Development of Dynamic Models & Tools for Interconnection-wide Simulations

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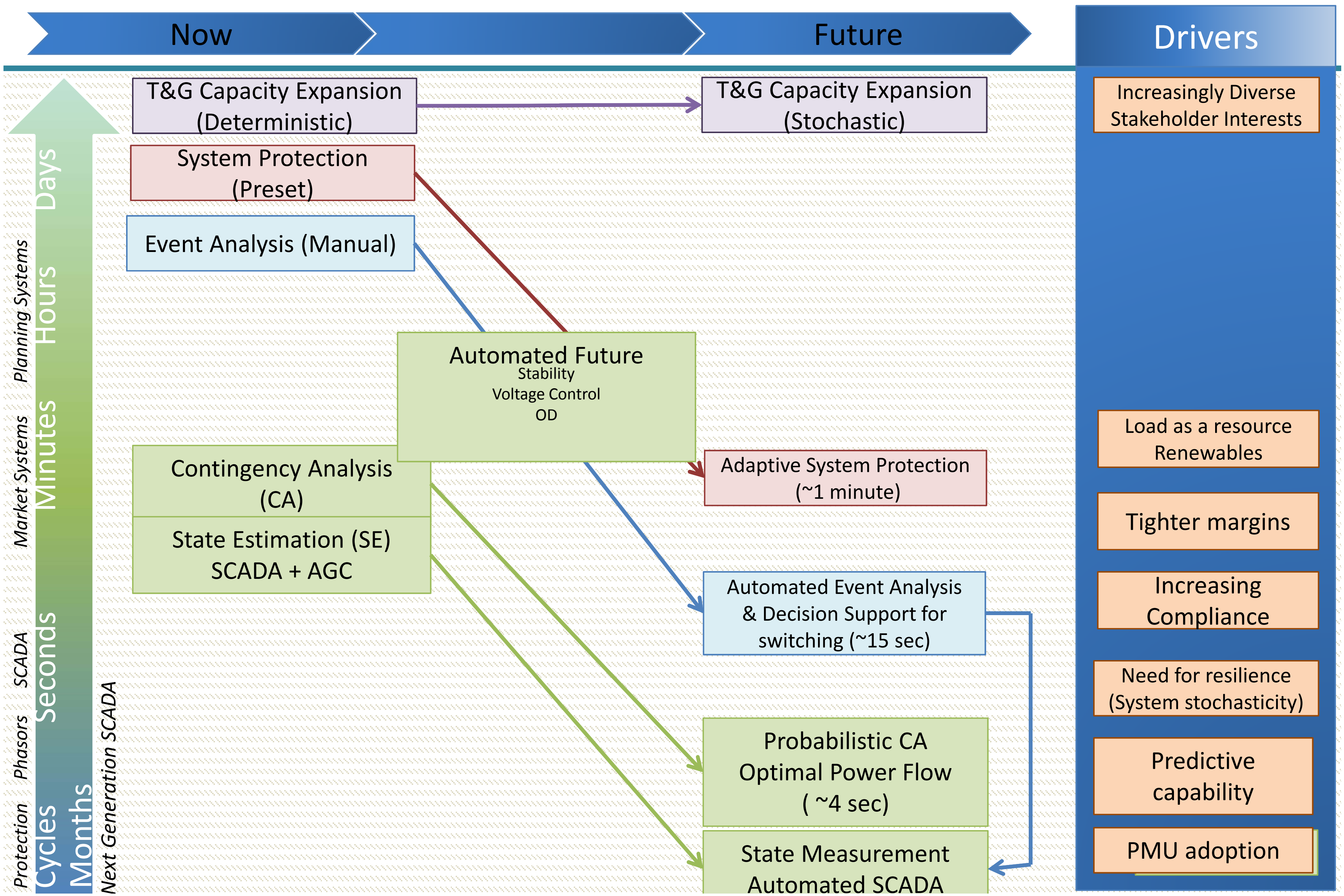
Oak Ridge National Laboratory

June 17, 2014

Overview

- *Vision*
- *Project purpose*
- *Significance & impact*
- *Technical approach*
- *Technical accomplishments*
- *Conclusions*
- *Future Effort*
- *Acknowledgements*

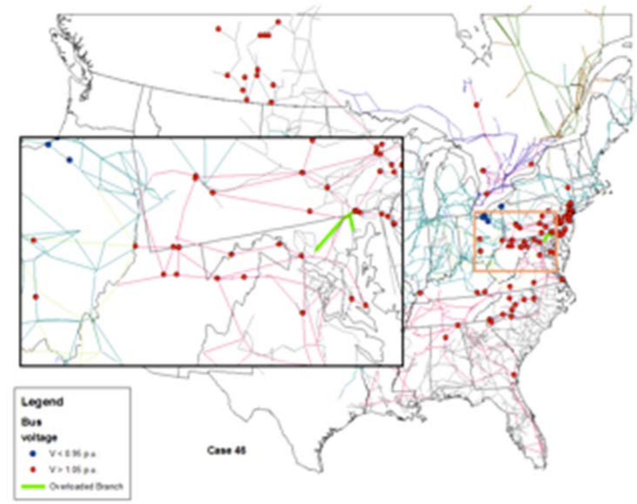
Vision – Faster, Dynamic, On-line Tools



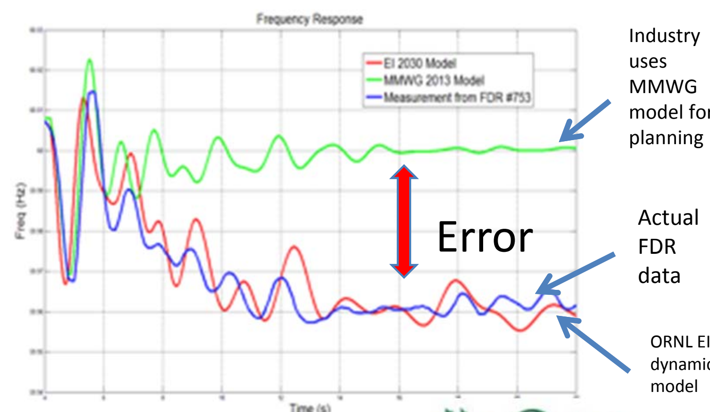
Significance: Why Perform Dynamic Modeling Analysis?

Dynamic Modeling Analyses

- Transient Stability: understand how a system responds to a disturbance
- Small Signal Stability: identify oscillation modes which can harm system stability
- Frequency Regulation: study frequency response, which will change with new types of generation
- Renewable Integration: evaluate impact of generation variability caused by wind & solar
- Control Strategies: serve as a large-scale base case for testing new and advanced control methods.



Model Validation Using Measurement based techniques



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ORNL Grid Related Software & Models

Commercial tools

- Siemens PSS/E,
- GE PSLF,
- PowerTech DSA
- PowerWorld Simulator
- Electrocon: Computer Aided Protection Engineering (CAPE)
- Electric Transients Programs ATP, EMTP-RV, PSCAD

Dynamic grid models

- EI (70,000+) models for year 2030 high wind
- Year 2015-17 EI Low coal, high gas, high wind dynamic models (26,000 buses);
- EI MMWG model (16,000 bus, 26,000 bus, 60,000 bus);
- WECC 13,000 bus system;
- WECC 200 bus system;
- 31 bus EI, 100 bus EI
- 12 bus integrated all US
- Int'l: Egypt system; South China Grid, India system

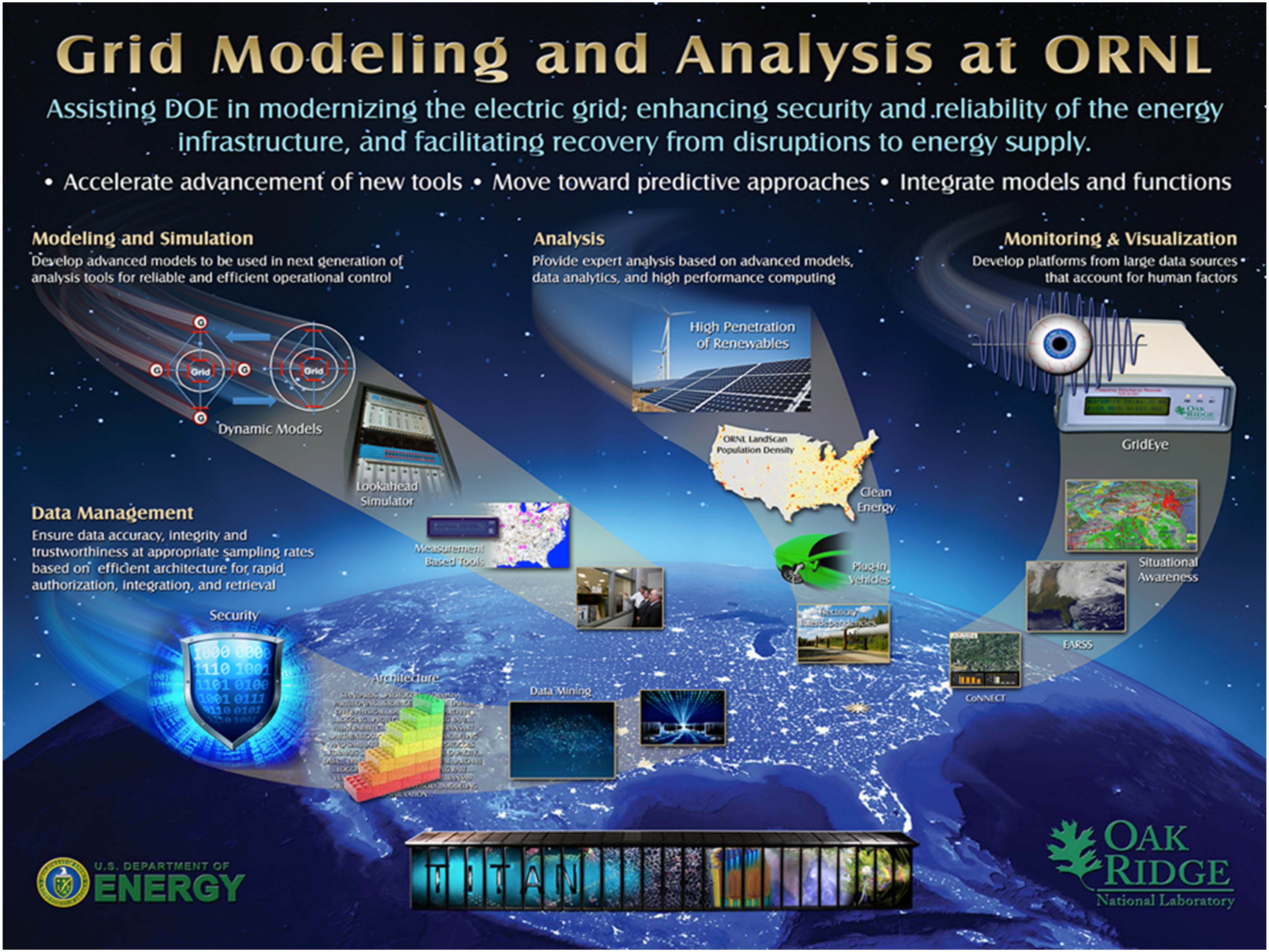
Custom developed

DOE's Advanced Grid Modeling Program Objectives

STRATEGY: Support mathematically-based power systems research to:

- ✓ ***Accelerate Performance –*** improve grid resilience to fast time-scale phenomena that drive cascading network failures and blackouts
  - Move from Off-line to On-line Dynamic Tools
- ✓ ***Enable Predictive Capability –*** rely on real-time measurements and improved models to represent with more fidelity the operational attributes of the electric system, enabling better prediction of system behavior and thus reducing margins and equipment redundancies
  - Goal to achieve faster than real-time & look ahead simulation

- ✓ ***Integrate Modeling Platforms (across the system) –*** capture interactions and interdependencies that will allow development of new control techniques and technologies
  - Integration of CAPE/PSSE



Grid Modeling and Analysis at ORNL
Assisting DOE in modernizing the electric grid; enhancing security and reliability of the energy infrastructure, and facilitating recovery from disruptions to energy supply.
• Accelerate advancement of new tools • Move toward predictive approaches • Integrate models and functions
Modeling and Simulation
Develop advanced models to be used in next generation of analysis tools for reliable and efficient operational control
Analysis
Provide expert analysis based on advanced models, data analytics, and high performance computing
Monitoring & Visualization
Develop platforms from large data sources that account for human factors
Grid
Grid
Dynamic Models
Lookahead Simulator
Measurement Based Tools
High Penetration of Renewables
ORNL LandScan Population Density
Clean Energy
Plug-in Vehicles
Electricity Interdependencies
GridEye
Situational Awareness
EARSS
CoNNECT
Data Management
Ensure data accuracy, integrity and trustworthiness at appropriate sampling rates based on efficient architecture for rapid authorization, integration, and retrieval
Security
Architecture
Data Mining
TITAN
U.S. DEPARTMENT OF ENERGY
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Project Outline

