.

Generators are one of the most important components of the power system. Having correct generator models is highly important. The traditional testing method of performing staged tests on generators is very expensive, time-consuming and may damage the equipment. The units have to be taken out of service for testing. GPV is a process of validating the generator model parameters using synchrophasor data. Using synchrophasor data, the models can be periodically validated without taking the generators offline. The GPV tool uses measured disturbance data captured by Phasor Measurement Units (PMUs) to validate the generator models. The types of models that can be validated are generator models, exciter models, governor models and stabilizer models.

The generator parameter validation consists of three processes: validation, sensitivity analysis and optimization. In the validation process, the model simulation output waveform is compared to the PMU measured waveform. If the validation results indicate a poor match between the simulated and measured waveforms, sensitivity analysis should be performed. Sensitivity analysis identifies the model parameters which have the greatest effect on the output of the simulation. Thus, sensitivity analysis helps to identity the key parameters that need to be selected for the final step, which is the optimization process. Sensitivity analysis also enables plotting of trajectories of the change in active and reactive power for every parameter. Optimization is the process of finding the set of parameter values for which the simulation output best matches the PMU recorded measurements. Advanced algorithms are used for the optimization process. Also, the variation of parameters can be restricted by specifying a maximum and minimum value for individual parameters. This enables fine-tuning of the identified parameters and helps to converge on the most representative parameter values. The newly identified parameter values can then be used for calibrating the models. The GPV tool provides a user interface for all three steps in the generator parameter validation process.

This report includes a brief description of the generator parameter validation process. It includes the work done towards the development of the GPV tool and also includes some results obtained by using the tool.

3. Process and Methodology

The steps involved in the generator parameter validation process are shown in Figure 1 below:

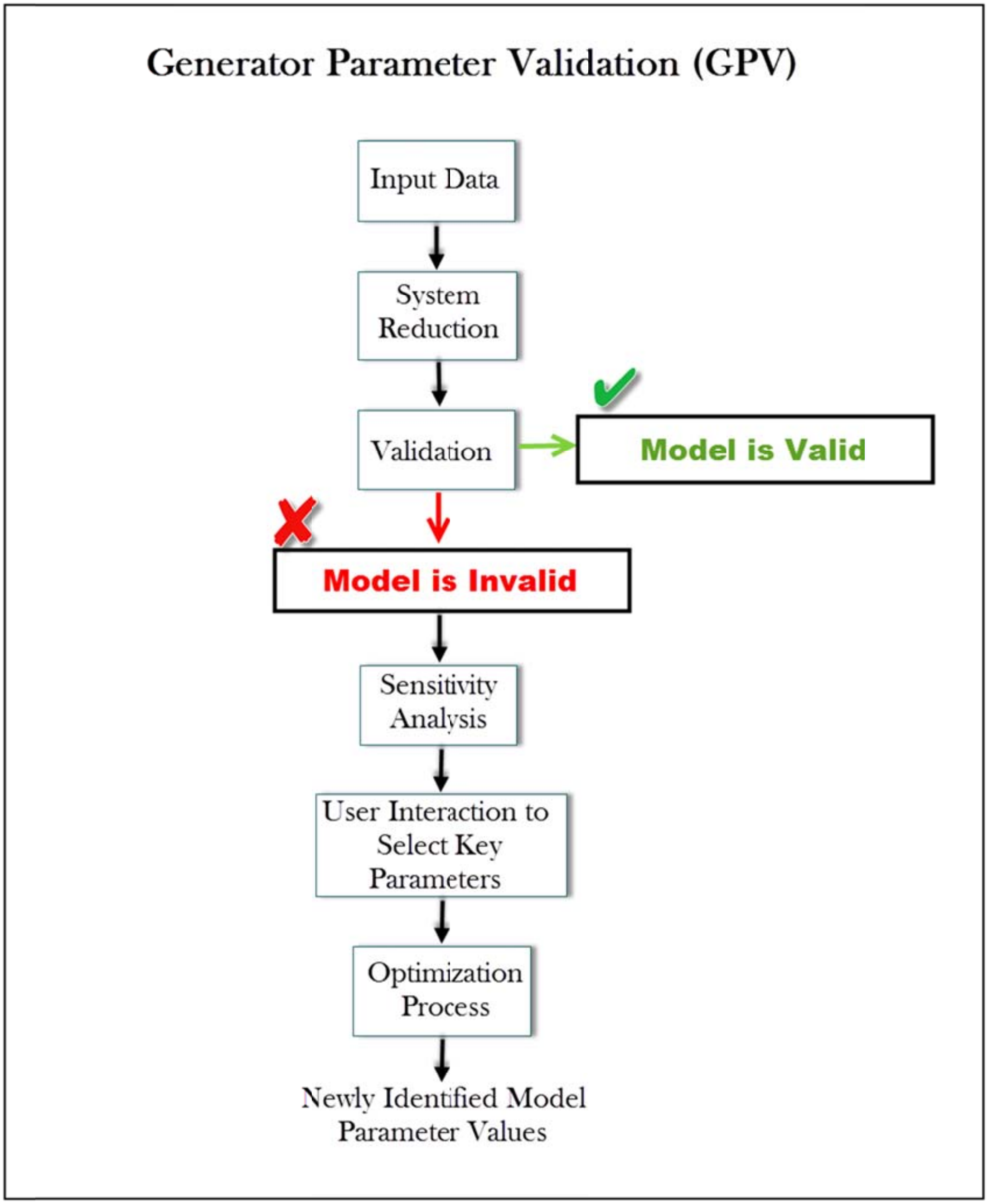


Figure 1. Generator Parameter Validation Process Workflow

Step 1 Obtain PMU measured data (Voltage, Voltage angle, Active Power and Reactive power) at the output of the individual generator unit as input data in the format required by the tool.

