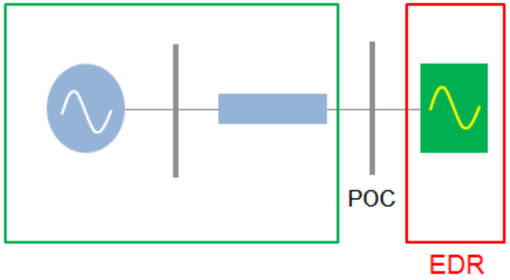
Integrating Synchrophasor Data with Simulations for Automated Model Calibration



Presented at 'Phasor Measurement Task Force' Meeting at ERCOT on August 06, 2014

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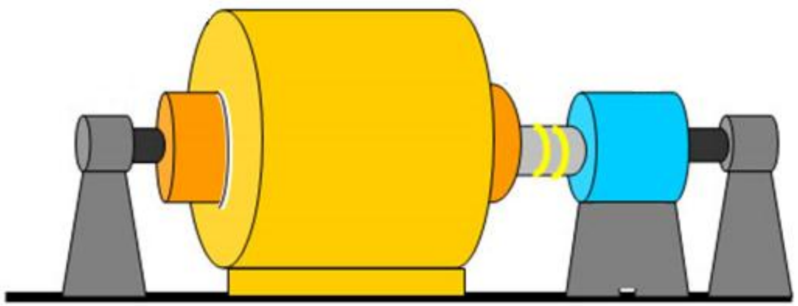
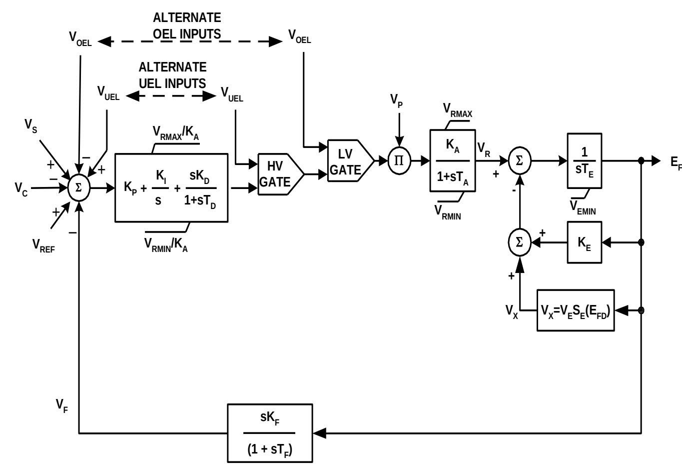
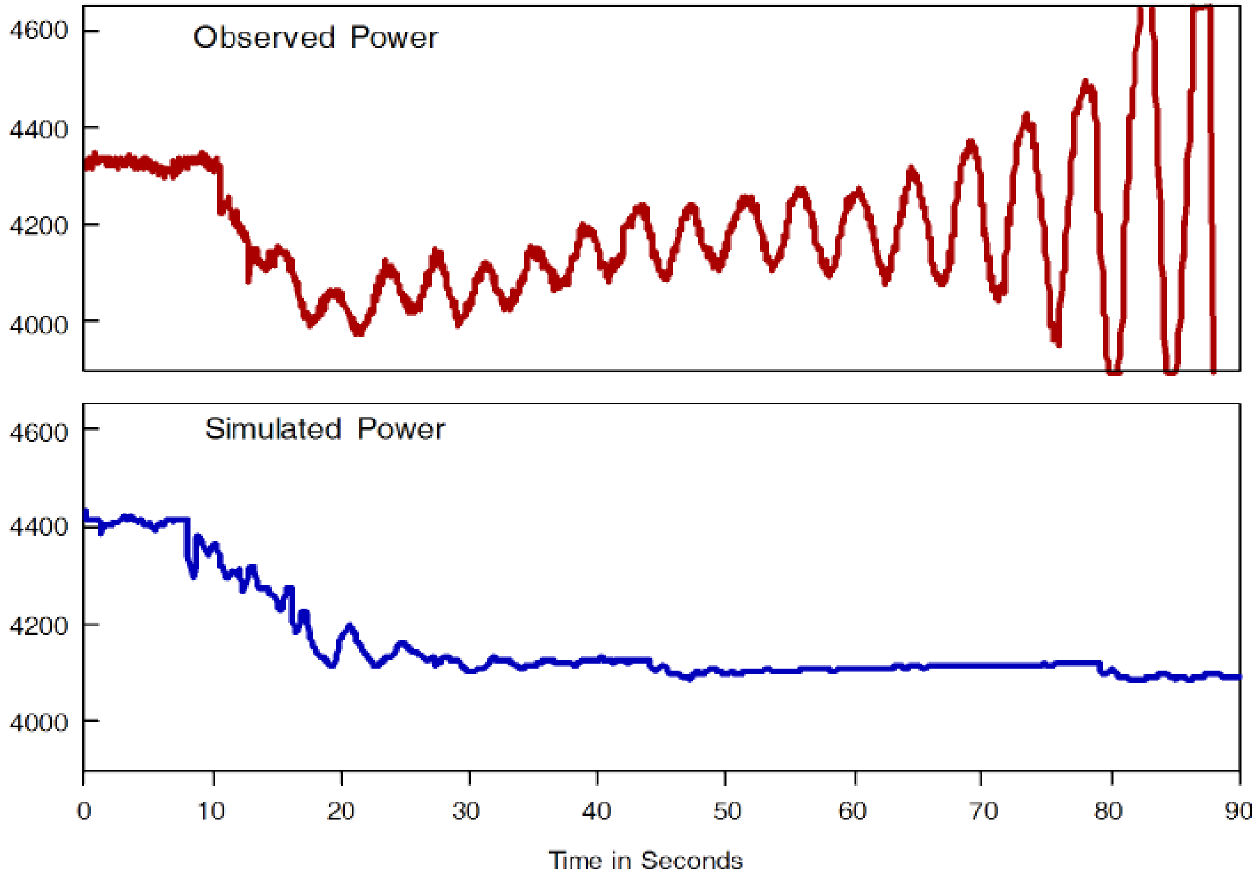
NERC Regulation (MOD 26/27) Generator/Exciter Modeling & Validation





Challenge: Build a good dynamic model for a Generator/Excitation System that matches the actual equipment in the field and validate it through offline/online testing

Motivation



WSCC August 10, 1996 disturbance

Agenda

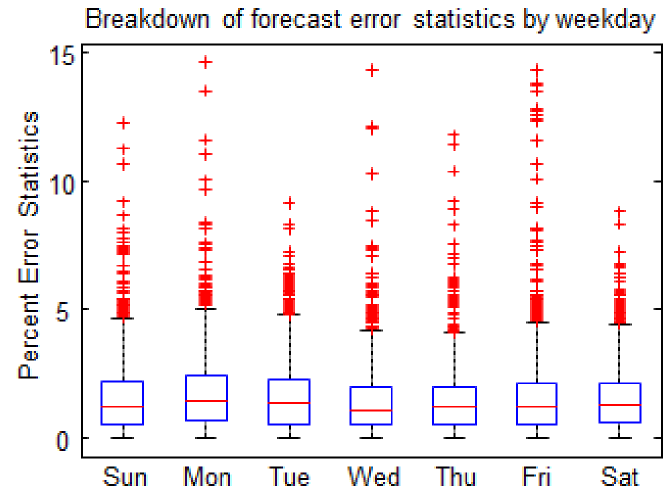
- Modeling & Simulation of Power Generation Equipment
- Benefits of Synchrophasor Measurements in Support of Model Validation
- Integrating a Measured Response with a Simulation
  - *ERCOT Case Study*: Type IV wind turbine model validation using PMU data captured for a voltage oscillation event
- Automated Parameter Estimation

Core MathWorks Products

MATLAB®

The Language of Technical Computing

In the Utilities and Energy sector, MATLAB is used primarily for data analysis, optimization, algorithm development, and application deployment.