Dynamic Simulation Capability Development

1. Create 2030 eastern interconnect (EI) dynamic model
   a. Working with EIPC and EISPC
   b. Develop dynamic models to understand dynamics of high renewable penetration
2. Improve today's dynamic EI model
   a. Dynamic model validation & model improvements
3. Develop new wide-area dynamic control capability for wind and solar
   a. Augmenting model library to study advanced controls
4. Integrating dynamic simulation into protection tool (PSS/e - CAPE)

Develop 2030 Dynamic Model for Eastern Interconnection (EI)

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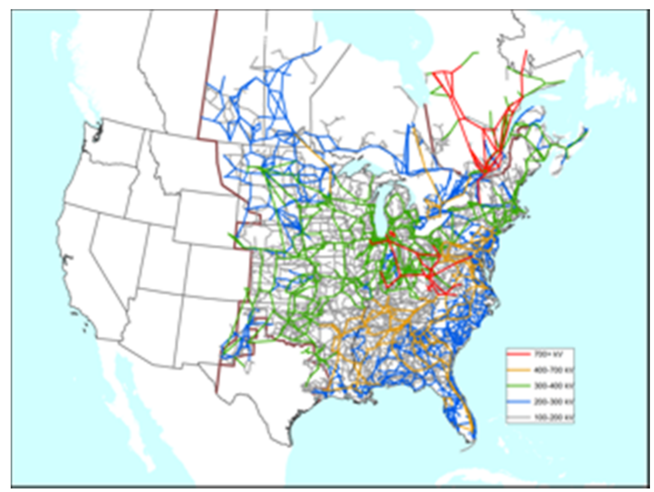
Oak Ridge National Laboratory
June 17, 2014

Overview

- The Eastern Interconnection Planning Collaborative (EIPC) has built three major power flow scenarios for the 2030 Eastern Interconnection (EI)
- They are based on various energy and environmental policies, technology advances, and load growth.
- Model size is 70,000+ buses and 8,000+ generators.
- This effort is to develop dynamic models based on EIPC load flow cases by using:
  1. All generic dynamic parameters
  2. MMWG 2015 dynamic parameters, only generic parameters for wind

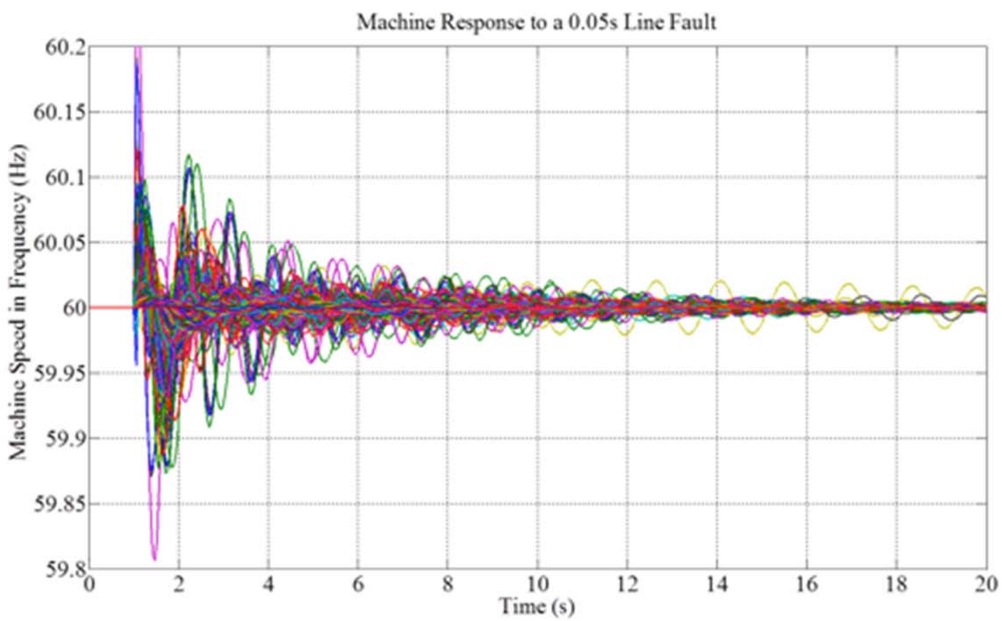


Model Construction Procedures

- Clean up data errors in the power flow model.
- Assign machine, exciter, and turbine governor dynamic models with typical parameters based on the fuel type
- Or transfer over the MMWG dynamic parameters.
- Represent 17% wind output by the generic type 3 and the GE wind machine model
- Debug debug debug….
- Validation

Model Validation

- Known contingencies are used to check the reasonableness
- Indirectly validated against measurements by *displacing* the wind generation.



OPF and Location Data Integrated to 2030 Transmission Models

- Bus location (lat/long) values allow the models to be visualized using PowerWorld
  - Energy Visuals data gives locations to many buses
  - Interpolation approximates missing locations
- Optimized Power Flow data will allow economic analysis of changing generation
  - EIPC and Energy Visuals have provided data for most generators in the 2030 cases
  - New and modified plants are given OPF data based on averages of existing units
  - Further tuning of data and adjustment to 2030 case values is ongoing

EI 2030 Dynamic model development roadmap

Case Name and #	High wind high peak S1B1	High wind low peak S1B13	Local renewable high peak S2B1	Local renewable low peak S2B13	BAU high peak S3B1
Classic generator model GENCLS	Done	FY2015			FY2014
Thermal plant generator model GENROU	Done	FY2015			FY2014
Hydro plant generator model GENSAL	Done	FY2015			FY2014
Simplified exciter model	Done	FY2015			FY2014
Steam turbine governor model TGOV1	Done	FY2015			FY2014
Hydro turbine governor model HYGOV	Done	FY2015			FY2014
IEEE type 1 turbine governor model IEEEG1	Done	FY2015			FY2014
IEEE type 1 turbine governor model with deadband WSIEG1	FY2014	FY2015			FY2014
Generic wind model WT3	FY2014	FY2015			FY2014
Solar model	FY2014	FY2015			FY2014
Motor load	FY2015	FY2015			FY2015
Controllable load	FY2015	FY2015			FY2015
Energy storage	FY2015	FY2015			FY2015
Renewable in wide-area control	FY2015	FY2015			FY2015
Compare results between scenarios	FY2015	FY2015			FY2015

EI 2030 OPF model development roadmap

Install OPF module into working version of PowerWorld and/or PSS/E	FY2013
Develop generator cost and operations parameters from generic data for each major technology type	FY2014
Identify of technology types for plants listed in the EI PSS/E model	FY2014
Examine changes to power generation and flows when activating the OPF	FY2014
Develop variations in generation under security constraints	FY2015
Examine curtailment and generation patterns with modified transmission capabilities	FY2016

Improve Today's EI Dynamic Models

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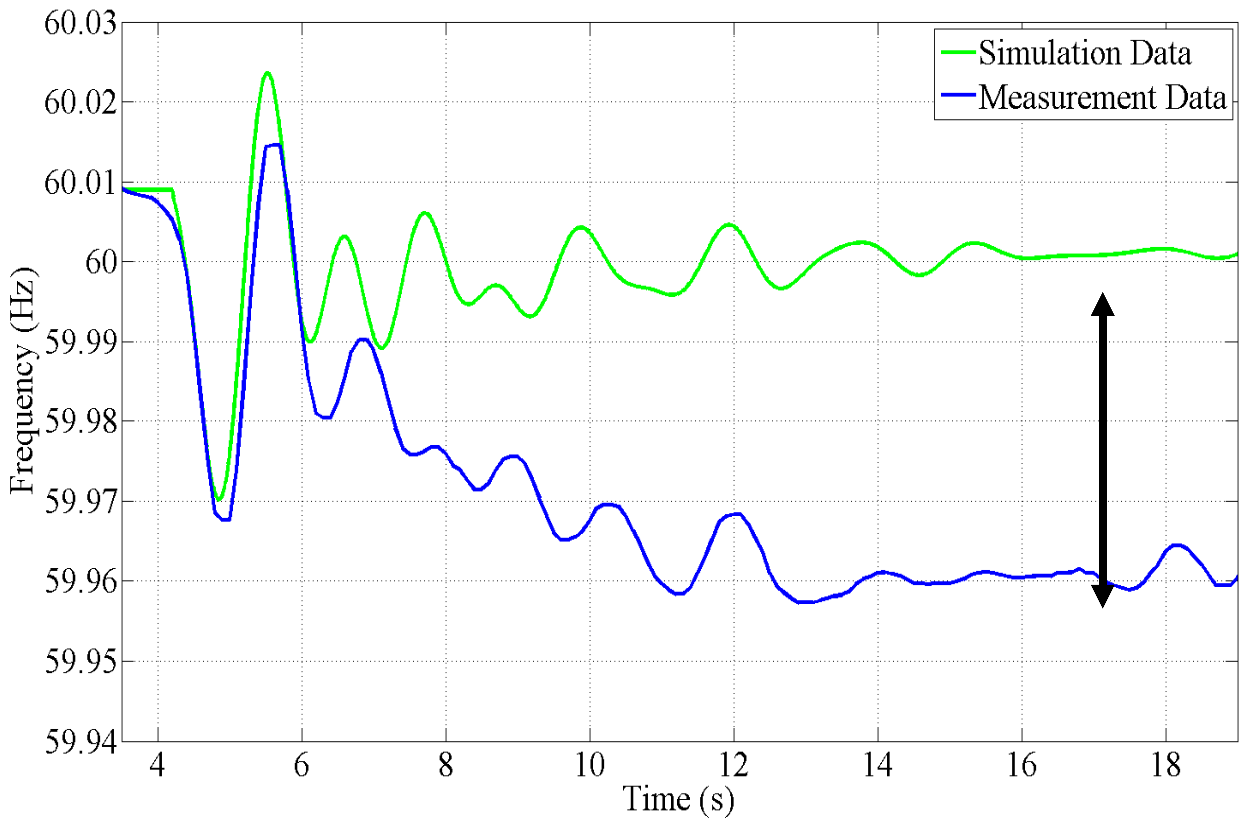
Motivation

- Mismatch in frequency response of EI MMWG model



Mismatch in frequency responses !

Technical Approach

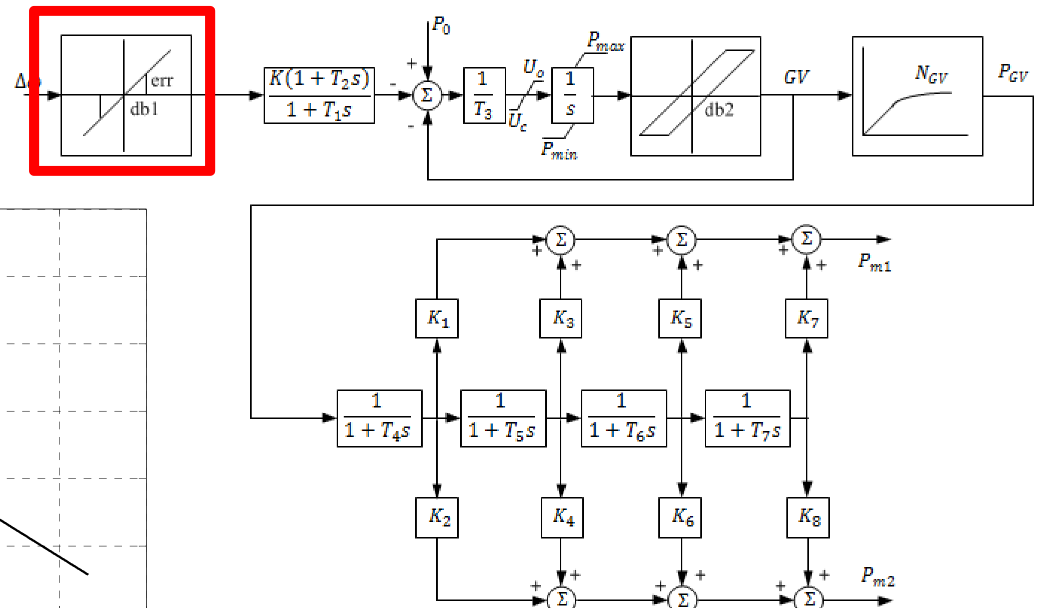
Many contributing factors for frequency response:

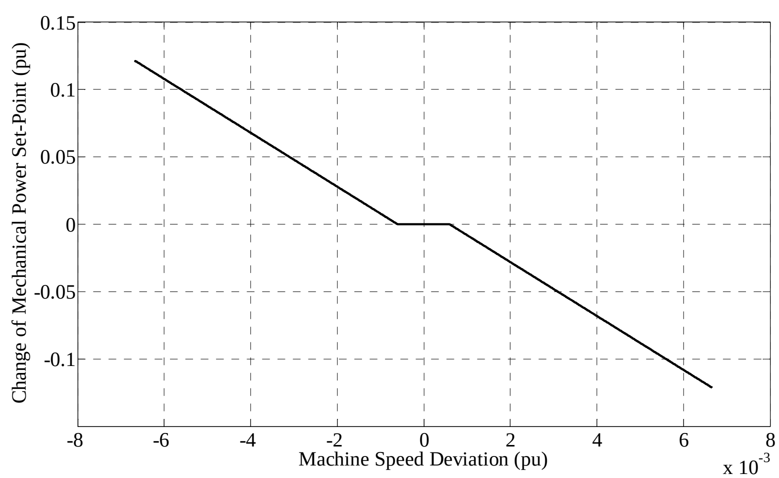
- Governor deadband
- Droop
- Inertia
- Load composite
- The outer loop control
- PSS, exciter, and others

Implement Deadband Model - example

- The typical standard turbine governor models do not represent deadband.
- An augmented version of IEEE type 1 model, WSIEG1 (WECC modified) is adopted.