Step 2 Using a system reduction approach, reduce the entire system to a smaller system at the output of the generator.

Step 3 Perform the validation process by comparing model simulation results with the measured data and evaluate the need for calibration.
Step 4 Run sensitivity analysis to display sensitivity of power flows to each parameter.
Step 5 Select key parameters for the optimization process based on the sensitivity analysis results. Optionally specify range (minimum, maximum) limits for parameter variation.
Step 6 Run the optimization process to identify correct parameter values.

The generator parameter validation process requires three input data files: an Excel file with PMU measured data in the required format; a PSS\E saved case file, and PSS\E dynamics file corresponding to the electrical network at the time of the recorded disturbance. A system reduction approach is used whereby the entire power system is reduced to a smaller system at the output of the generator, and the simulations are then performed using a concept called as hybrid dynamic simulation [1][2]. Hybrid dynamic simulation uses measured data as well as the simulation model to perform dynamic simulations. The GPV tool runs the PSS\E simulation engine in the background using the python programming language.

The system reduction process is followed by three processes: validation, sensitivity analysis, and optimization. In the validation process, the model simulation output waveform is compared to the PMU measured waveform. If the validation results indicate a poor match between the simulated and measured waveforms, sensitivity analysis should be performed. Sensitivity analysis identifies those model parameters which have the greatest effect on the output of the simulation. Thus, sensitivity analysis helps to identity the key parameters that need to be selected for the next step, which is the optimization process. Sensitivity analysis also enables plotting of trajectories of the change in active and reactive power for every parameter. These trajectory plots provide an additional visualization of the sensitivities of the power flows to each parameter change.

When there is a mismatch in the simulation results and measured results, it is important to identify the parameters that caused the mismatch. Optimization is the process of finding the set of parameter values for which the simulation output best matches the PMU recorded measurements. Two advanced algorithms, namely Particle Swarm Optimization (PSO) and Simultaneous Perturbation Stochastic Approximation - Particle Swarm Optimization (SPSA-PSO) Cooperative Method may be used for the optimization process [1][2]. For the optimization process, the variation of parameters can be restricted by specifying maximum and minimum values for individual parameters. This enables fine-tuning of the identified parameters and helps to narrow down on the correct parameter values. The newly identified parameter values will be useful for calibrating the models.

4. User Interface

A user interface was built for the GPV process.

The interface allows users to:

1. Select input data files.
2. Specify case and model information.
3. Run the validation process and view results and plots.
4. Perform sensitivity analysis and view results.
5. Select key parameters.
6. Select algorithm for optimization process.
7. Run the optimization process and view results and plots.

The GPV tool interface is shown in Figure 2 below.