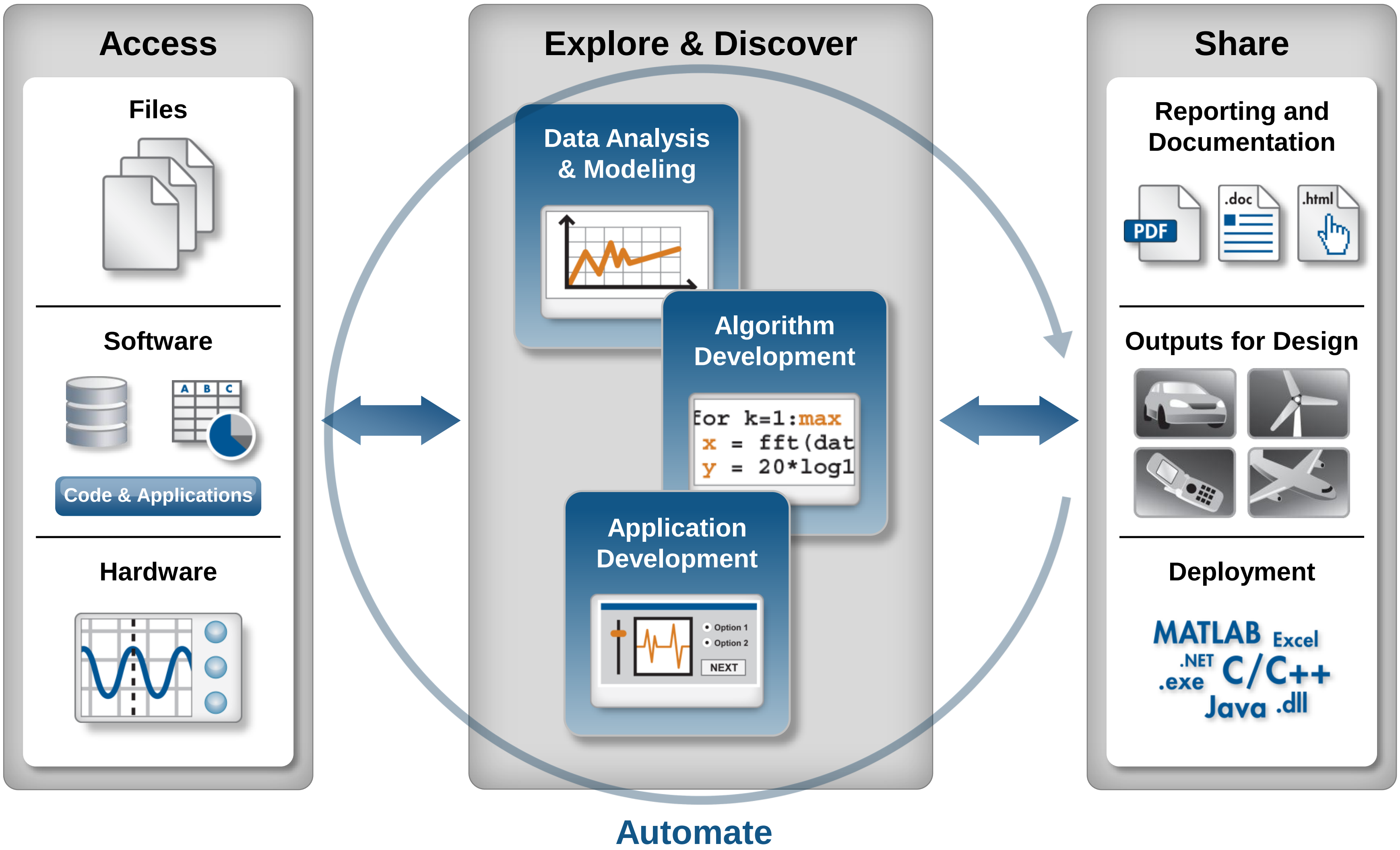

```
% Create training set
trainInd = data.NumDate < datenum('2012-01-01');
trainX = X(trainInd,:);
trainY = data.SYSLoad(trainInd);
```

GAS NATURAL FENOSA

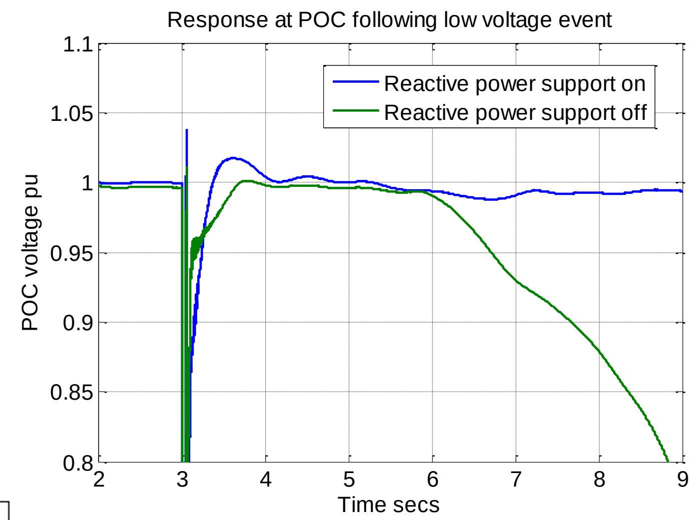
– Predict energy supply and demand

"Because we need to rapidly respond to shifting production constraints and changing demands, we cannot depend on closed or proprietary solutions. With MathWorks tools we get more accurate results — and we have the flexibility to develop, update, and optimize our models in response to changing needs"

MATLAB: Technical Computing Workflow



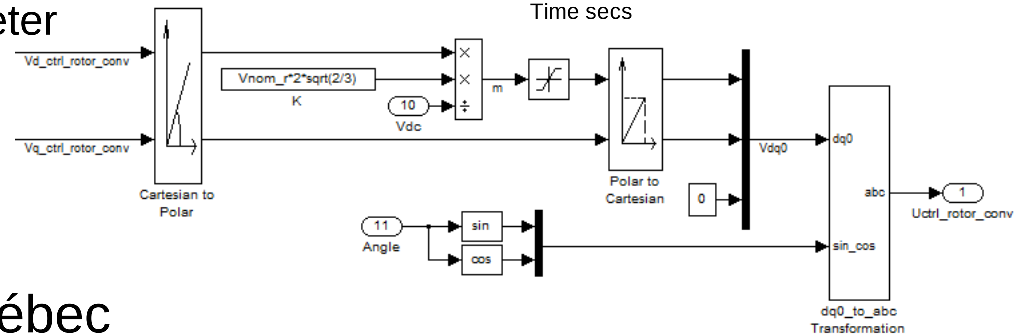
Core MathWorks Products



SIMULINK®

Simulation and Model-Based Design

In the Utilities and Energy sector, Simulink is used primarily for grid integration studies, grid equipment design, and equipment parameter estimation and optimization.