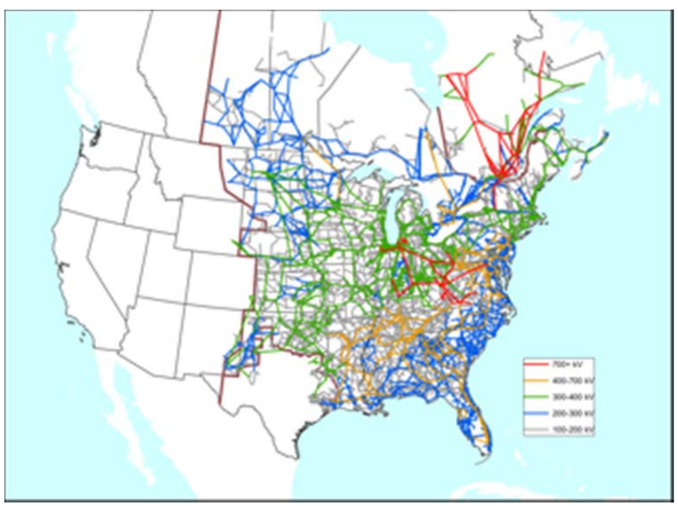
Droop 5%
36 mHz deadband

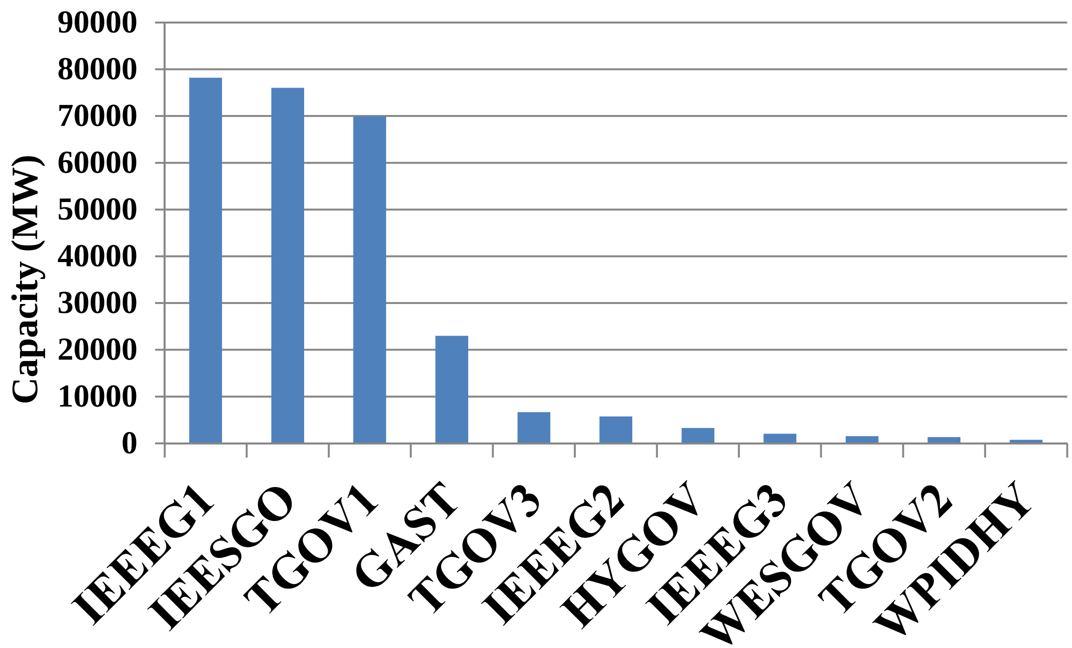




Focus on typical EI governor types

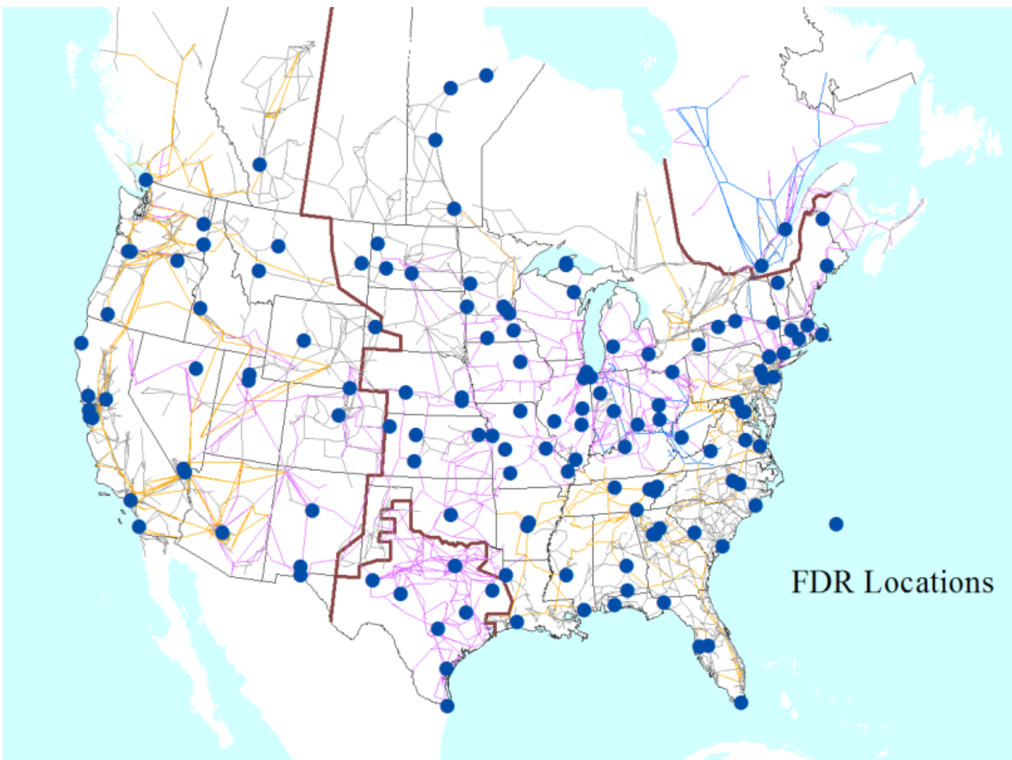
- The 16,000+ bus 3,000+ machine EI dynamic model is used. Winter Peak total capacity of 591 GW.
- The dominant turbine governor types, including TGOV1, IEESGO, GAST, IEEEG1, are converted to WSIEG1.

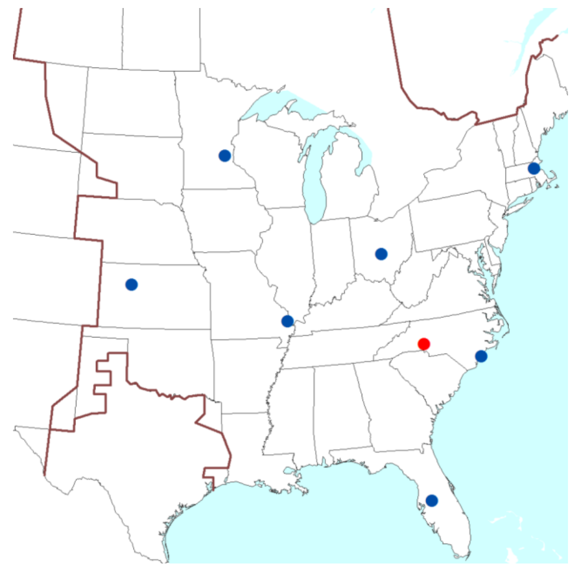




Results

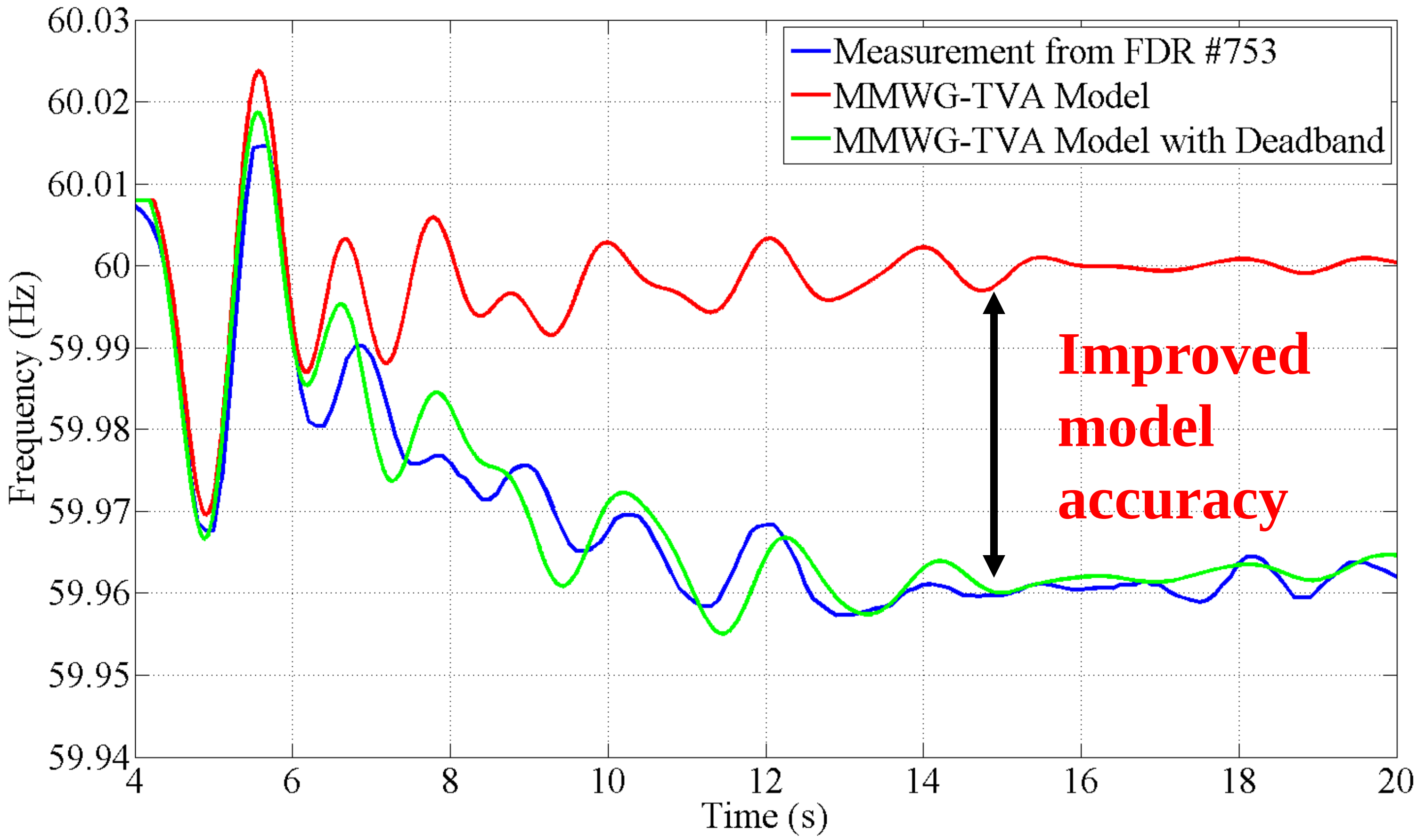
- 1100 MW Generation Trip @ McGuire Unit 1, NC, 2013.02.21,14:57:00 UTC.