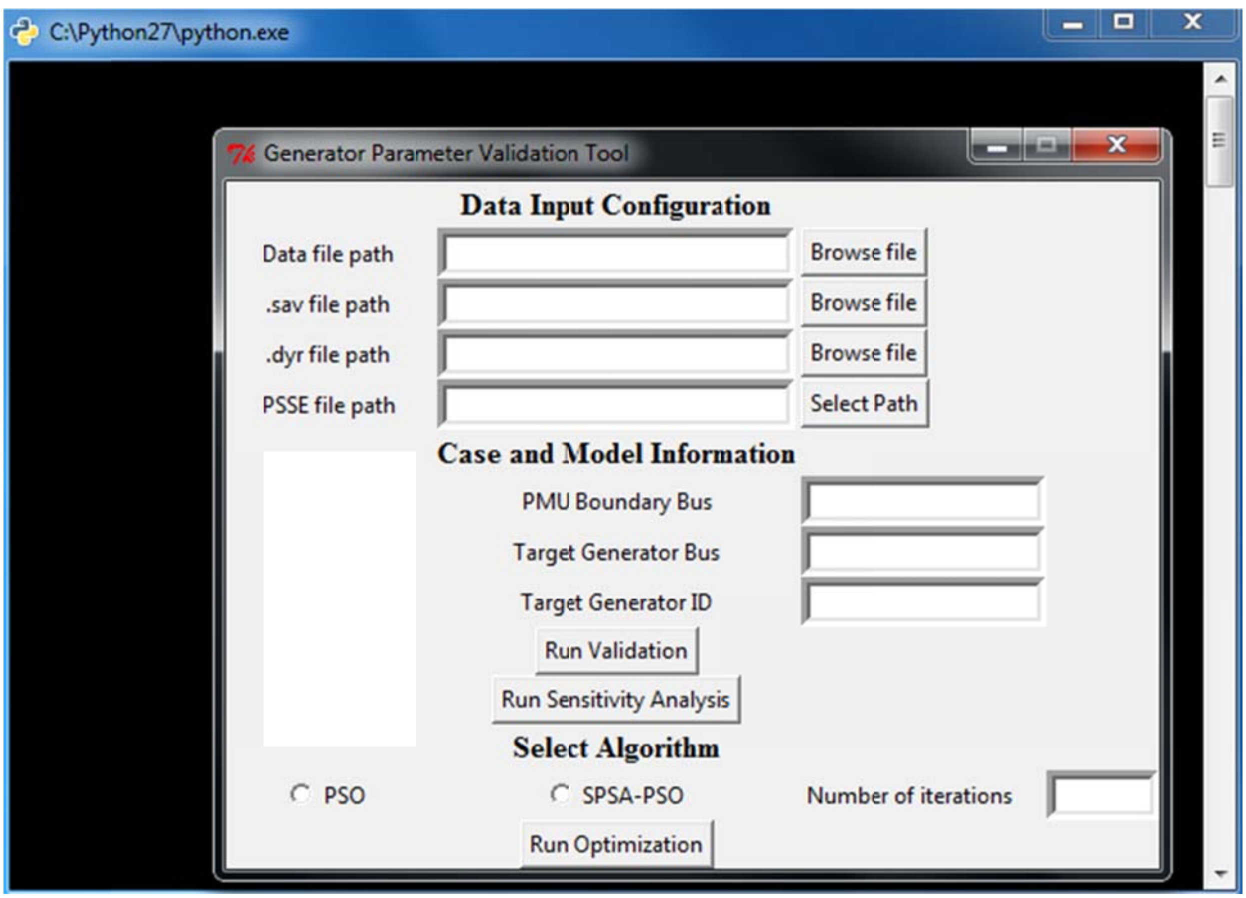


Figure 2. GPV tool user interface

5. Tool Features

Some of the key features of the GPV tool are listed below:

1. Automation of the system reduction process.
2. Sensitivity analysis results with ranked and color coded parameter values.
3. Comparison plots for validation – simulation output vs. measured data.
4. User interaction to select key parameters and optionally specify range for each parameter.
5. Plot trajectories for sensitivity of active and reactive power flows to each parameter.
6. Optimization process with two advanced algorithms.
7. Plots comparing measured data, actual model simulation output and new identified model simulation output .

6. Test Case Results

The GPV tool was tested on PSS\E example case files using simulated data as input measured data. Input data for 10 seconds was obtained by simulating a bus fault event and obtaining P, Q, V, and Angle measurements at the PMU boundary bus (201) in order to validate a hydro generator at bus number 211. The one-line diagram view of the generator is shown in Figure 3 below. This generator is a part of a 23 bus example system provided by PSS/E. The models associated with this generator are generator model - GENSAL, governor model – HYGOV and exciter model - SCRX. One of the dynamic model parameters was manually changed to create a mismatch between the simulated and measured results. Parameter number 3 (H-Inertia) from the GENSAL model was changed from 5 to 4 per unit on machine MVA base. In other words, simulation data that was used as measured data input to the tool was obtained with the parameter value of 5 but the input dynamic data for running simulations with the tool had parameter value set to 4.

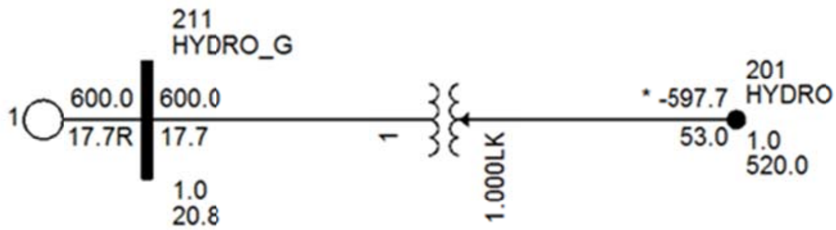


Figure 3. One-line diagram view of the target generator

The results from the validation process are shown in figures 4 and 5 below.

Active Power (P)