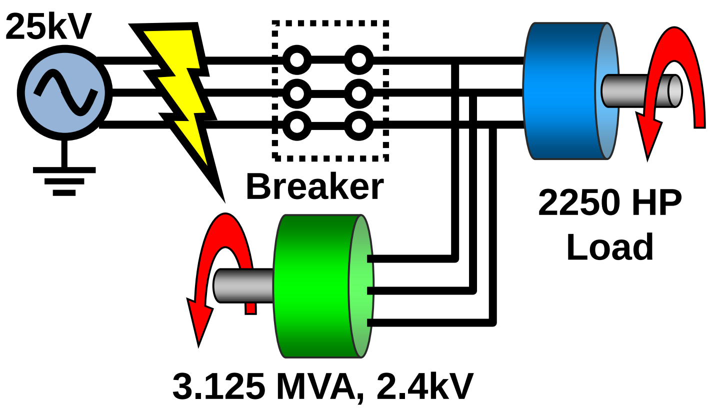
Hydro-Québec

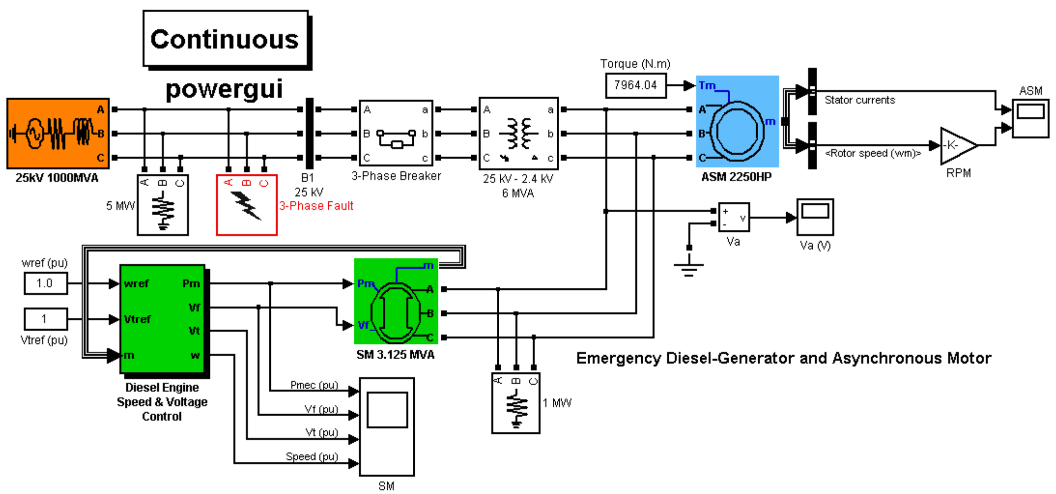
– Model Wind Power Plant Performance

“Without accurate models, we risk installing millions of dollars’ worth of unnecessary equipment or not having the equipment we need to meet our reliability and production goals.”

Simulink & SimPowerSystems

- Block-diagram environment
- Environment for modeling electrical power systems
- Electrical system topology represented by schematic circuit



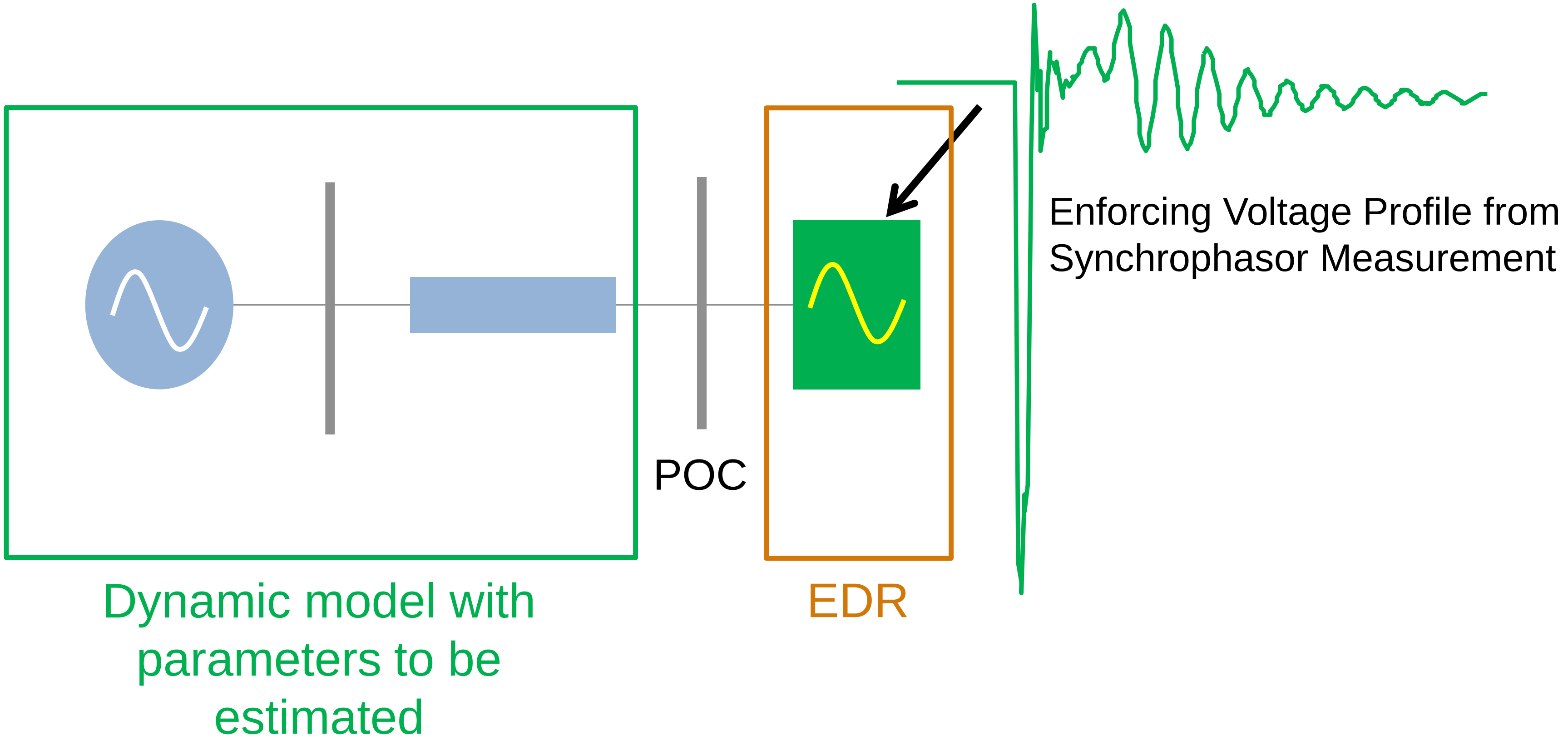


Benefits of Synchrophasor Measurements in Support of Model Verification and Validation

- Synchrophasor measurements have several benefits for enhancing a model verification and validation effort
  - Provide additional high accuracy measurements for comparison against simulation
  - Reduce model complexity, and hence simulation time, by allowing model components to be replaced with a data driven component.
  - Enable model verification of on-line phenomena that may not be captured with off-line field testing

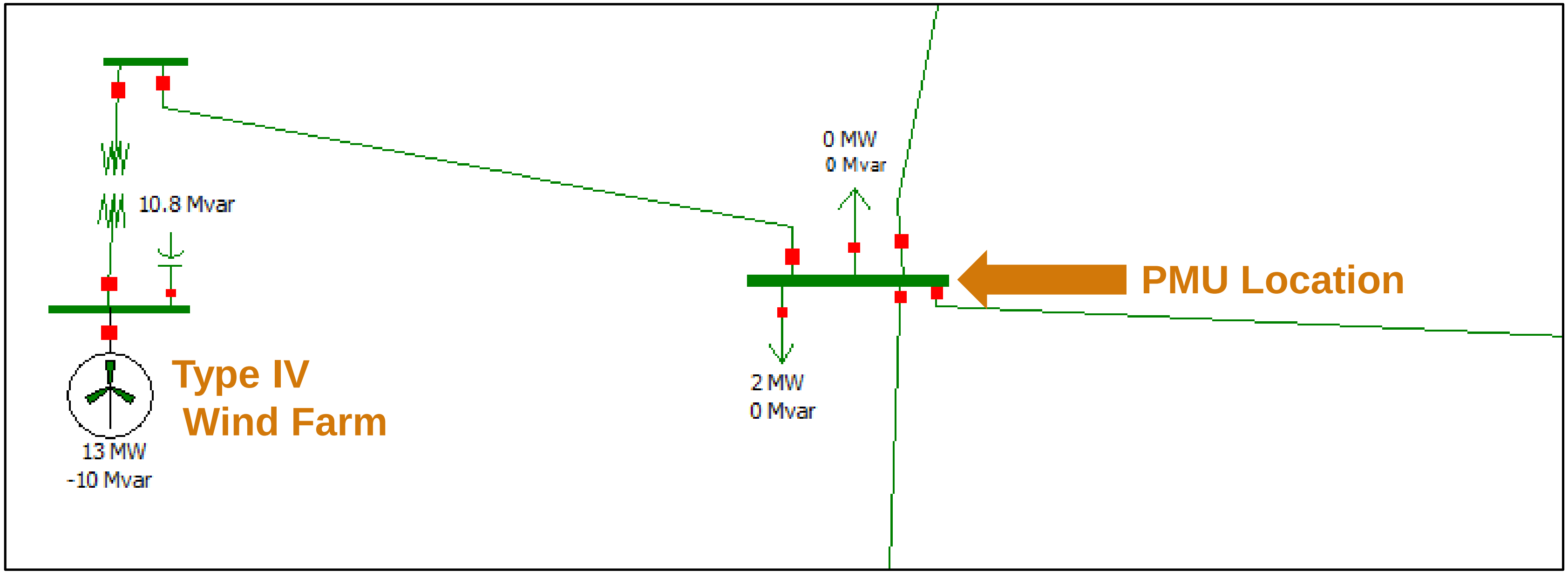
Integrating Measured Response with a Simulation