Disturbance Location
Measurement Location

Generator Trip in NC



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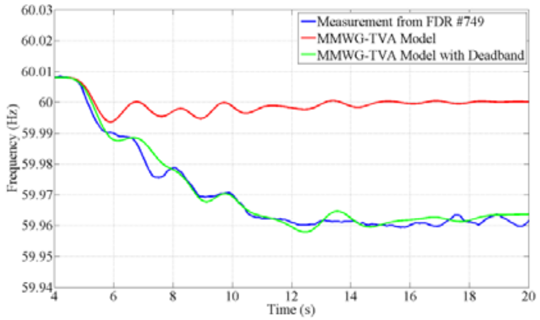

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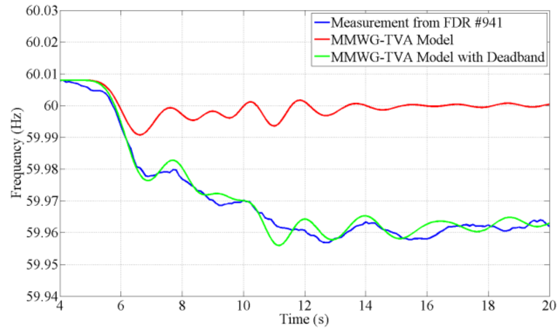

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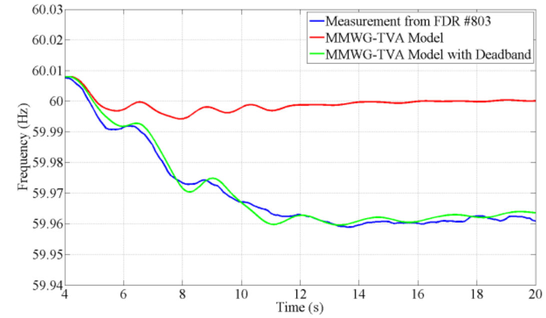

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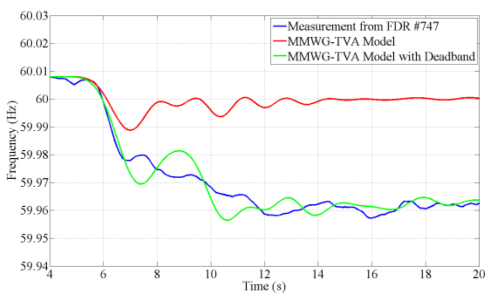

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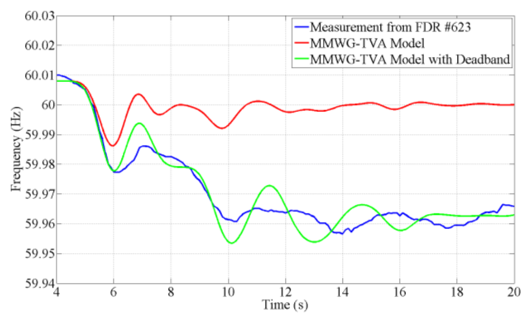

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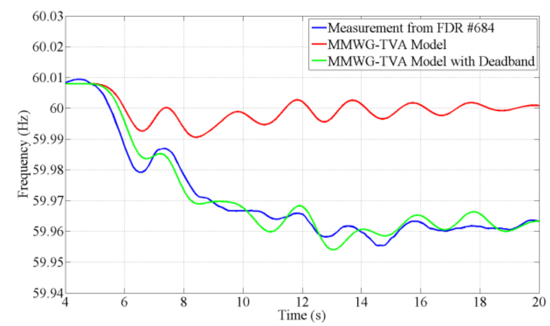

Future Work

Many contributing factors for frequency response:

- Governor deadband
- Droop
- Inertia
- **Load composition**
- **Outer loop control**
- **others**

Implement System-Level Control Functions in Wind/PV - Oscillation Damping Example in EI

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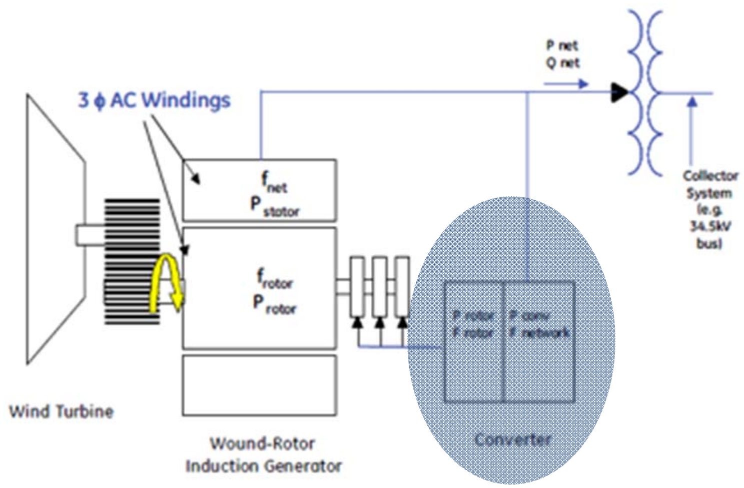
Oak Ridge National Laboratory
June 17, 2014

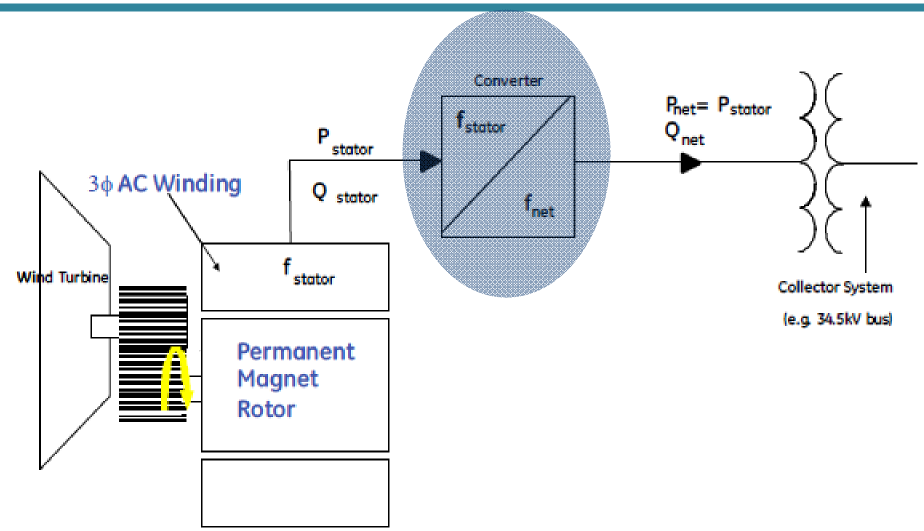
CURENT Member Sponsored Focused Research

CURENT

Capability of Power Electronic Converter



DFIG



PMSG/PV

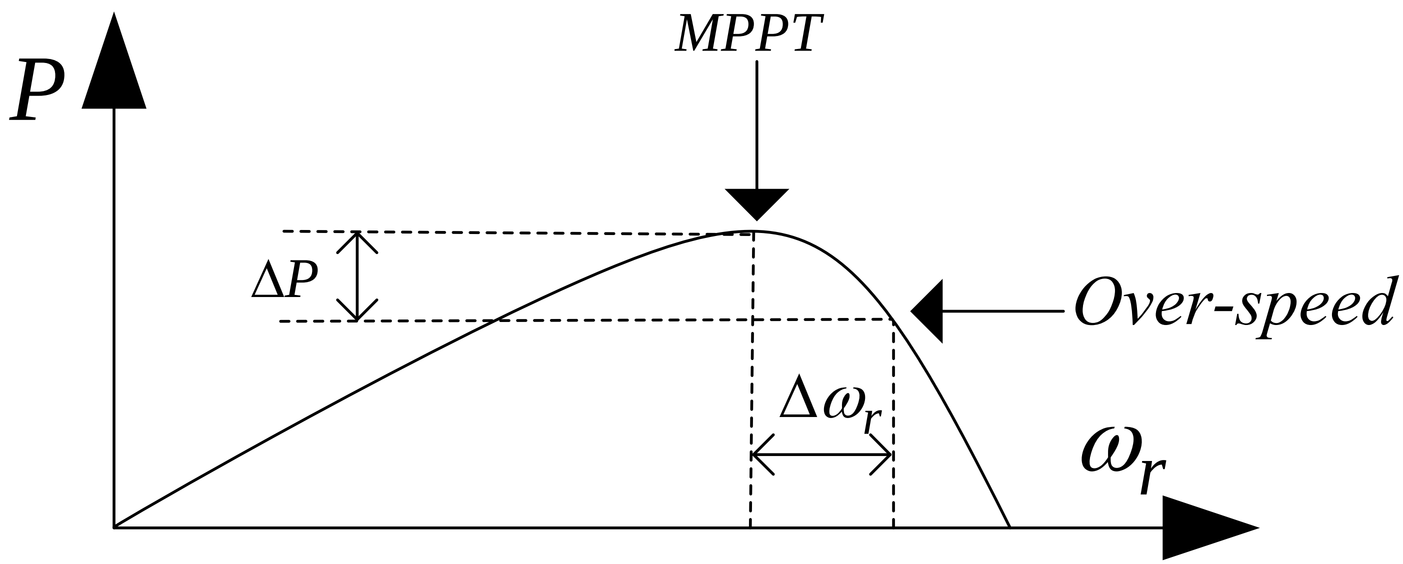
Available functions:

- Capture maximum wind/solar energy
- Regulate reactive power

New system level functions

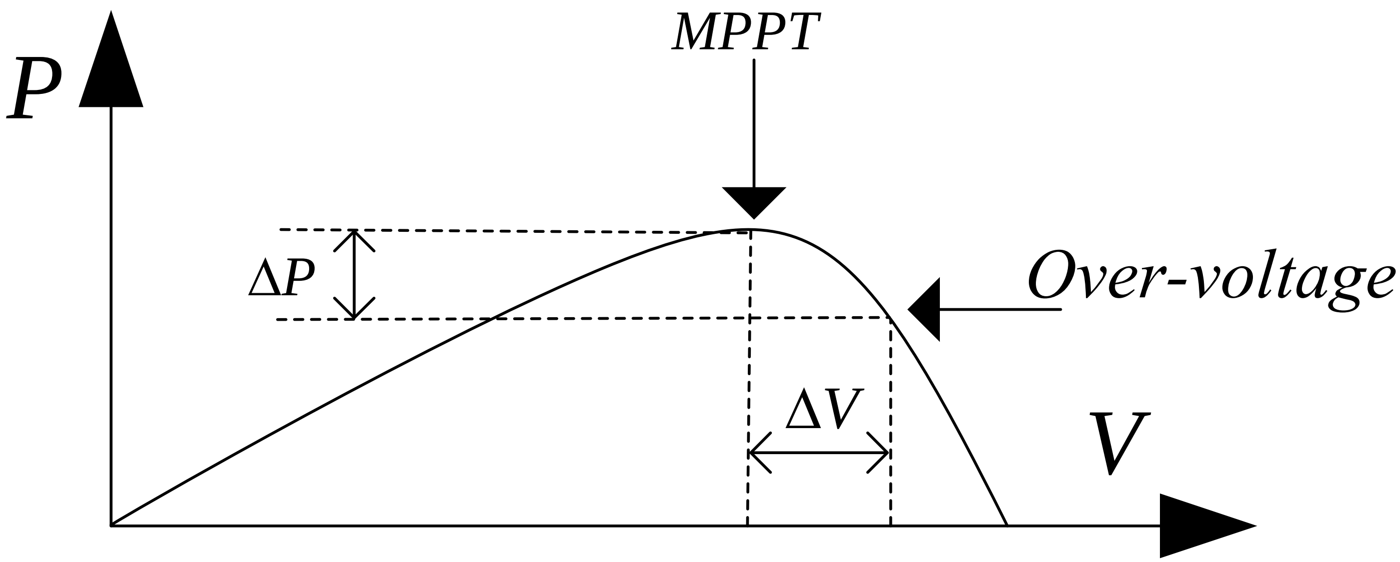
- Frequency Regulation
- Inter-area Oscillation Damping

Approach: Over-speed for Wind generators



- For the fixed wind speed and pitch angle, the mechanical power P is only related to the turbine rotational speed ω_r.
- Instead of MPPT, wind turbines need to work in over-speed ($\omega_{r\ MPPT} + \Delta\omega_r$) mode to have reserve ΔP.