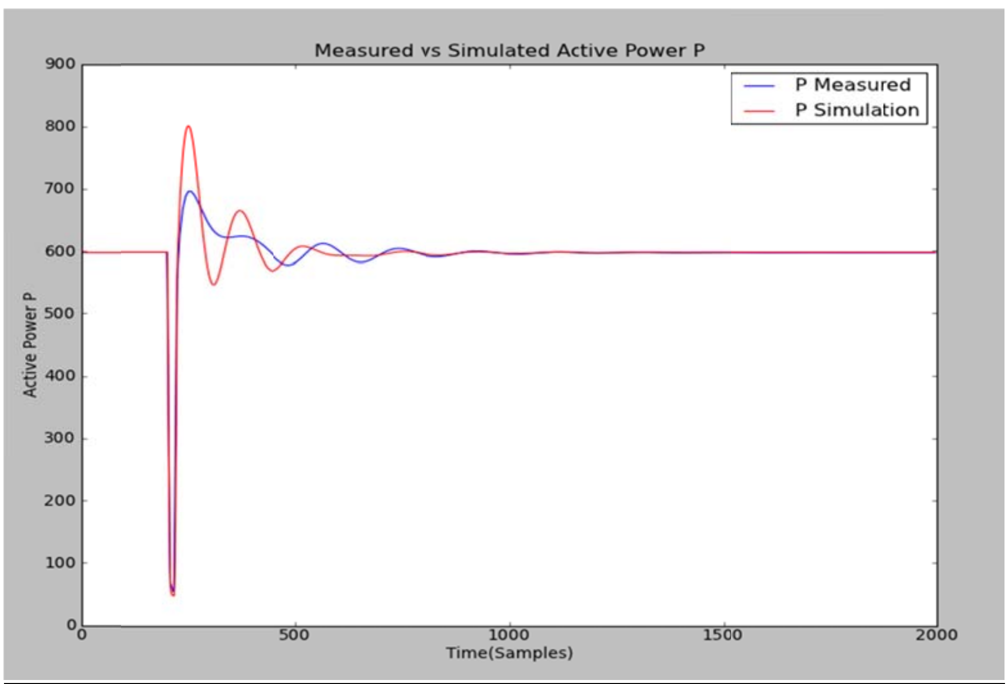


Figure 4. Validation Plots for active power (P)

Reactive Power (Q)

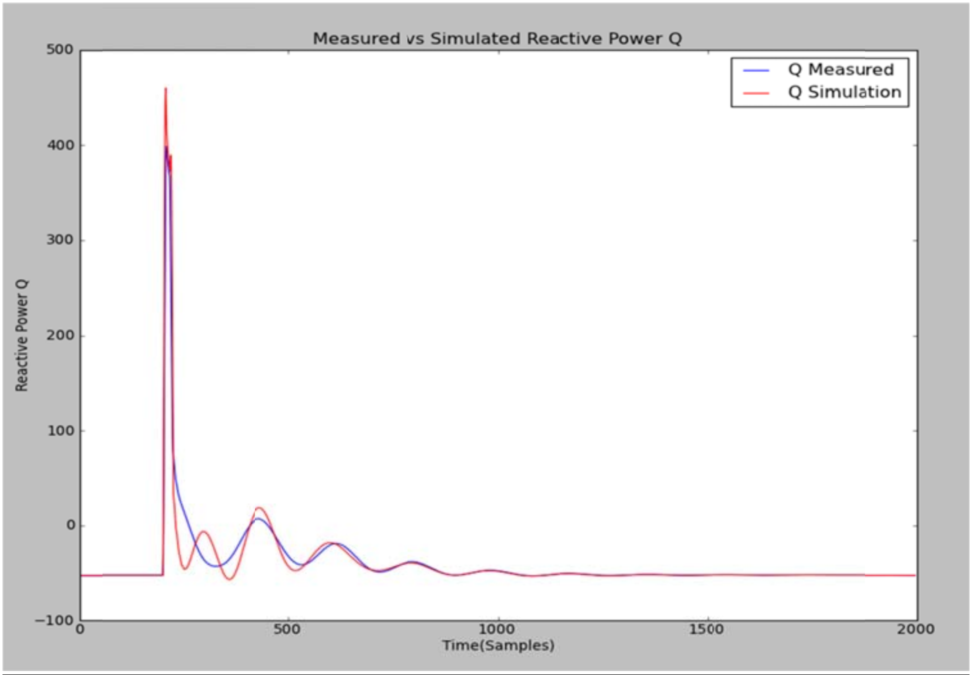


Figure 5. Validation plots for reactive power (Q)

A mismatch in the measured and simulation results is observed in the validation plots. Sensitivity analysis was then performed to identify the key parameters that have highest impact on the simulation response. The sensitivity analysis results are shown in figure 6 below.

Sensitivity Analysis/Parameter Selecti...

Parameter	MSE-P	MSE-Q	Ranks		Min	Max
GENSAL- Par 0	0.35171	1.18298	7	☐		
GENSAL- Par 1	0.05296	0.07701	14	☐		
GENSAL- Par 2	1.43549	0.39824	6	☐		
GENSAL- Par 3	19.03361	3.87913	1	☑		
GENSAL- Par 4	0.0	0.0		☐		
GENSAL- Par 5	0.02876	0.13491	12	☐		
GENSAL- Par 6	3.0208	1.10109	4	☐		
GENSAL- Par 7	1.7801	3.23206	3	☐		
GENSAL- Par 8	1.10012	4.82334	2	☐		
GENSAL- Par 9	0.00126	0.00175	22	☐		
GENSAL- Par 10	0.00029	0.00273	21	☐		
GENSAL- Par 11	0.00433	0.1711	11	☐		
HYGOV- Par 0	0.00022	3e-05	25	☐		
HYGOV- Par 1	0.01574	0.00143	17	☐		
HYGOV- Par 2	0.00126	7e-05	23	☐		
HYGOV- Par 3	0.00439	0.00031	20	☐		
HYGOV- Par 4	0.00796	0.00123	19	☐		
HYGOV- Par 5	0.02005	0.00101	16	☐		
HYGOV- Par 6	0.0	0.0		☐		
HYGOV- Par 7	0.0	0.0		☐		
HYGOV- Par 8	0.00872	0.00102	18	☐		
HYGOV- Par 9	0.0216	0.00277	15	☐		
HYGOV- Par 10	0.00075	0.00015	24	☐		
HYGOV- Par 11	0.00013	2e-05	26	☐		
SCRX- Par 0	0.10718	1.12362	8	☐		
SCRX- Par 1	0.00672	0.49471	9	☐		
SCRX- Par 2	0.11912	0.39971	10	☐		
SCRX- Par 3	0.01846	0.12846	13	☐		
SCRX- Par 4	0.0	0.0		☐		
SCRX- Par 5	0.4519	1.62349	5	☐		
SCRX- Par 6	0.0	0.0		☐		
SCRX- Par 7	0.0	0.0		☐		

