Real-time Dynamic Model Reduction and Calibration for Electric Power Systems

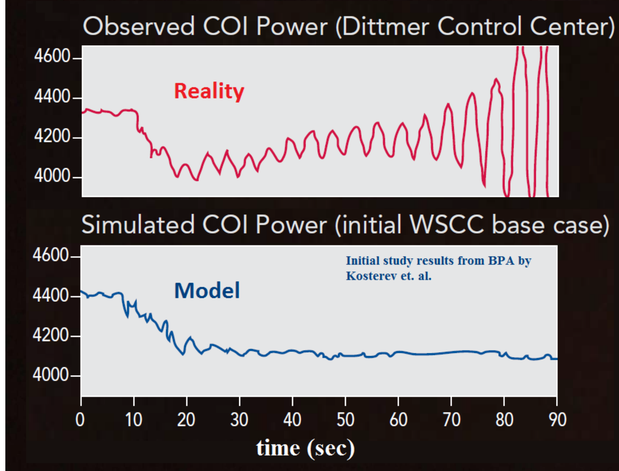
Shuai Lu, Ning Zhou, Guang Lin, Marcelo Elizondo, Shaobu Wang, Ruchi Singh, Da Meng

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Background:

- ❑ **Power system models are used to guide operations in real time.**
- ❑ **Accuracy of the models is critical to system reliability and efficiency.**
- ❑ **Challenges:**
  - ✓ High complexity
  - ✓ High uncertainty



An Example:

✓Western Interconnection of North America experienced an unstable oscillation which led to large scale blackout on Aug 10th, 1996.

✓7.5 million customers lost power.

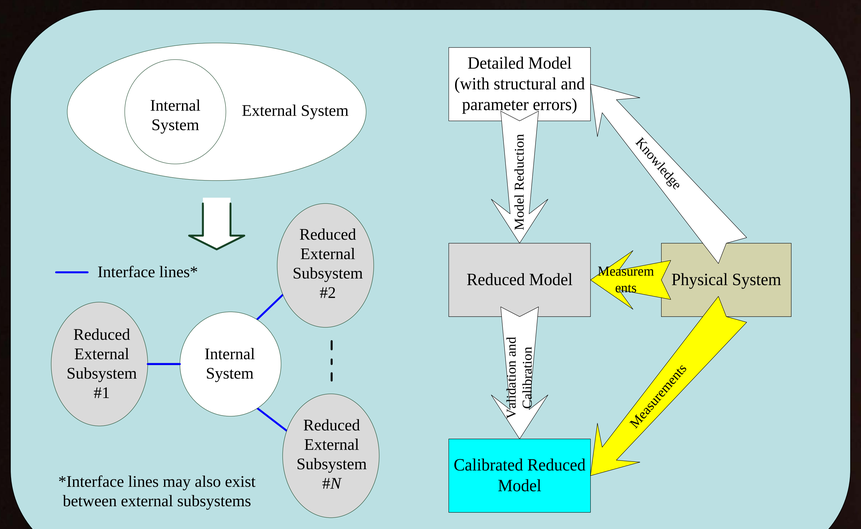
✓Initial simulations based on the best available model showed that the power system 'should be' stable.

✓The inconsistency between model responses and the actual measurements from system is an indication of model insufficiency.

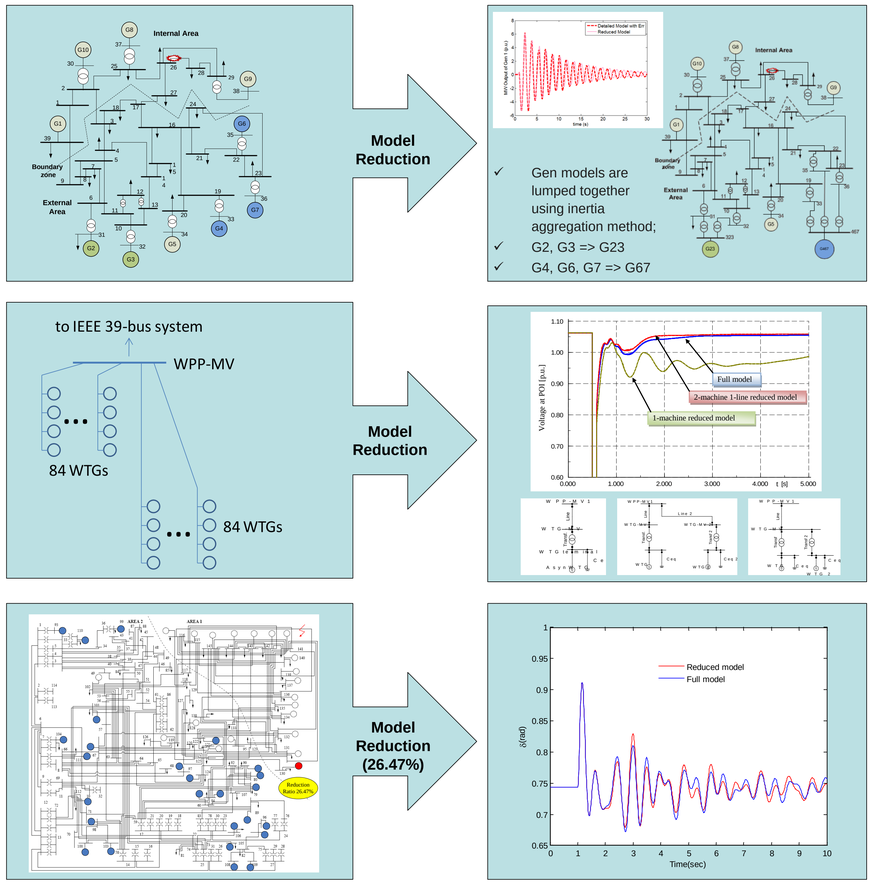
Objectives and Approaches:

Build an accurate dynamic model in real time for power system operations through:

- ❑ **Model Reduction**
- ❑ **Model Calibration**
- ❑ **Uncertainty Quantification**

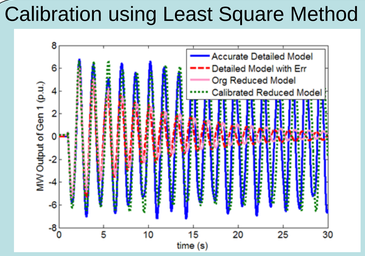


Model Reduction



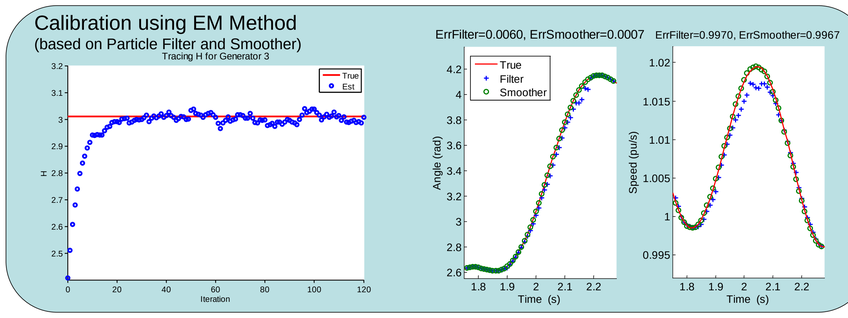
Model Calibration

Calibration using Least Square Method

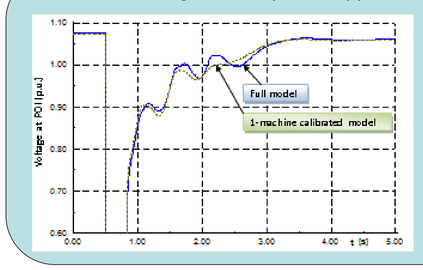


	K_D (with added Err)	K_D (after Reduction)	K_D (after calibration)
G1	20	20	0.097
G2	20	40	0.152
G3	20		
G4	20	60	0.517
G6	20		
G7	20		
G5	20	20	0.750
G8	20	20	-0.070
G9	20	20	0.348
G10	20	20	0.841

Calibration using EM Method
(based on Particle Filter and Smoother)



Calibration using Least Squares Approach



Parameter name	Calculated parameters	Calibrated parameters, Case 1	Calibrated parameters, Case 2
X_{line} [Ω]	0.05311	0.0532 (0.2%)	--
R_s [p.u.]	0.0122	0.0116 (-4.9%)	--
X_s [p.u.]	0.2002	0.3007 (50.2%)	0.3321 (65.9%)
X_m [p.u.]	6.8825	6.3425 (-7.8%)	--
R_r [p.u.]	0.013	0.0172 (32.3%)	0.0175 (34.6%)
X_r [p.u.]	0.1256	0.1577 (25.6%)	--
J_{turb} [kg m²]	4	3.7564 (-6.1%)	3.6211 (-9.5%)
K_{shaft} [Nm/rad]	100000000	102087752 (2.1%)	--

Accomplishments

Model Reduction:

- ❑ **Implemented the slow coherency method, and inertia aggregation method for reducing classical generator models.**
- ❑ **Implemented wind farm model reduction. Explored reduced model structure.**
- ❑ **Implemented various reduced load models. Modeled detailed feeder load model to compare with reduced models.**

Model Calibration:

- ❑ **Implemented and tested a Least Square method for calibrating reduced classical generator models and reduced load models**
- ❑ **Implemented and tested an Expectation Maximization approach for calibrating classical generator models**
- ❑ **Implemented particle filter and smoothers**
- ❑ **Calibrated a reduced wind farm model in DIgSILENT (least square method).**

Uncertainty Quantification

- ❑ **Apply collocation method for quantifying uncertainty of dynamic simulations of full WECC model**

Publication:

- ❑ **4 conference papers published**
- ❑ **1 journal paper submitted**

Future Work

Model Reduction:

- ❑ **Sensitivity based model reduction**
- ❑ **Wind farm reduction considering wake effect**

Model Calibration:

- ❑ **Improved the performance of the particle filter/smoothers based approach**
- ❑ **Wind farm model calibration with uncertainty quantification**
- ❑ **Load model calibration (composition of load and values of dynamic parameters) against detailed distribution feeder load model**

Uncertainty Quantification

- ❑ **Apply collocation method for quantifying uncertainty of dynamic simulations**
- ❑ **Apply uncertainty quantification to wind farm model**

For more information about the science you see here, please contact:

Shuai Lu

Pacific Northwest National Laboratory

P.O. Box 999, MSIN K1-85 , Richland, WA 99354 USA

509-375-2235, shuai.lu@pnnl.gov

Supported by DOE ASCR program in FY2010 and 2011