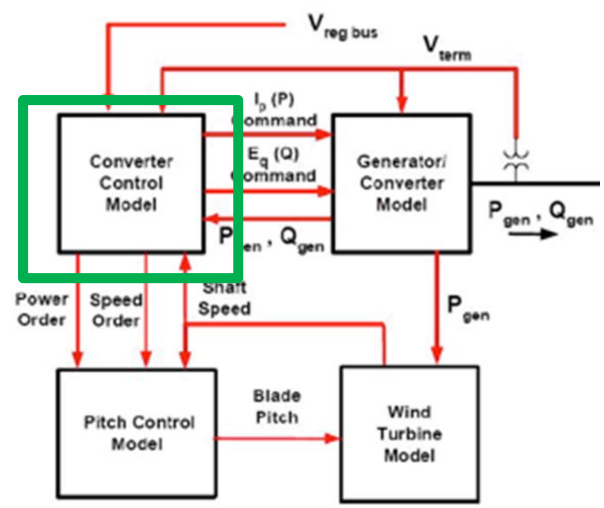
Approach: Over-voltage for PV generators



- For the fixed solar irradiance and temperature, DC power generated by PV panel P is only related to the output voltage V.
- Instead of MPPT, PV panels need to work in over-voltage $(V_{MPPT} + \Delta V)$ mode to have reserve ΔP.

System Setup

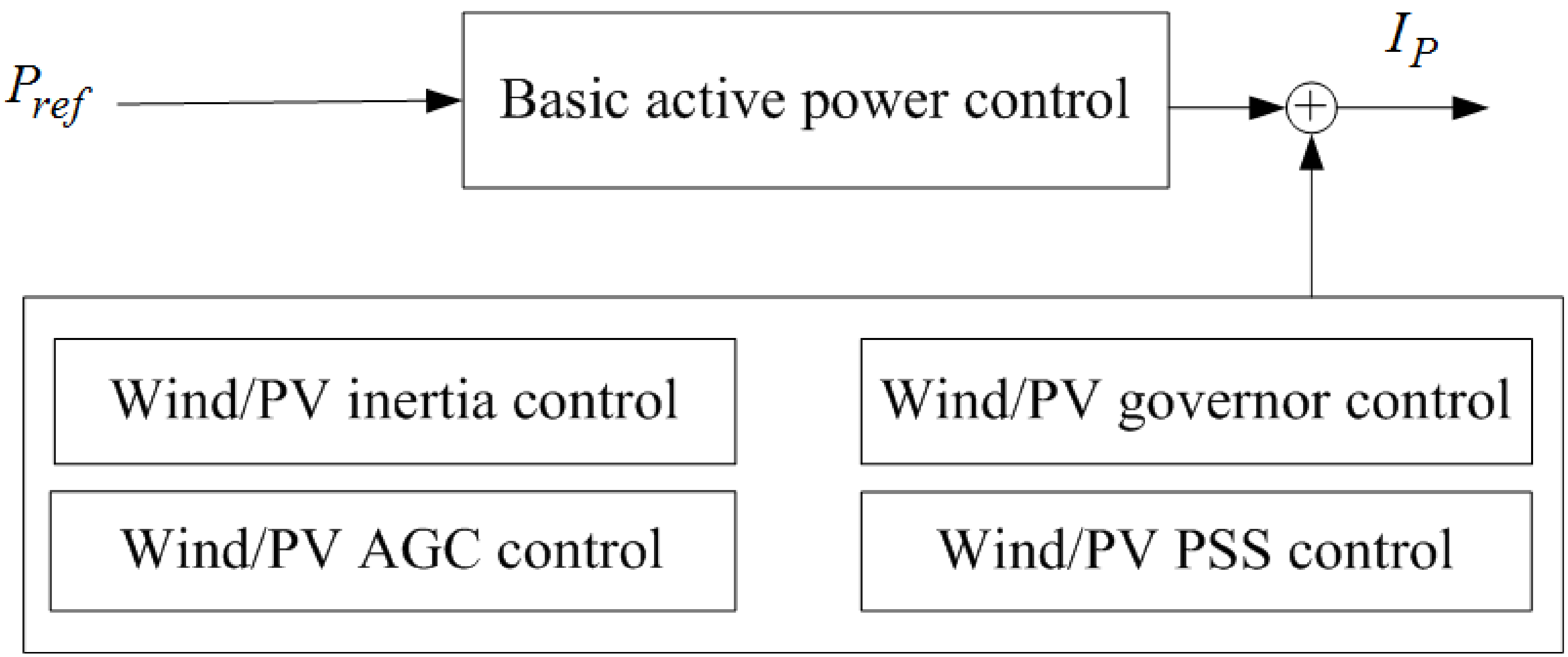
- EI system model
  - 16,000-bus dynamic model
  - 590 GWs / 3000+ generators



- Wind/PV generation model
  - Wind generation model based on PSS/E GE WT3 DFIG model
  - PV model based on PSS/E WT4 PV model
  - User-defined electrical control model that includes additional controllers

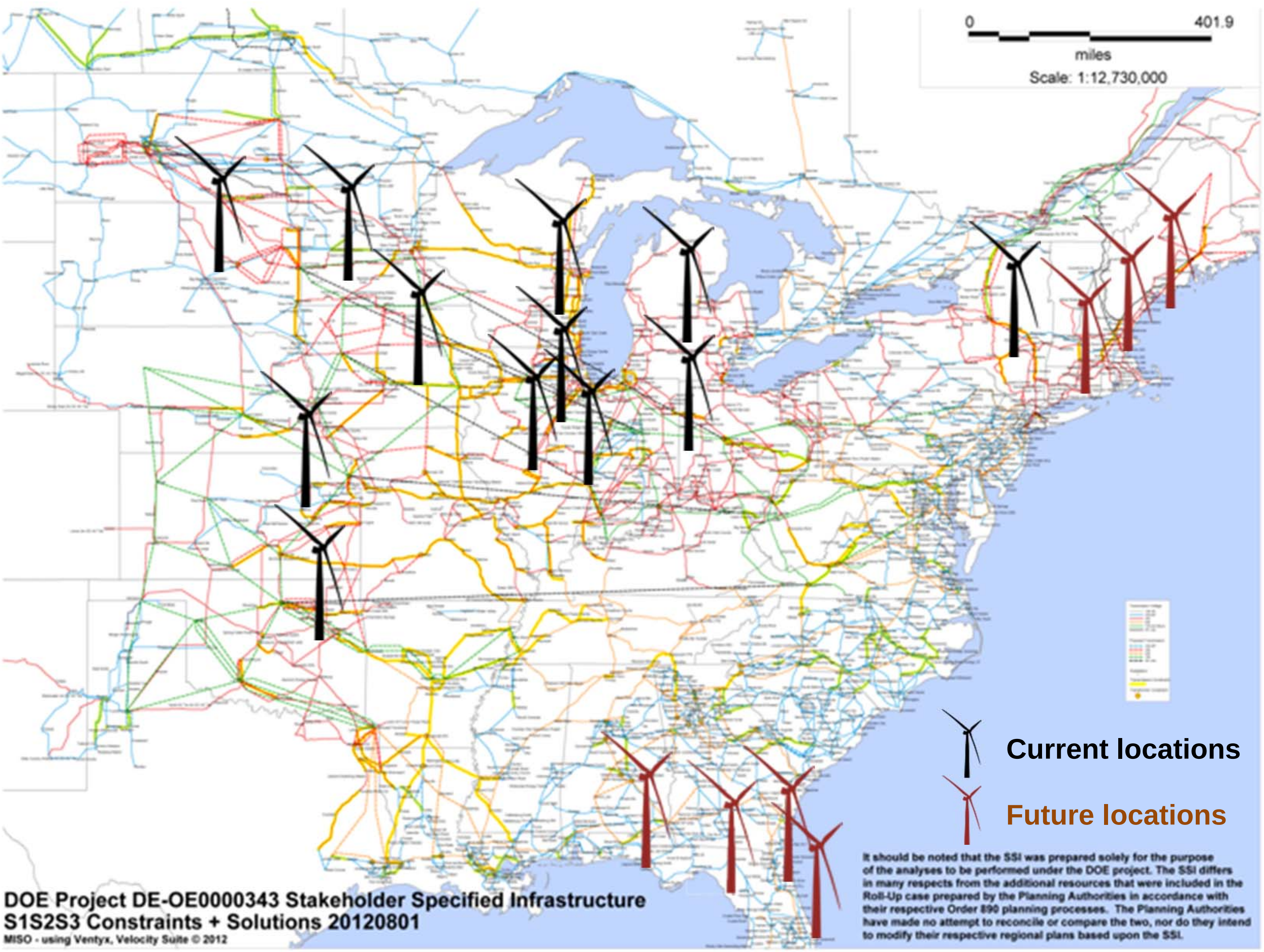
Approach: User-defined Wind/PV Electrical Control Modules (active power part)

- Convert a portion of the active power output of conventional generators to Wind/PV generation
- Power flow distribution is not changed
- 20% renewables