Figure 6. Sensitivity Analysis Results

Note that the top five highest sensitivity parameters are color-coded in red. Parameter 3 (Inertia-H) from the GENSAL model was ranked 1 in the sensitivity analysis results. This parameter was selected for the optimization process.

Results from the optimization process for one iteration using the SPSA-PSO [1][2] algorithm are shown below.

Active Power (P)

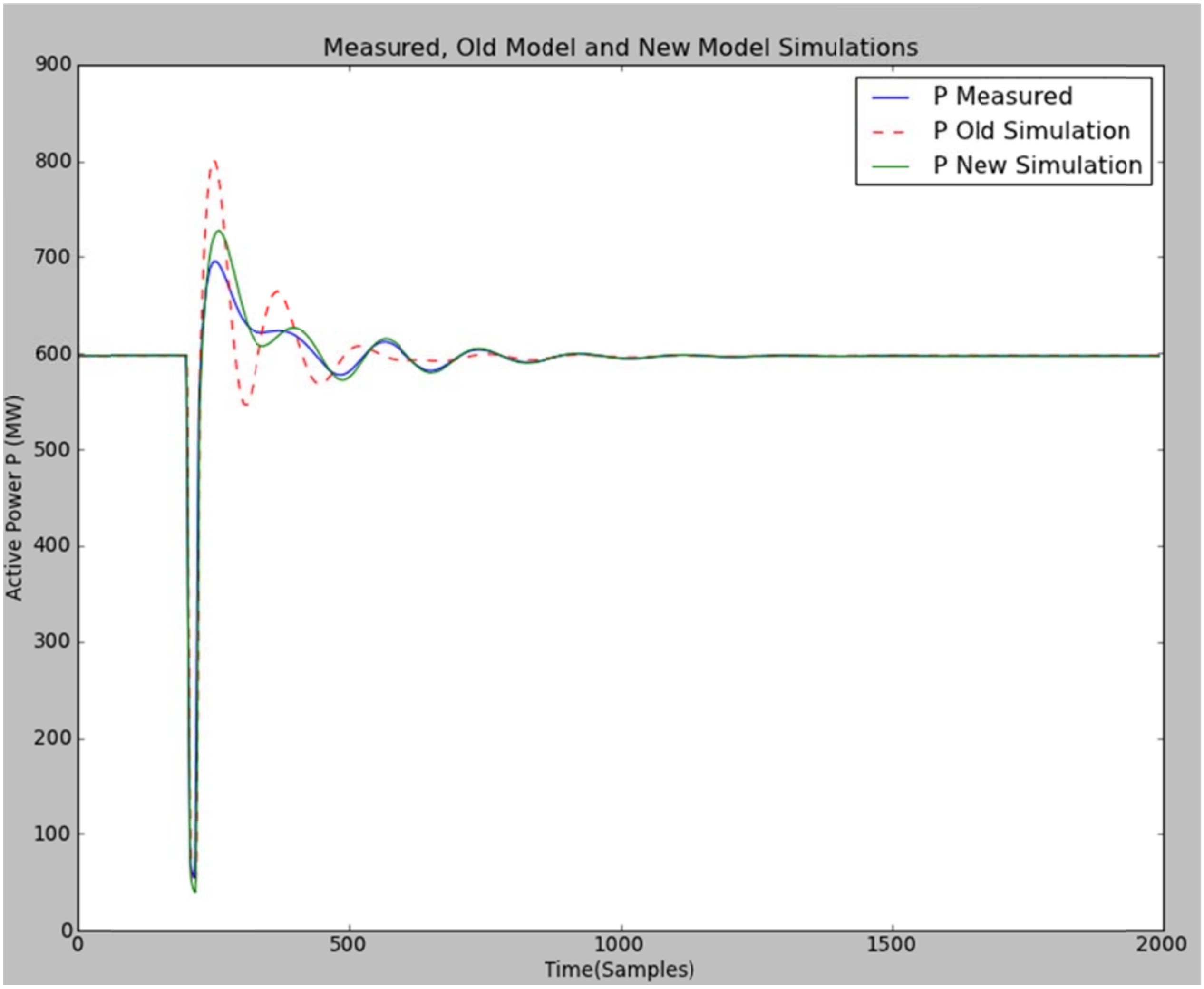


Figure 7. Active power plots after the optimization process

Reactive Power (Q)