- A synchrophasor measurement may be brought into a simulation model as an ‘enforced dynamic response’ (EDR)



ERCOT Case Study
Validating Wind Turbine Parameters

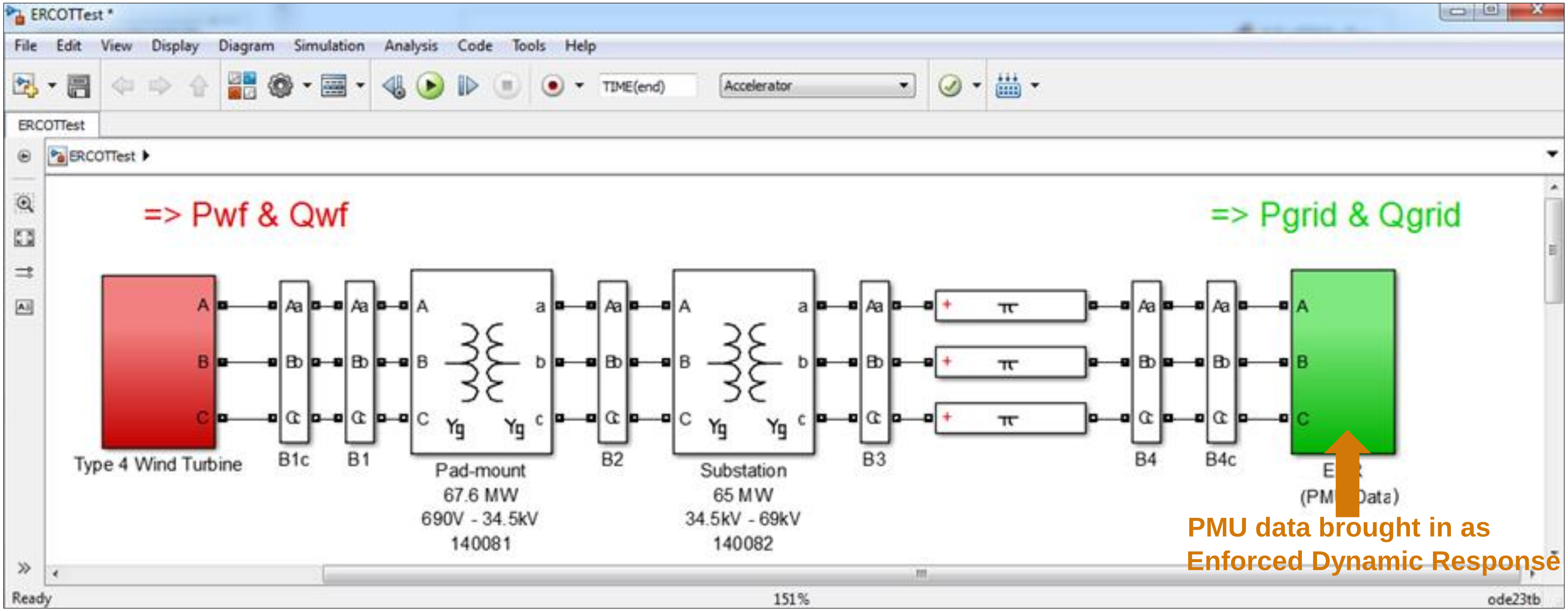
- Case study work done with ERCOT operations planning team lead by Bill Blevins
- A Type IV wind turbine farm was analyzed using PMU data collected at the grid point of connection
- PMU captured a voltage oscillation event when one of the two 69 KV lines connecting wind farm to rest of the grid was taken for an outage



ERCOT PMU & Associated System

Validating Wind Turbine Parameters

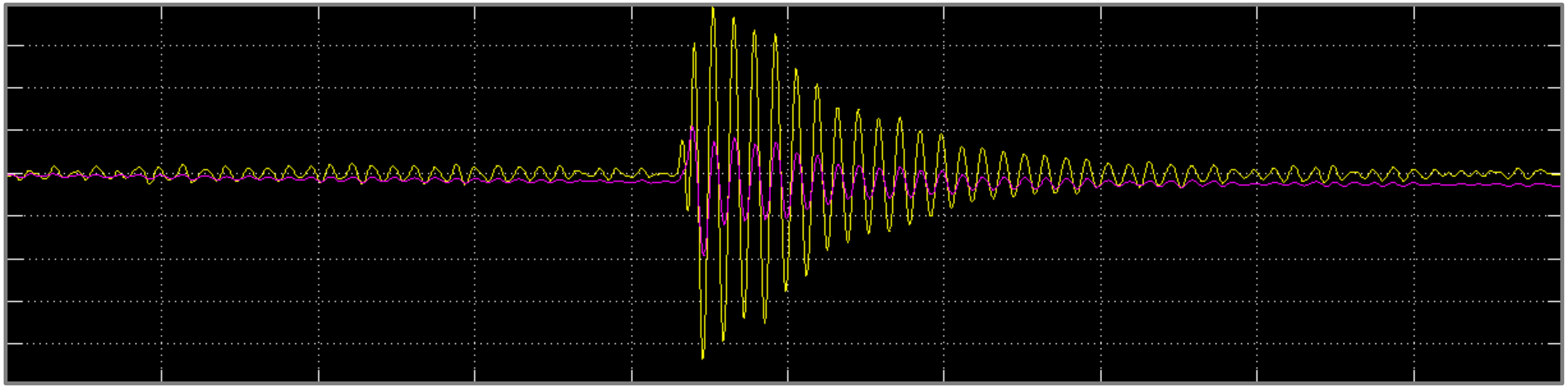
- Following is a model of the ERCOT system under consideration built with blocks from Simulink and SimPowerSystems product library
- SimPowerSystems library offers a wide collection of power systems components that can be used to build your system model using a simple drag-and-drop approach



ERCOT PMU & Associated System

Validating Wind Turbine Parameters

- Voltage oscillation captured by the PMU at the grid point of connection was used as an ‘Enforced Dynamic Response (EDR)’ to drive the Simulink and SimPowerSystems model
- The simulation outputs of active and reactive power (with initial wind turbine parameter settings) were then compared with those calculated from the PMU voltage and current data
- The following plot of ‘Reactive Power’ for simulation versus measured data shows a clear mismatch and a need for calibration