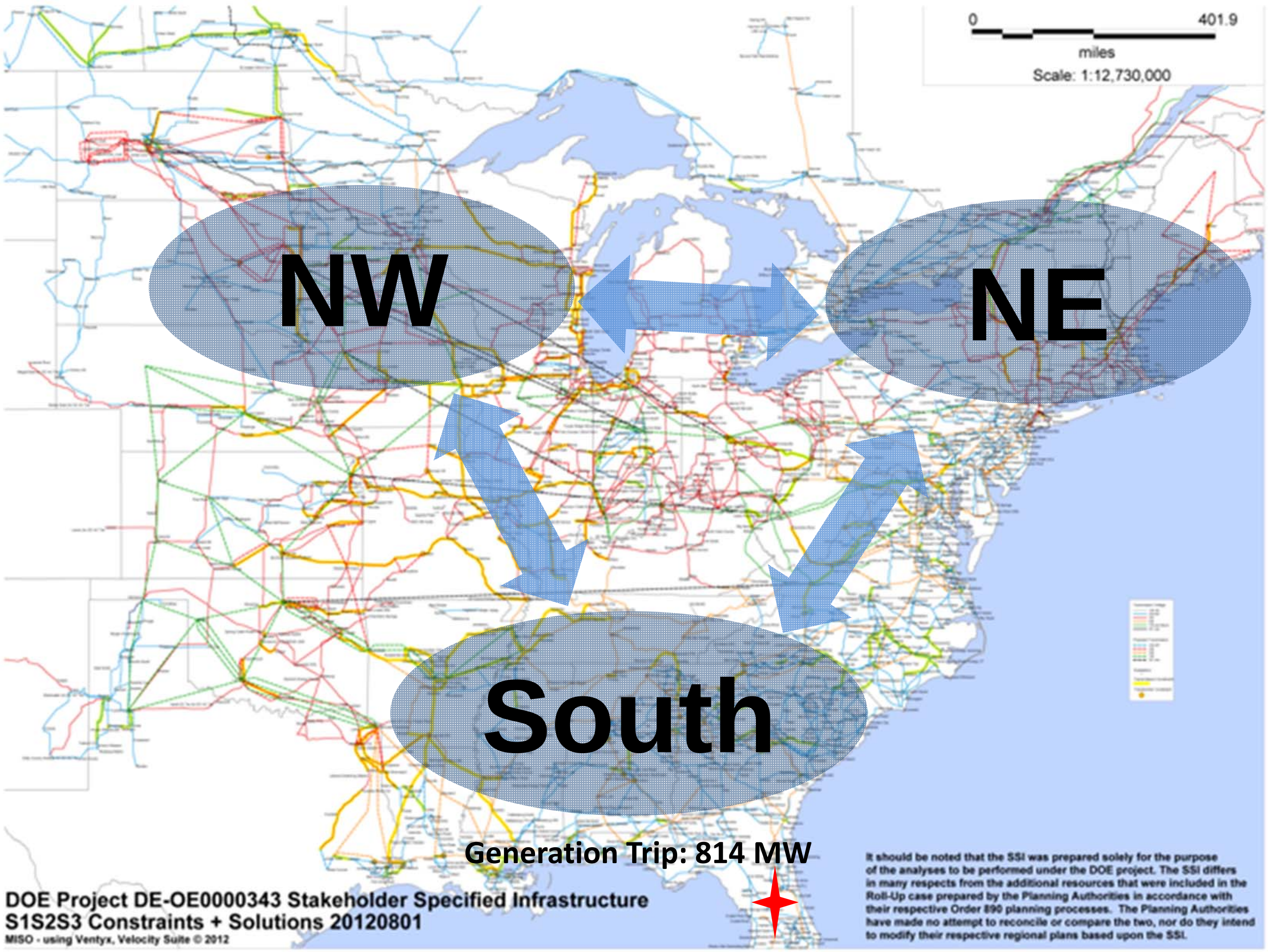


Additional Controllers

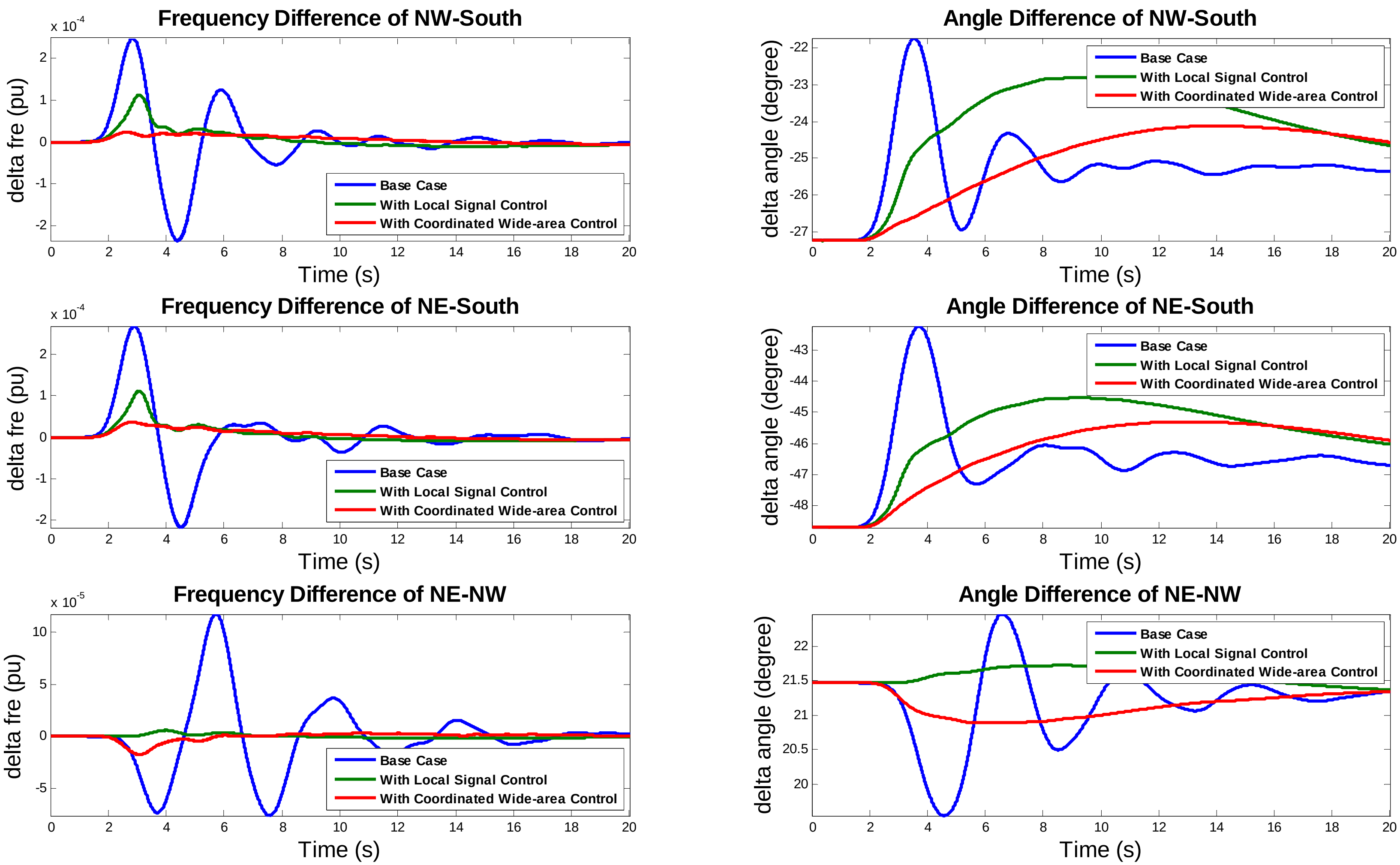
Wind Generation Location Map



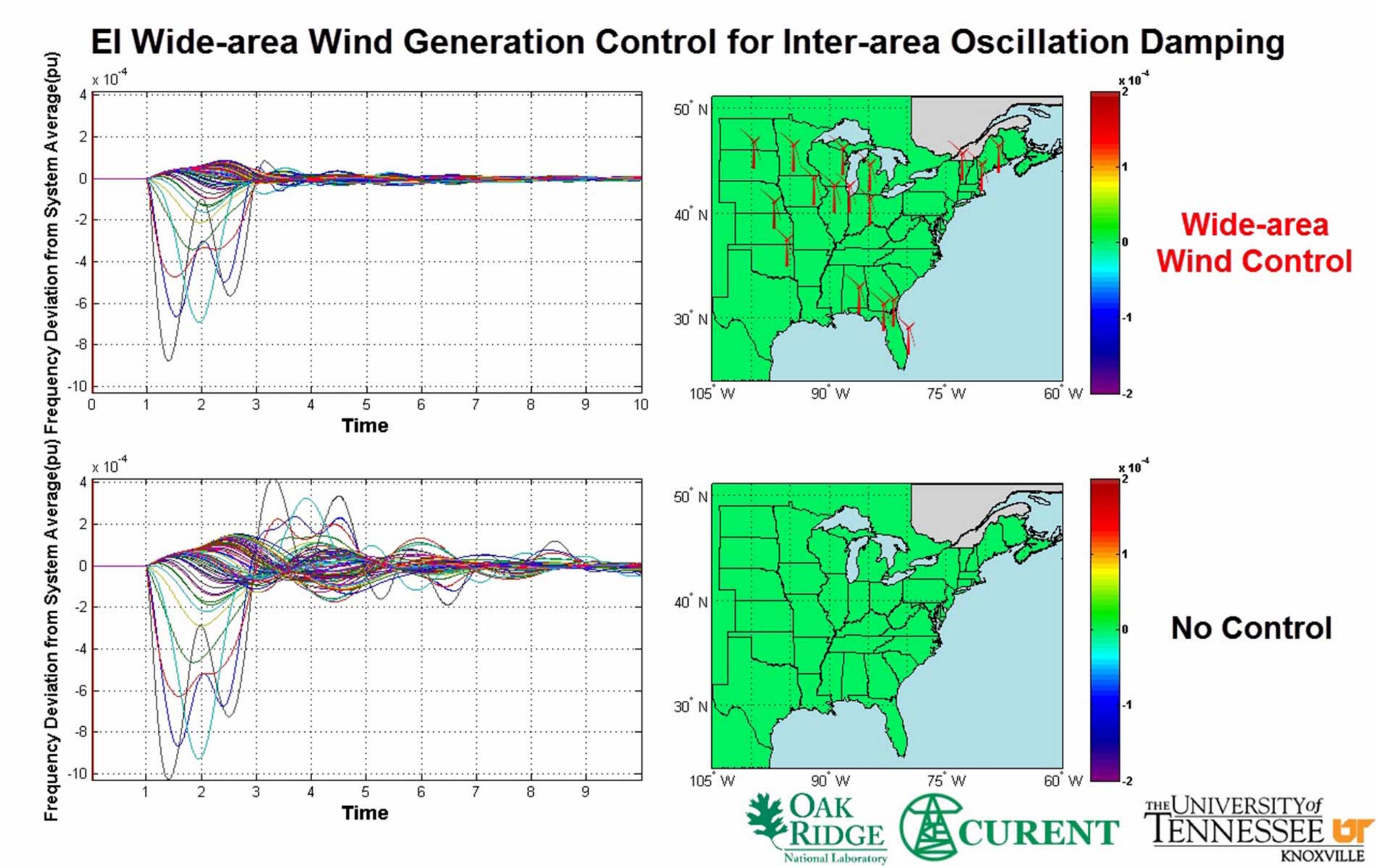
EI Inter-area Oscillation Map



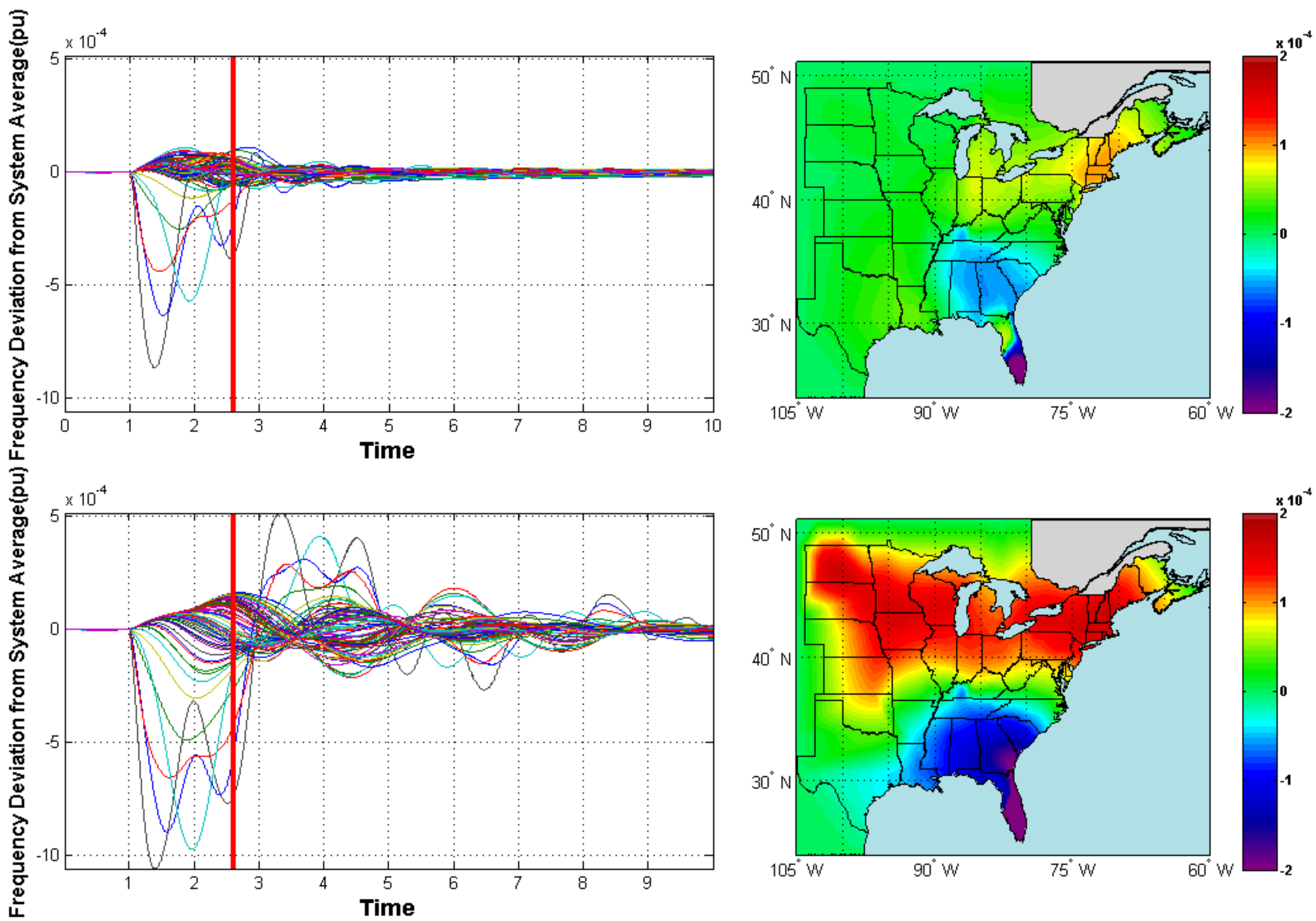
Case Study-Wind



Inter-area Oscillation Damping by Wind



Inter-area Oscillation Damping by PV



Wide-area PV Control

No Control

Next Steps

- Implement wide-area control in 2030 dynamic model
- Coordination strategies for multi-mode inter-area oscillation damping

Conclusions

- High wind and high built-out EI 2030 dynamic model is ready for beta testing.
- Demonstrated the importance of modeling additional devices and functions such as deadband. Today's EI model is not representing deadband, load composite, motor, outer loop, HVDC, etc.
- Overcome the limitation of PSS/e model library for remote control functions. New user defined wind and solar dynamic models allow advanced wide-area control using renewables, oscillation damping example.

Dynamic Protection Planning Simulation

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Daryl Coleman[2], Paul McGuire[2], Sandro Aquilles-Perez[2], Jeff Quada[2]
[1]Oak Ridge National Laboratory, [2]Electrocon International Inc.

June 2014

Objective

- Integrated planning dynamics and system protection simulation models for assessing **future grid scenarios** and **impact on protective relaying schemes** during power system disturbances.
  - CAPE/PSSE Integration & Study Cases
  - CAPE/ATP Integration
- The end results for this simulation, will create the foundation for future research in **prediction and identification of system vulnerabilities** with respect to system dynamics and system protection schemes per NERC criteria for out-of-step, generator, and under-frequency load shed protective relays.