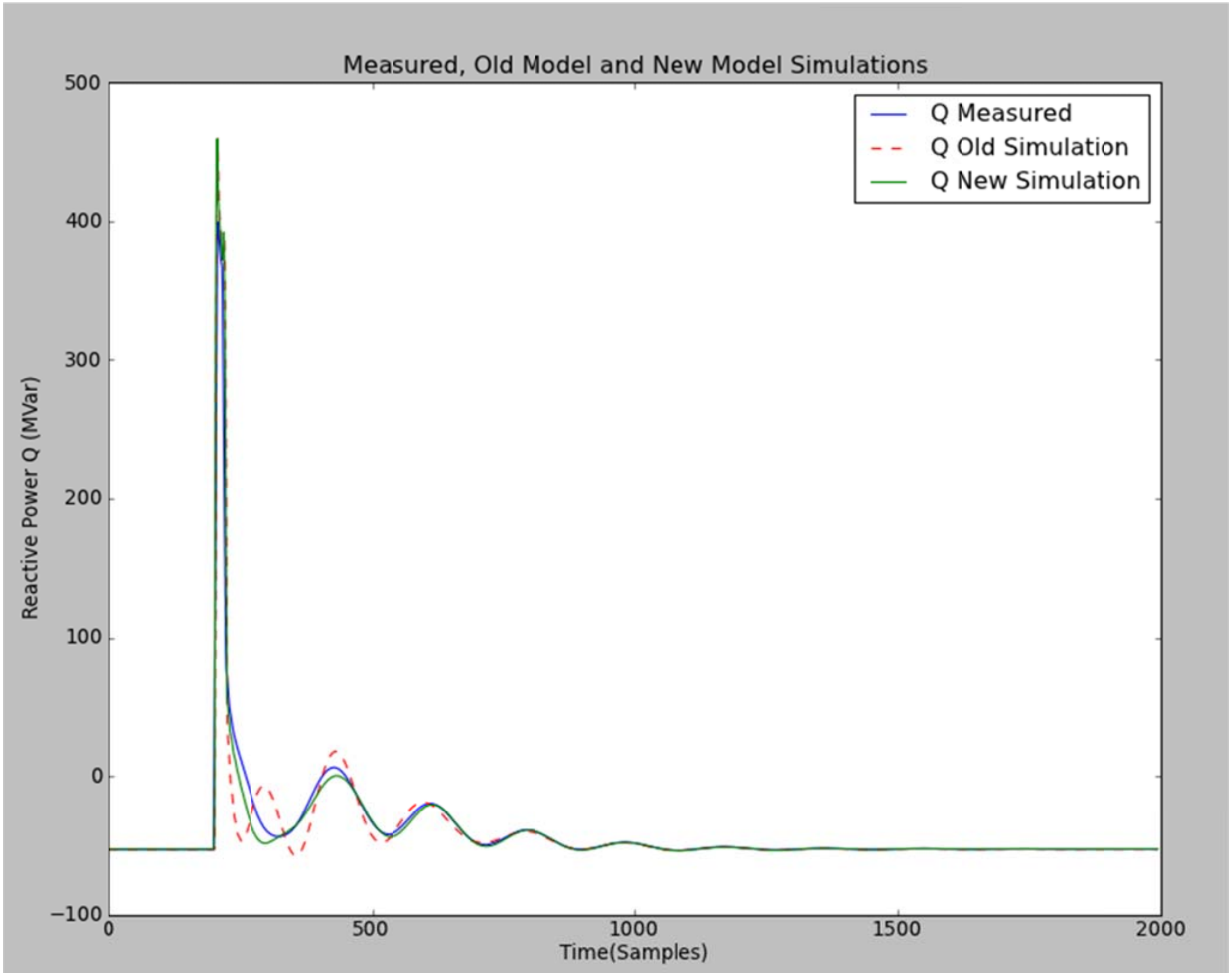


Figure 8. Reactive power plots after the optimization process

Parameter Validation Results

Model	Parameter	Old Value	New Value
Model-GENSAL	Par- 3	4.0	5.05573574144

Figure 9. Parameter validation results – new identified parameter values

It can be seen from the figures 7 and 8 that the P and Q response with the new identified parameter value (green line) is much closer to the measured input value (blue line) than the original model simulation (red line). Note that some error due to the use of a reduced system is inevitable. The newly identified parameter value for GENSAL parameter 3 is 5.056 as shown in figure 9 above. This value is very close to the actual value (5) of the parameter in the model.

Some information with regards to the tool run time is provided below:

For the input data corresponding to 10 second duration:

1. Validation Process took about 15 seconds.
2. Sensitivity Analysis took about 7 minutes.
3. Optimization process with one iteration took about 8 minutes.

It was observed that with simulation data as input, one or two iterations were sufficient to identify the parameter change and reduce the mismatch. However, the optimization process for two iterations and five iterations takes approximately 11 minutes and 23 minutes, respectively on the test machine.