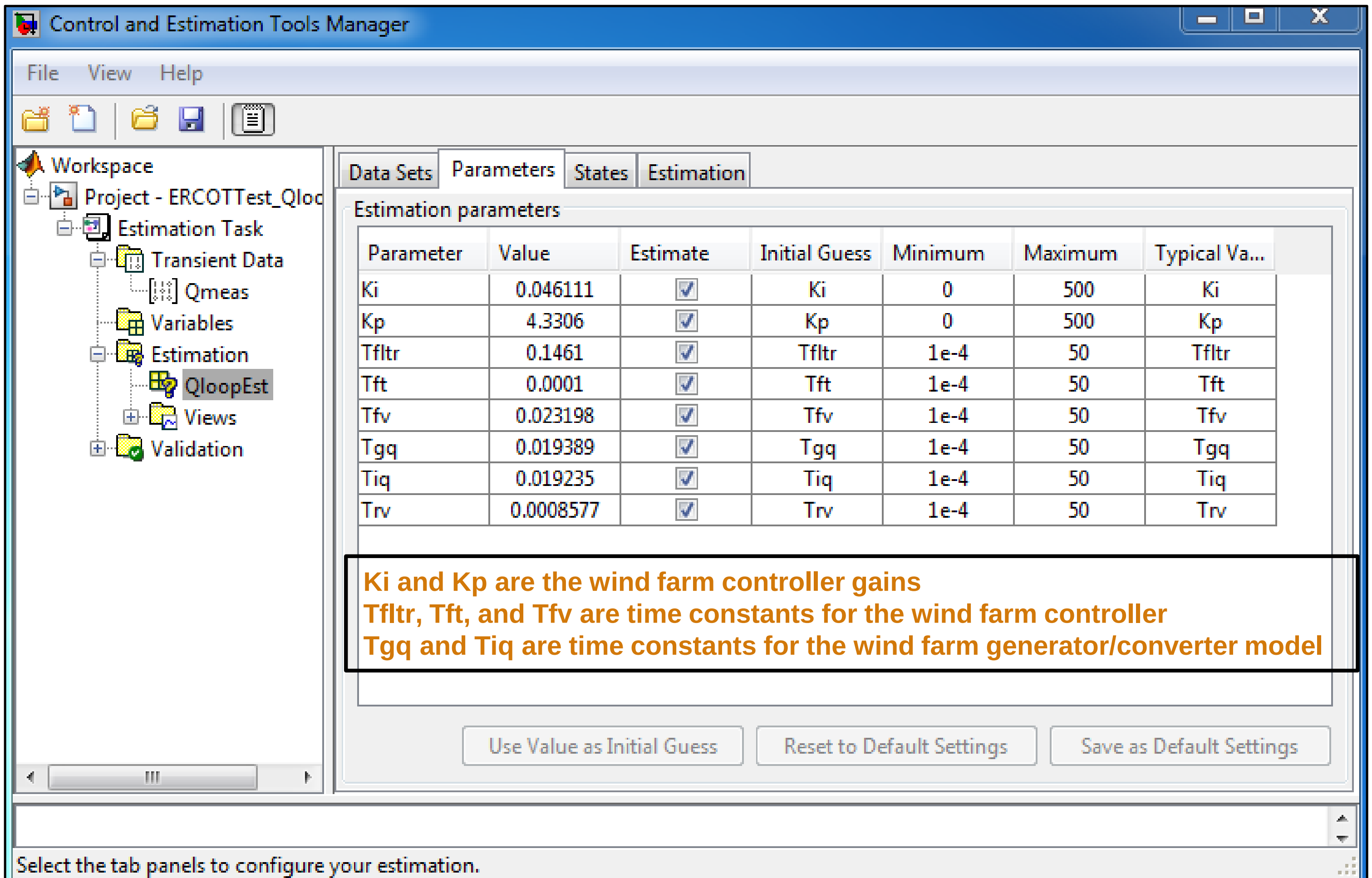
Parameter Estimation/Model Calibration Workflow

- **Step 1:** Load field test data into MATLAB
- **Step 2:** Perform post processing on the data if needed
- **Step 3**: Initialize parameters and set upper and lower bounds
- **Step 4**: Launch parameter estimation GUI and start the automated tuning process
- **Step 5:** Export estimated parameters from MATLAB to your choice of power system simulation software

Parameter Estimation GUI

Reactive Power Loop Tuning for Generic Model of Type IV Wind Turbine

- Following GUI shows how parameters from the wind farm model can be selected (using the check-box) for inclusion in the estimation process
- Each parameter can be assigned a minimum and maximum bound as well as an initial guess



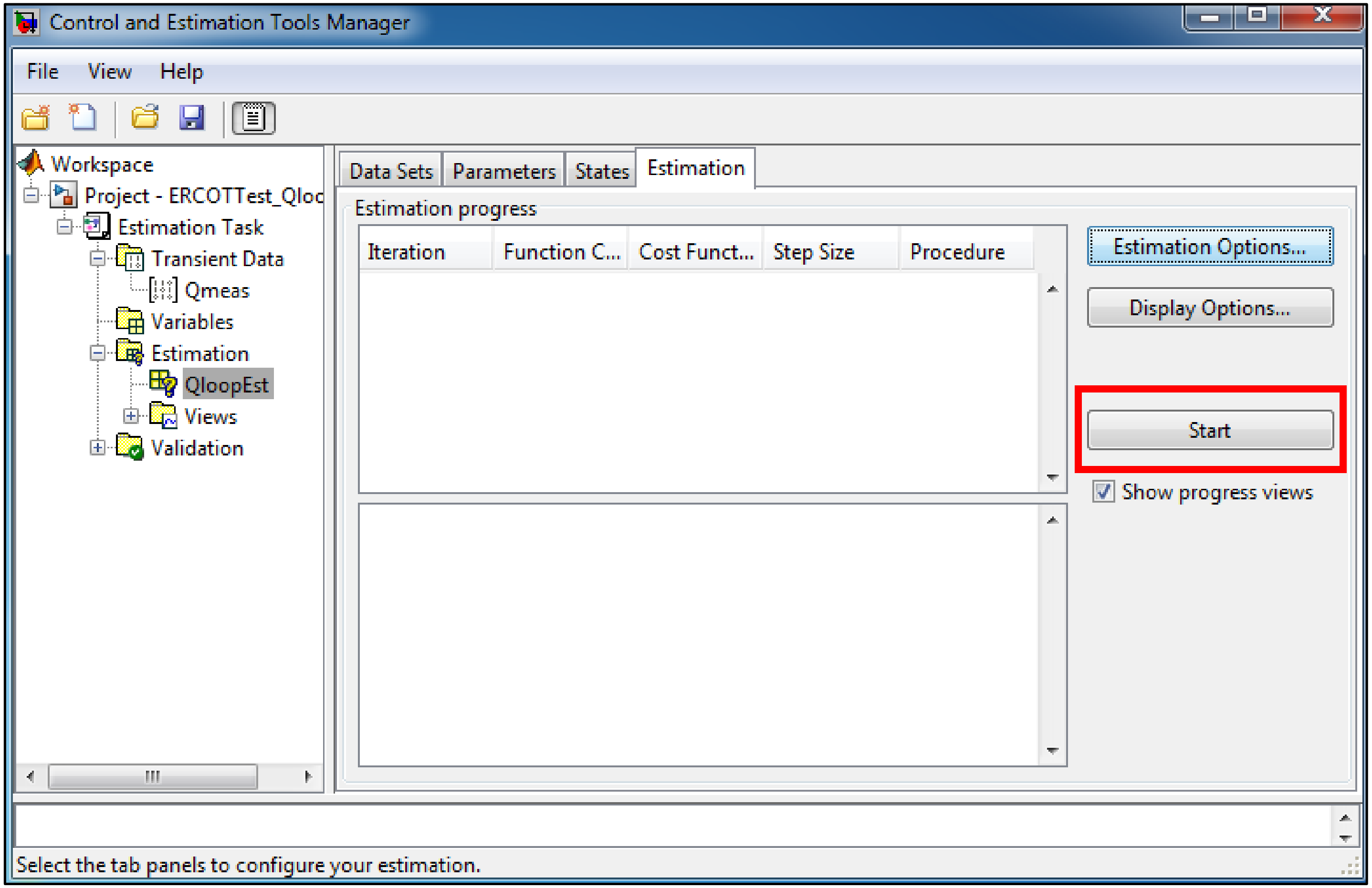
Parameter	Value	Estimate	Initial Guess	Minimum	Maximum	Typical Va...
Ki	0.046111	☑	Ki	0	500	Ki
Kp	4.3306	☑	Kp	0	500	Kp
Tfltr	0.1461	☑	Tfltr	1e-4	50	Tfltr
Tft	0.0001	☑	Tft	1e-4	50	Tft
Tfv	0.023198	☑	Tfv	1e-4	50	Tfv
Tgq	0.019389	☑	Tgq	1e-4	50	Tgq
Tiq	0.019235	☑	Tiq	1e-4	50	Tiq
Trv	0.0008577	☑	Trv	1e-4	50	Trv