Technical Approach

- Develop a *base case protection* system model for the Eastern Interconnect Dynamic Planning model, using NERC criteria for *out-of-step, generator, and under-frequency load shed protection schemes.*

- Create algorithm for *identifying wide area protection operation* during system disturbances.

- *Demonstration* of protection planning *model capabilities* on the Eastern Interconnect power system model

CAPE/PSSE INTEGRATION

Significance for Protection

- This integrated protection-planning simulation tool provides the ability to assess current and future power systems with inclusion of dynamics and protection systems.

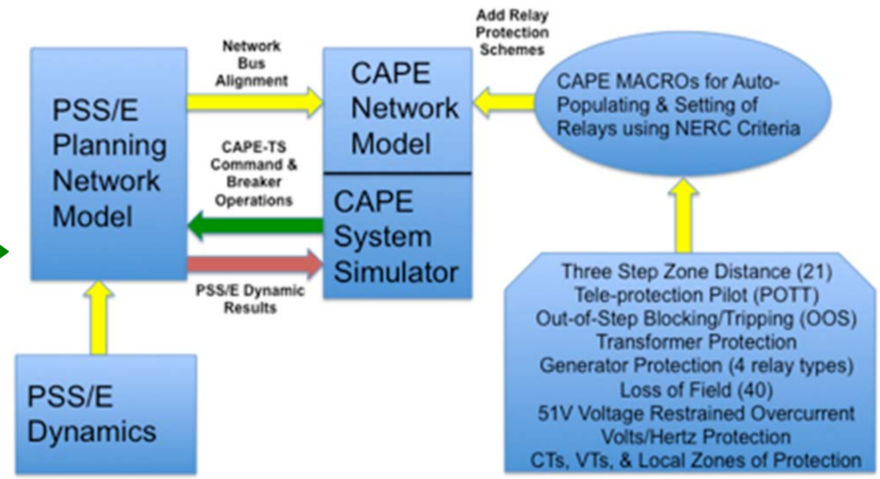
- Allows for systematic evaluation of the impact of future generation technologies on grid stability and predictive wide-area imminent fault detection methods.

- Provides a research platform for dynamic studies related to renewables integration, smart grid, and adaptive protection and control systems, with the ability to include relay protection system behavior.

- Integrated tools for system-wide automatic placement of protection and relay settings have been developed for inclusion and consideration in power system studies based on protection philosophy guidelines.

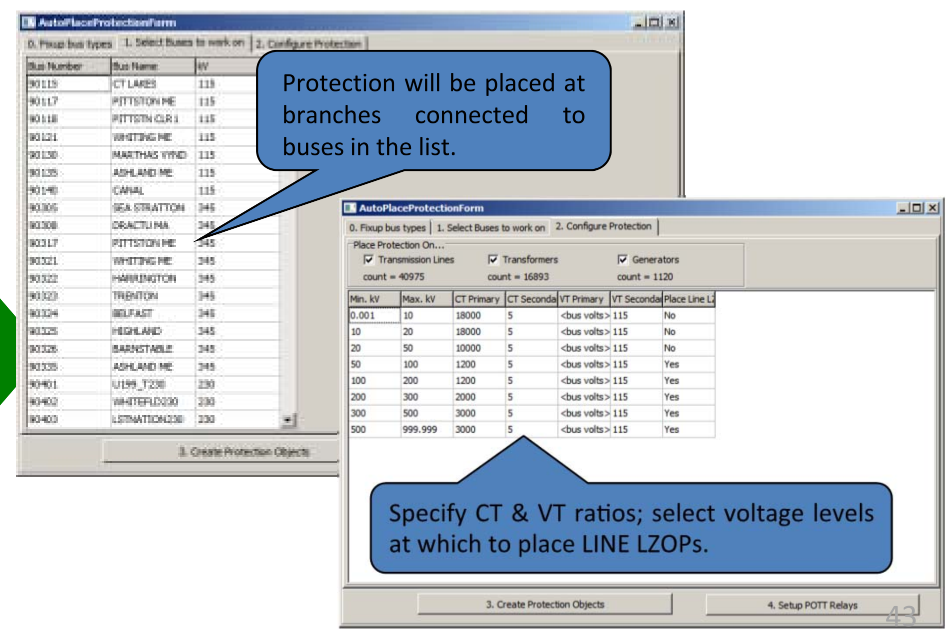
Protection Tool Integration

Inclusion of dynamics and protection systems.



Automatic Placement of Protection on large (EI about 60000 bus):

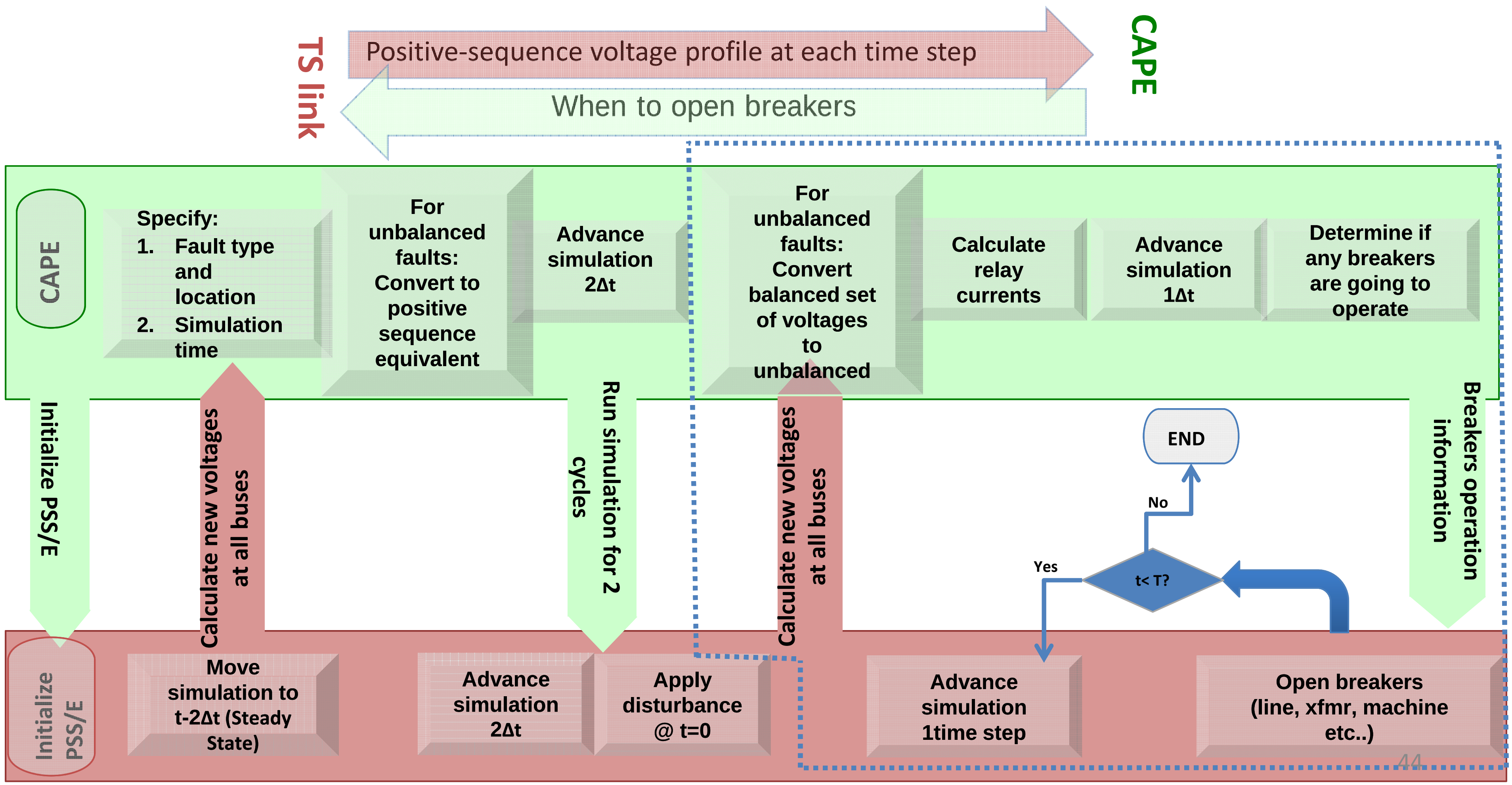
- Automated placement of CTs, VTs, LZOPs, relays and contact logic and settings.



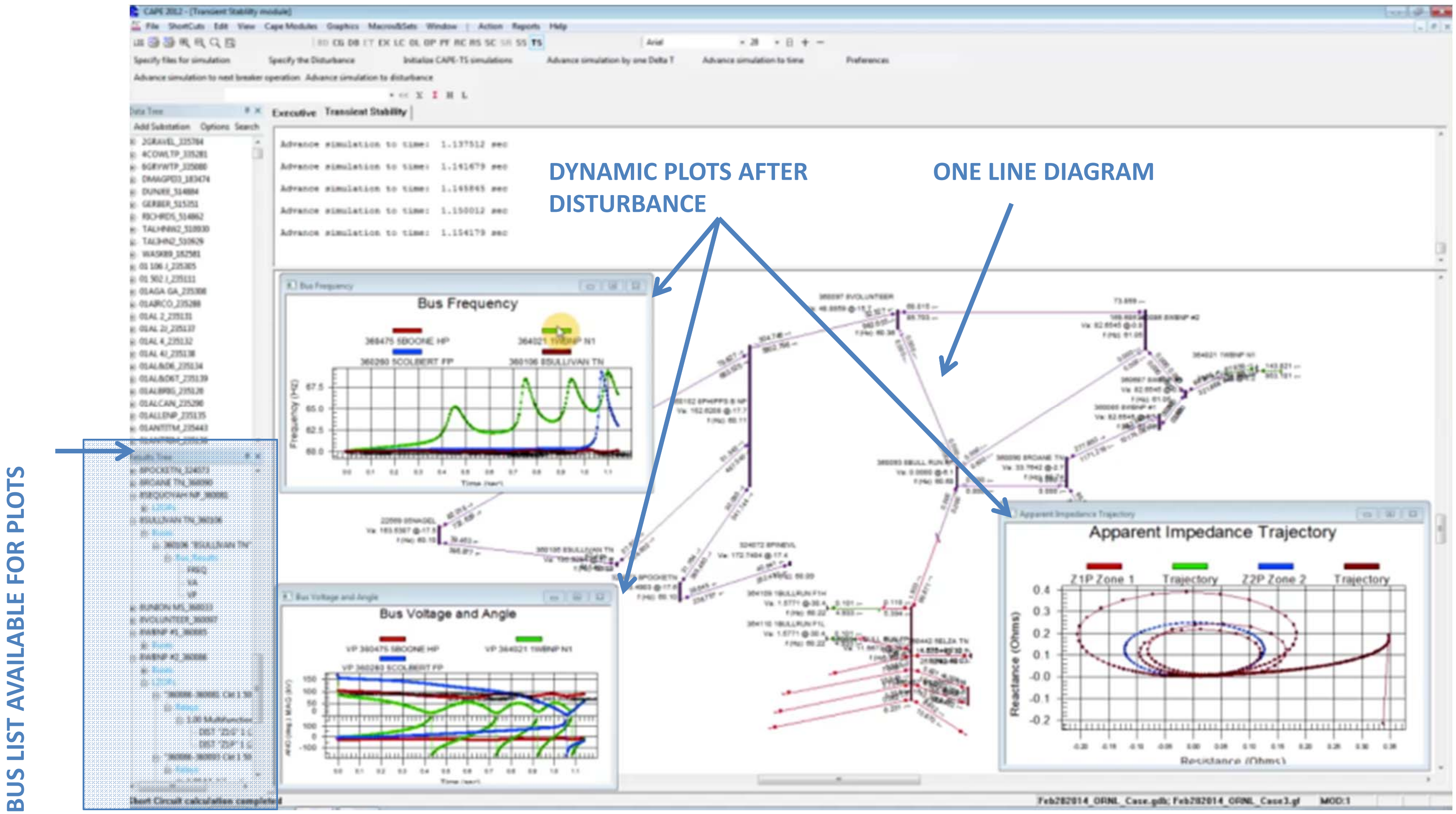
Integration Process: CAPE/TS Link

TS → Models the electromechanical dynamics of the system

CAPE → Computes unbalanced faults and models the response of the protection system