7. Testing with Real Data

The GPV tool was recently tested with real data obtained from an electric utility. The following data was obtained for the testing purpose.

1. PMU recorded Voltage and Current Phasors at the output of a generator corresponding to an event – Excel file (.xlsx).
2. PSS\E Model data – Case file (.sav) and Dynamic file (.dyr).

Validation was performed on generator, exciter, governor and stabilizer models. The results are shown in figures 10 and 11 below.

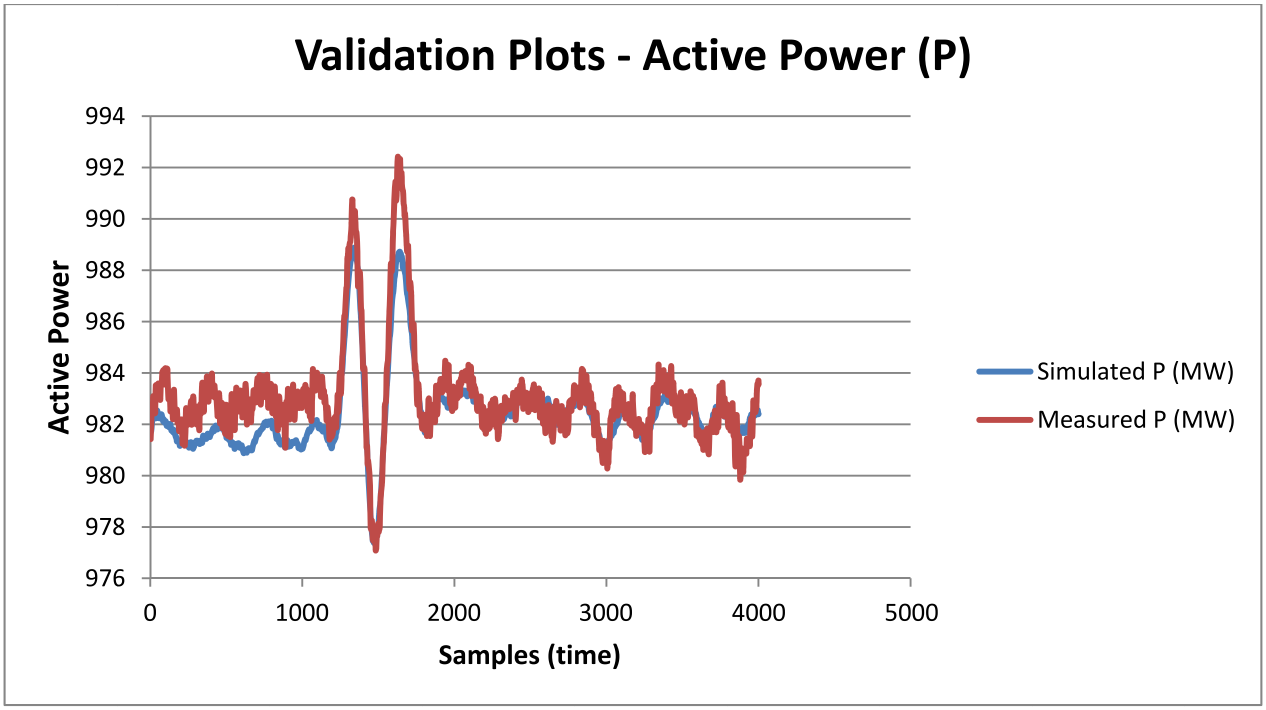


Figure 10. Validation plots for active power (P)