Ki and Kp are the wind farm controller gains
Tfltr, Tft, and Tfv are time constants for the wind farm controller
Tgq and Tiq are time constants for the wind farm generator/converter model

Parameter Estimation GUI

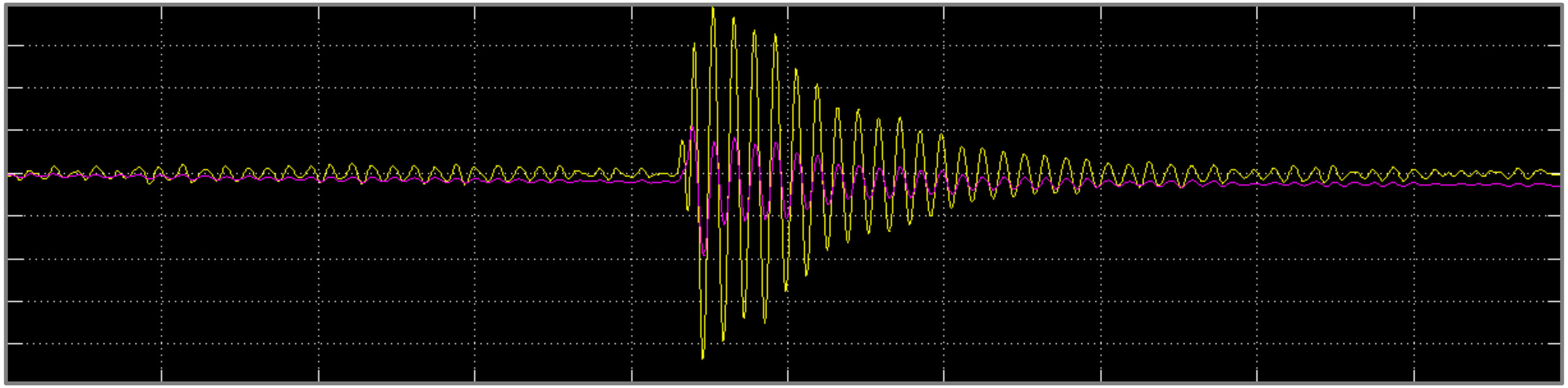
Reactive Power Loop Tuning for Generic Model of Type IV Wind Turbine

- Automated Parameter Estimation process begins with a simple click of the 'Start' button
- Various optimization algorithms can be selected to get a robust set of parameters that give a good correlation between measured PMU data and the simulation response.

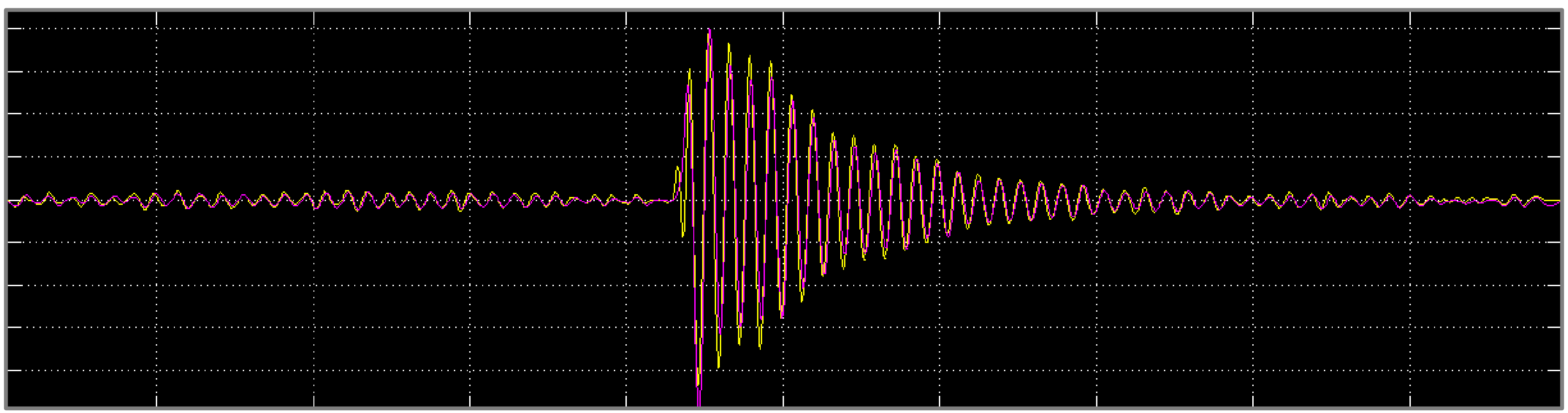


Measured PMU versus Simulated Response

Reactive Power Output of the Wind Farm



Before MATLAB Estimation



After MATLAB Estimation

Model Validation Challenges and Solutions offered by MATLAB & Simulink Approach

Challenges	Solutions
Parameter Estimation	**Automated Tuning** ▪ Powerful Optimization Algorithms ▪ High Precision ▪ Quick Convergence ▪ Parallel Computing
Inability to Customize	**Flexible Modeling** ▪ Block Diagram Environment ▪ Built-in Dynamic Model Library (Generator, Exciter, Governor, AC/DC Motors, PSS)
Lack of Transparency	**White-Box Modeling** ▪ Viewable-Source Functions ▪ Detailed Optimization Results ▪ Interactive Debugging

Additional Considerations

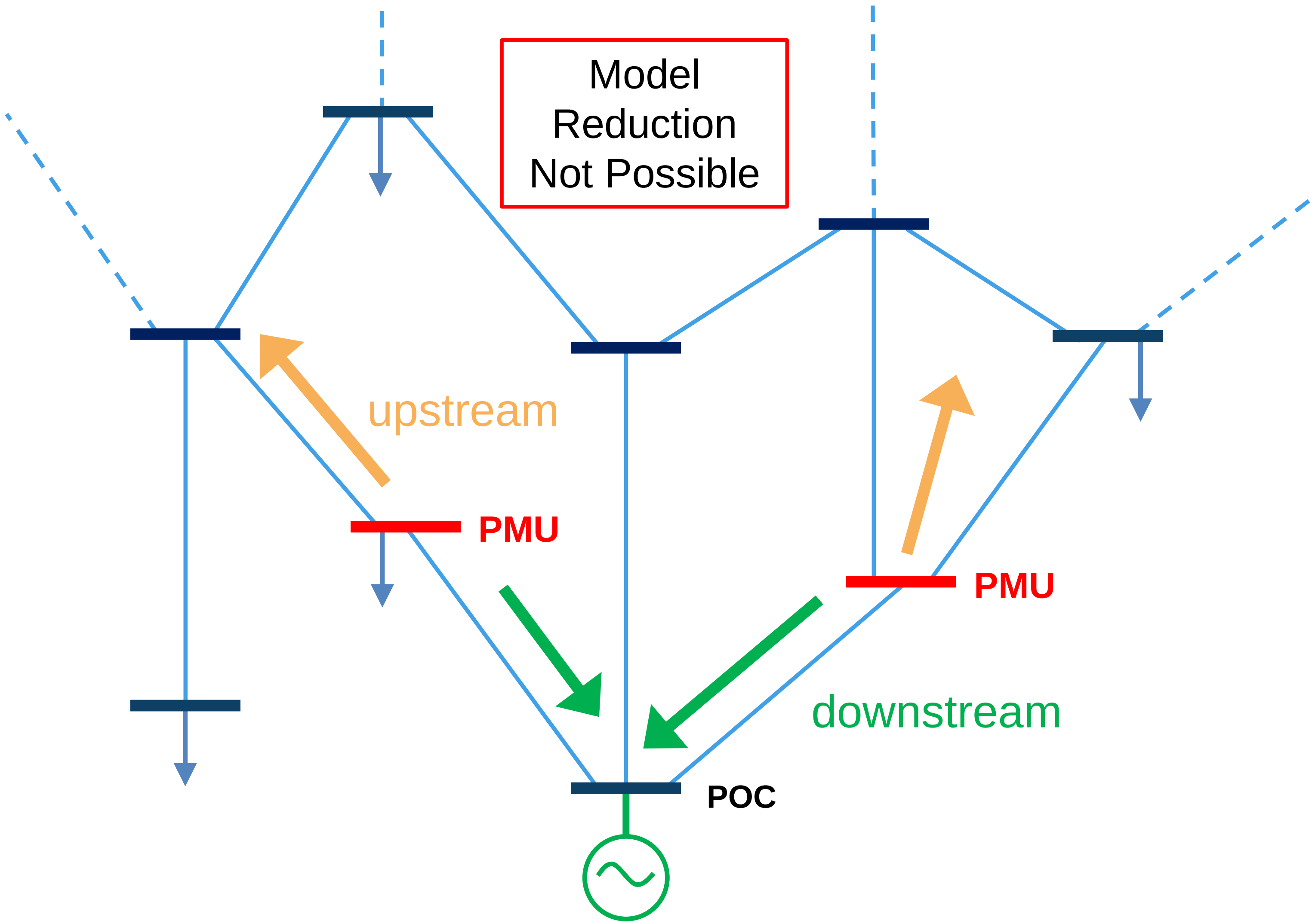
Reducing Model Complexity

- Given that an automated parameter estimation task must run a simulation multiple times *–hundreds or thousands of times depending on the number of parameters to be estimated* - the less complex the dynamic model, the faster the execution of the task.

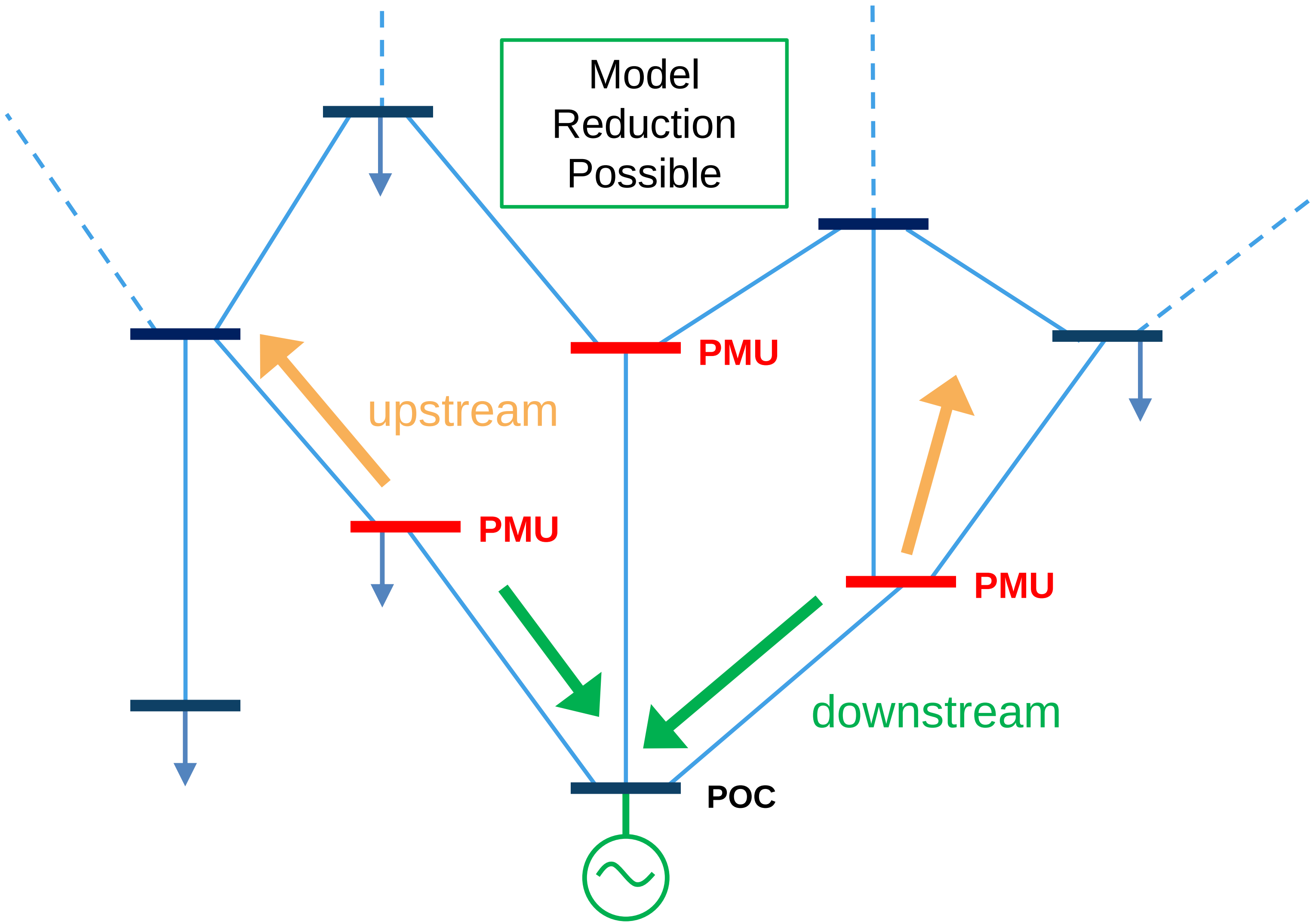
- Therefore, the ‘closer’ the EDR is to the equipment whose parameters are to be estimated, the better.

- If the equipment point-of-connection (POC) is not a PMU location, then model complexity can be reduced further, prior to a parameter estimation task, by computing the PQV dynamic profile at the POC.