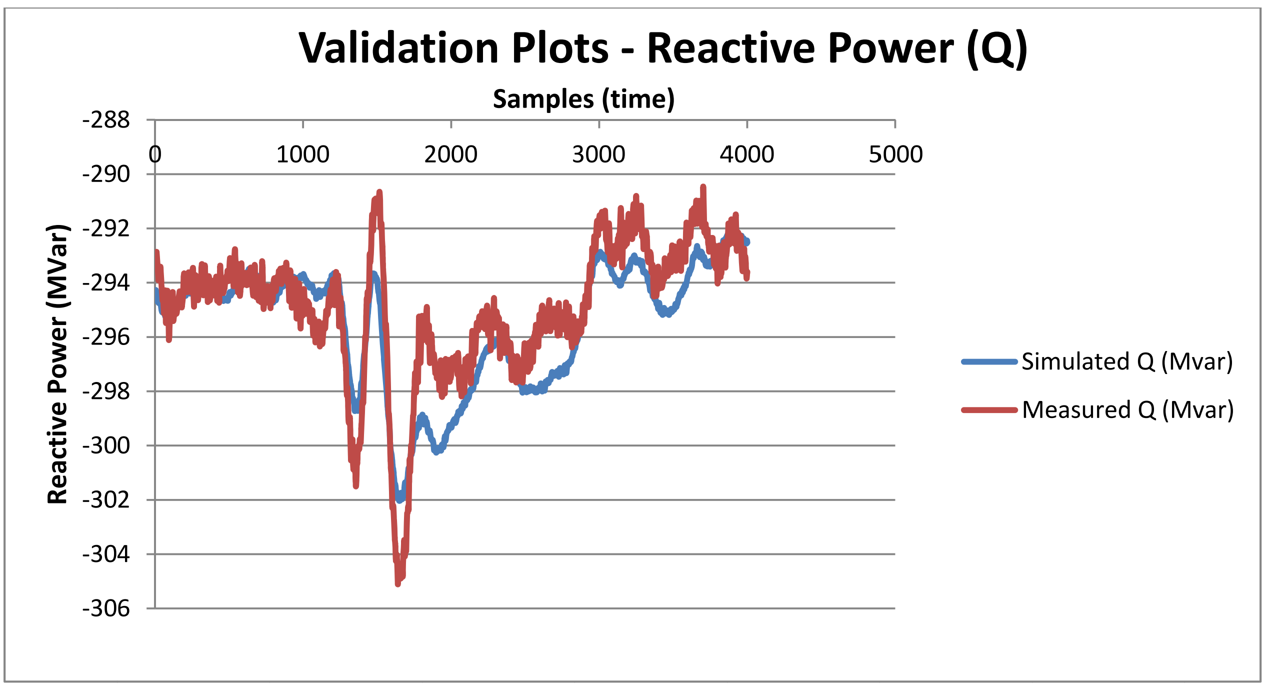


Figure 11. Validation plots for reactive power (Q)

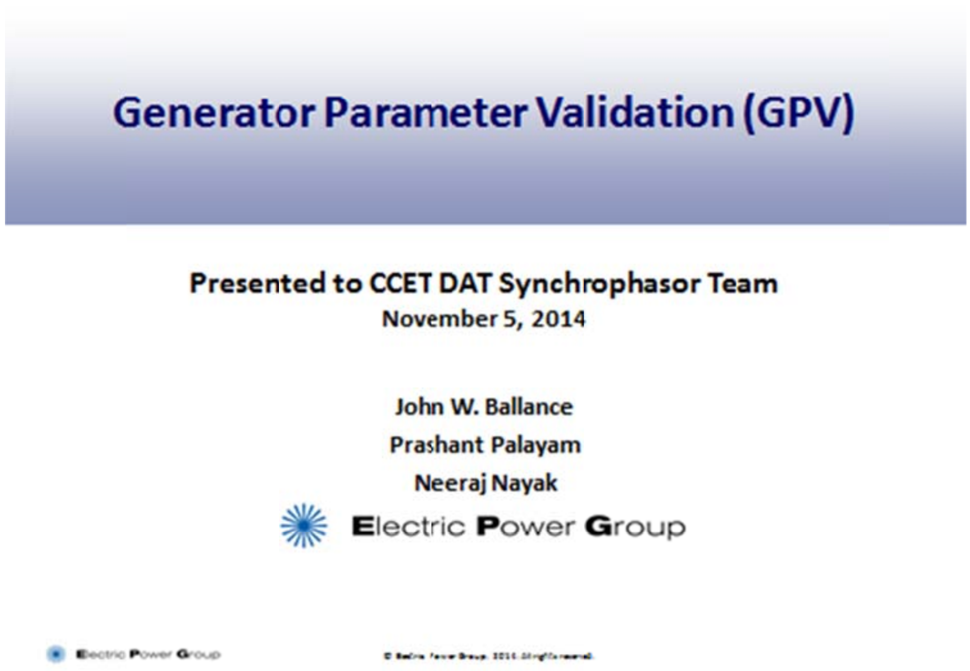
We can see from the plots above that the model simulation results reasonably match that of the measured data. It is important to remember that models are an approximation of the real system and some error due to the use of a reduced system is inevitable.

8. Conclusion

A tool was built for use by Electric Reliability Council of Texas (ERCOT) to perform the generator parameter validation process. The tool, Generator Parameter Validation, uses synchrophasor data from Phasor Measurement Units. The PMUs must be located at the output of the individual generator unit and measure the individual generator branch for validating the generator. The system reduction approach used for this methodology has been automated and is –built-in to the tool. The entire process is split into three steps in sequence - Validation, Sensitivity Analysis, and Optimization. Validation results show comparison plots between simulation and measured data. Sensitivity analysis shows sensitivity of the power flows to each parameter and identifies the key parameters. User interaction is enabled for key parameter selection and for fine-tuning parameter values by specifying a range for the parameters. The optimization process identifies new parameter values for which the model simulation results best match the measured data. The results from the optimization process produces plots comparing the measured, actual model and new model parameter simulation results. The entire validation process for a 10-second input data record takes approximately 20-minutes with one iteration of the optimization algorithm.

9. Appendix

<u>Generator Parameter Validation Presentation</u>



10. References

[1] Chin-Chu Tsai; Wei-Jen Lee; Nashawati, E.; Chin-Chung Wu; Hong-Wei Lan, "PMU based generator parameter identification to improve the system planning and operation.

[2] Chin-Chu Tsai, "PMU based parameter identification for the synchronous generator dynamic model", December 2011

[3] http://www.nerc.net/standardsreports/standardssummary.aspx