Reducing Model Complexity

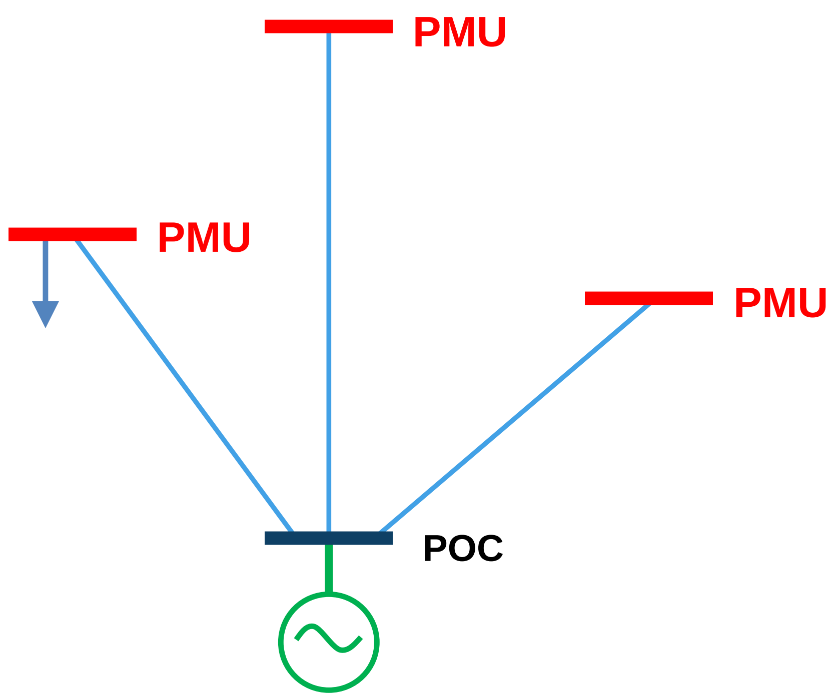


Reducing Model Complexity



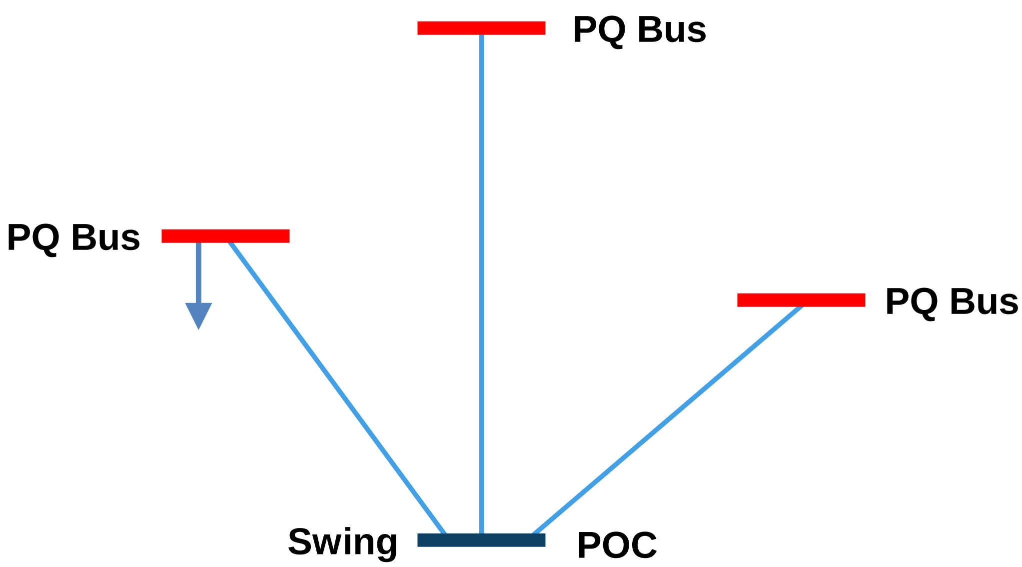
Reducing Model Complexity

Simplified
Model



Computing PQV Profile at the Point of Connection

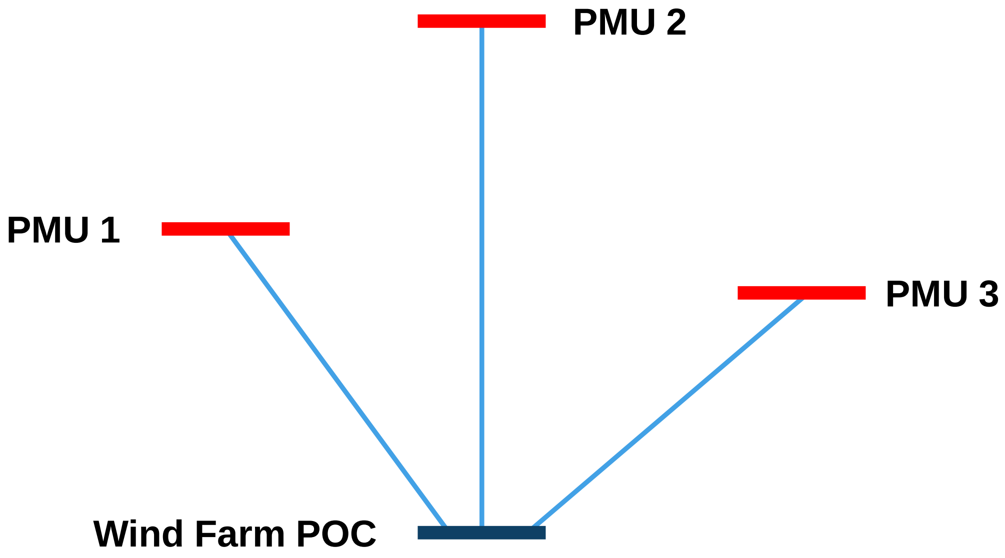
- The PMU locations are set as PQ buses
- PQ data for the PQ buses is calculated from PMU V and I data
- The point of connection is set as the swing bus
- A load flow is performed at each time-stamp during the transient period – this must be automated, and execution time is reduced by using multiple cores



Example: PQV calculation

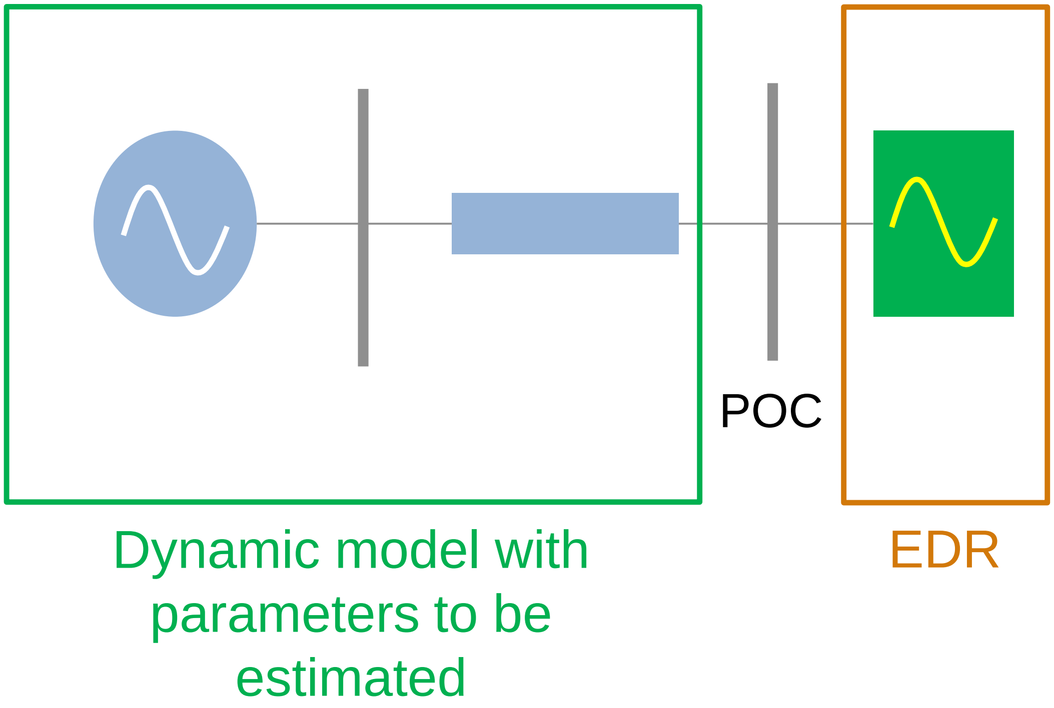
- To demonstrate this workflow, a detailed EMT model of a 29-bus network was simulated and phasor measurements were made downstream from a wind farm connection.

- Working with simulated results provides flexibility to test the workflow and allows direct comparison between ‘computed’ PQV conditions and ‘measured’ PQV.



Automated Parameter Estimation

- Once the PQV conditions at the POC have been determined, then an automated parameter estimation task can be executed as demonstrated previously



Summary

- Synchrophasor/PMU locations which allow model reduction and/or are at the generator terminals are of the highest value to model verification tasks
- An EDR that is a direct Synchrophasor measurement is ideal, although EDRs for other locations may be constructed through application of load flow methods at each sample time
- Automated parameter estimation technique in MATLAB significantly reduces the time and cost associated with the model validation tasks
- Estimated parameters can be then exported to your choice of power system simulation software to continue with further analysis
- For the ERCOT case under consideration, automated estimation was completed in less than 3 minutes using a dual core laptop
- We plan to extend the model validation work done with ERCOT to an addition use case of a thermal power generation station as a next step

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  - Modeling & Simulation of PV Solar Power Inverters
  - Modeling Wind Power Grid Integration

Q&A