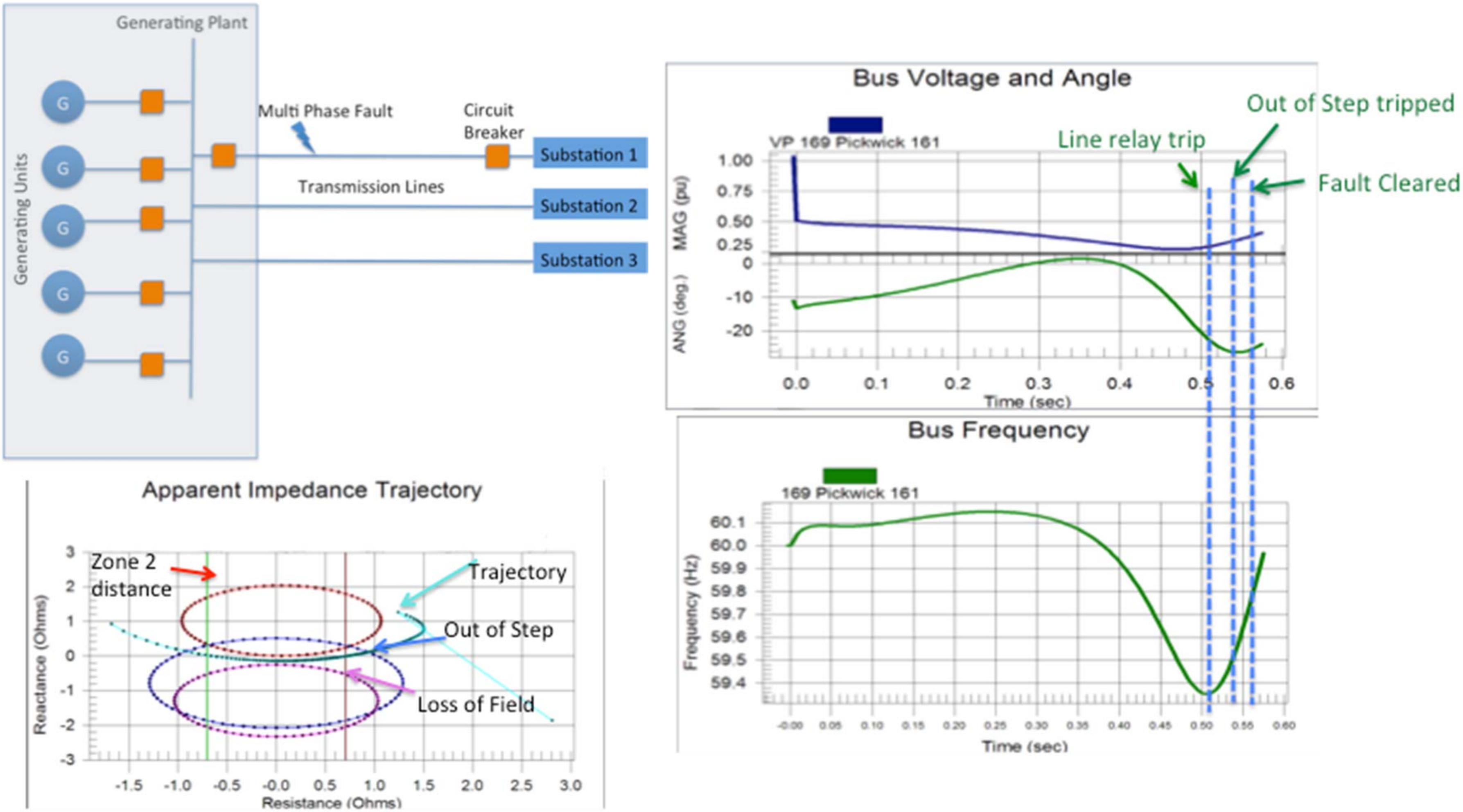


CAPE Output



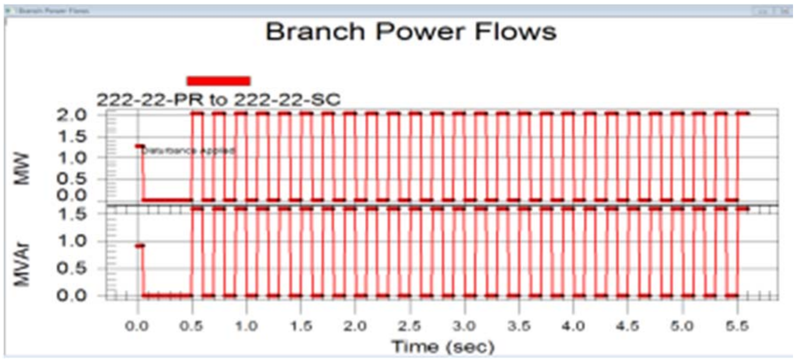
DYNAMIC PLOTS AFTER DISTURBANCE
ONE LINE DIAGRAM
BUS LIST AVAILABLE FOR PLOTS
Bus Frequency
Bus Voltage and Angle
Apparent Impedance Trajectory
Z1P Zone 1
Trajectory
Z2P Zone 2
Trajectory
Reactance (Ohms)

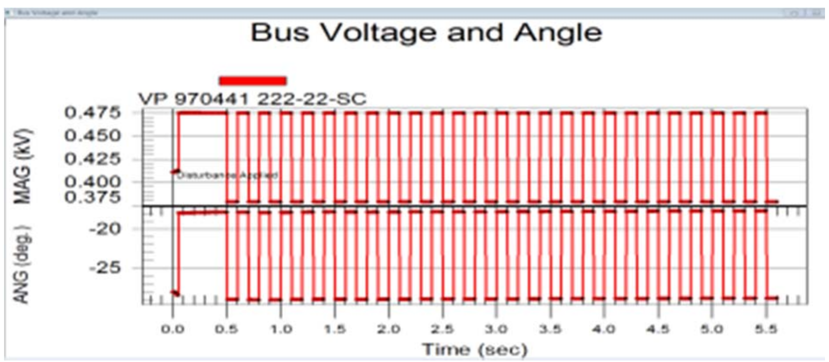
Study Case: Generators go out of step



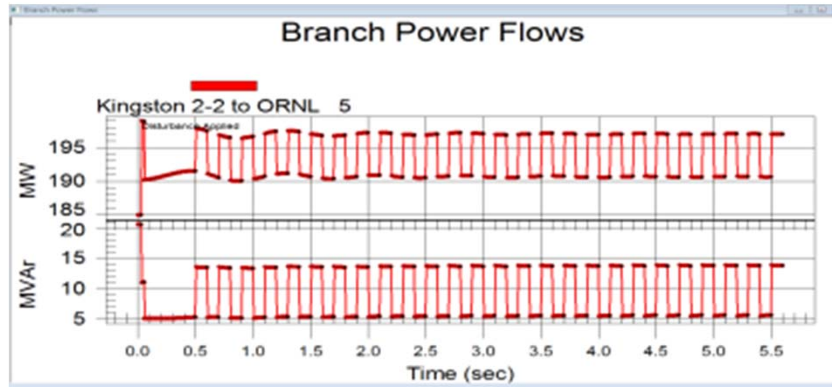
Study Case: Load Modulation

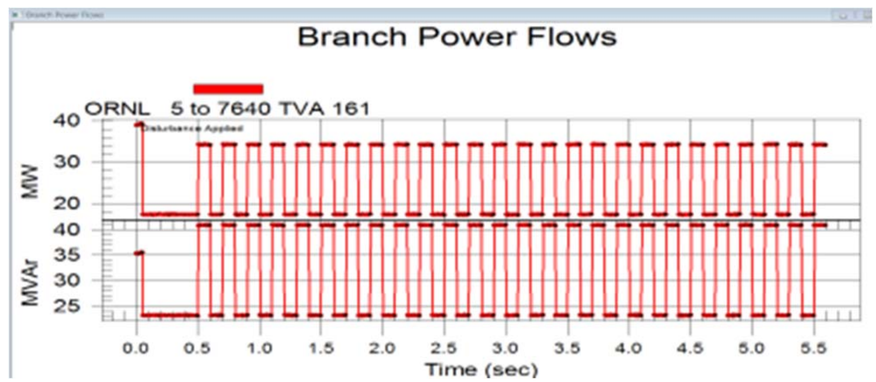
At modulated Load

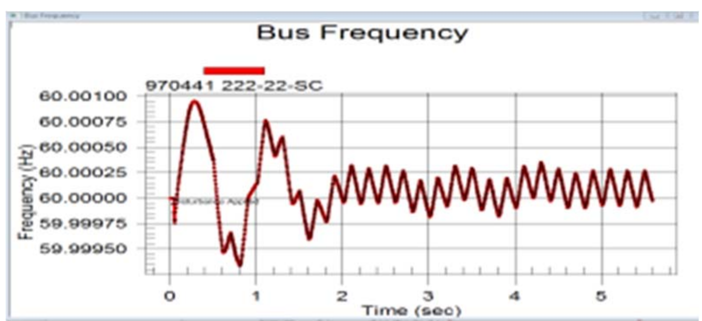




At Point of Interconnection

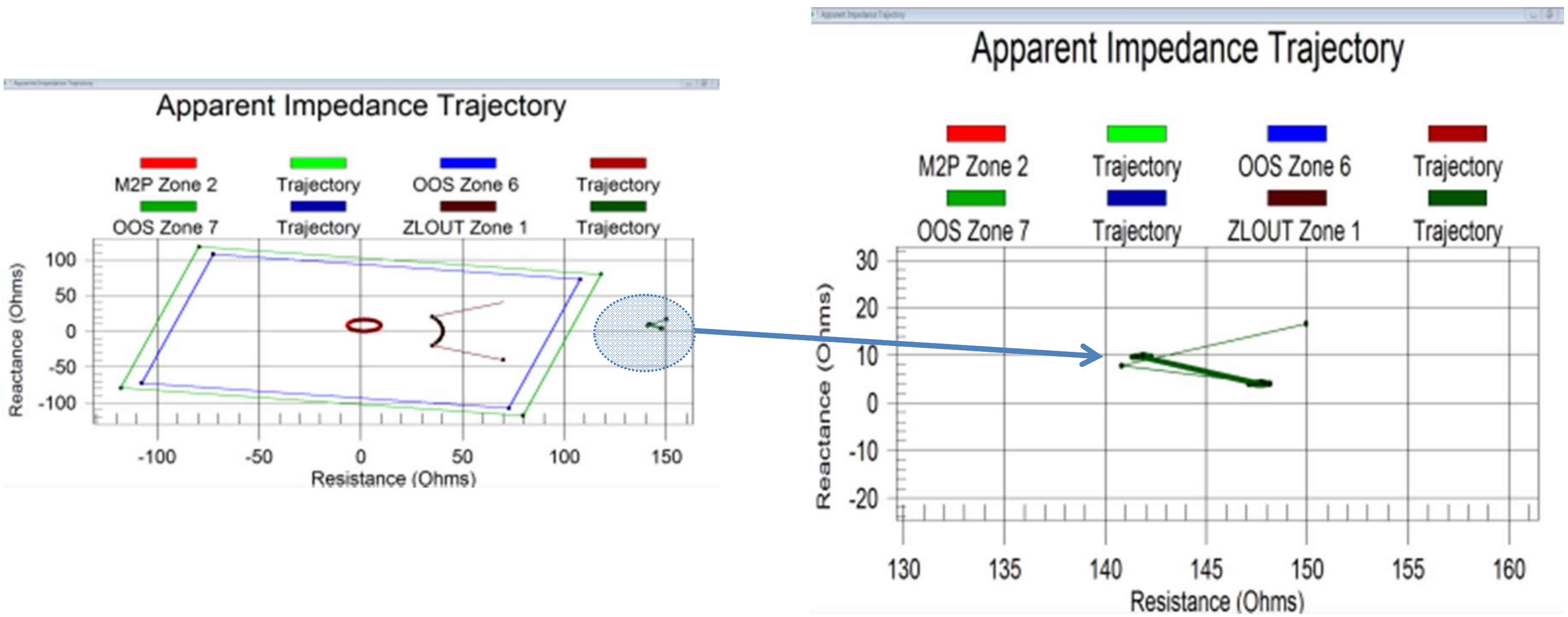






Study Case: Load Modulation

Out of Step Relay Impedance Trajectory during load modulation



Computing Performance

- Current simulation durations vary between 20min to 120min for 15s simulation time. The variation is mainly driven by:
  - The database size and the number of protection devices implemented.
  - The computer speed

- Future work will focus on the algorithm processing and the use of cluster to improve simulation duration to approach real time.

CAPE Integration with EMT (Electro Magnetic Transient) program

Significance for Protection

- EMT studies provide important protection information during the first cycles after the occurrence of a fault or switching operation on the system.
- PSS/E: ¼ cycle time resolution versus EMT allows to run higher time resolution (1µs range) for a specific area (series compensated line).
- This approach will allow performing a more accurate analysis of the behavior of the protection equipment during the first cycles after a fault condition

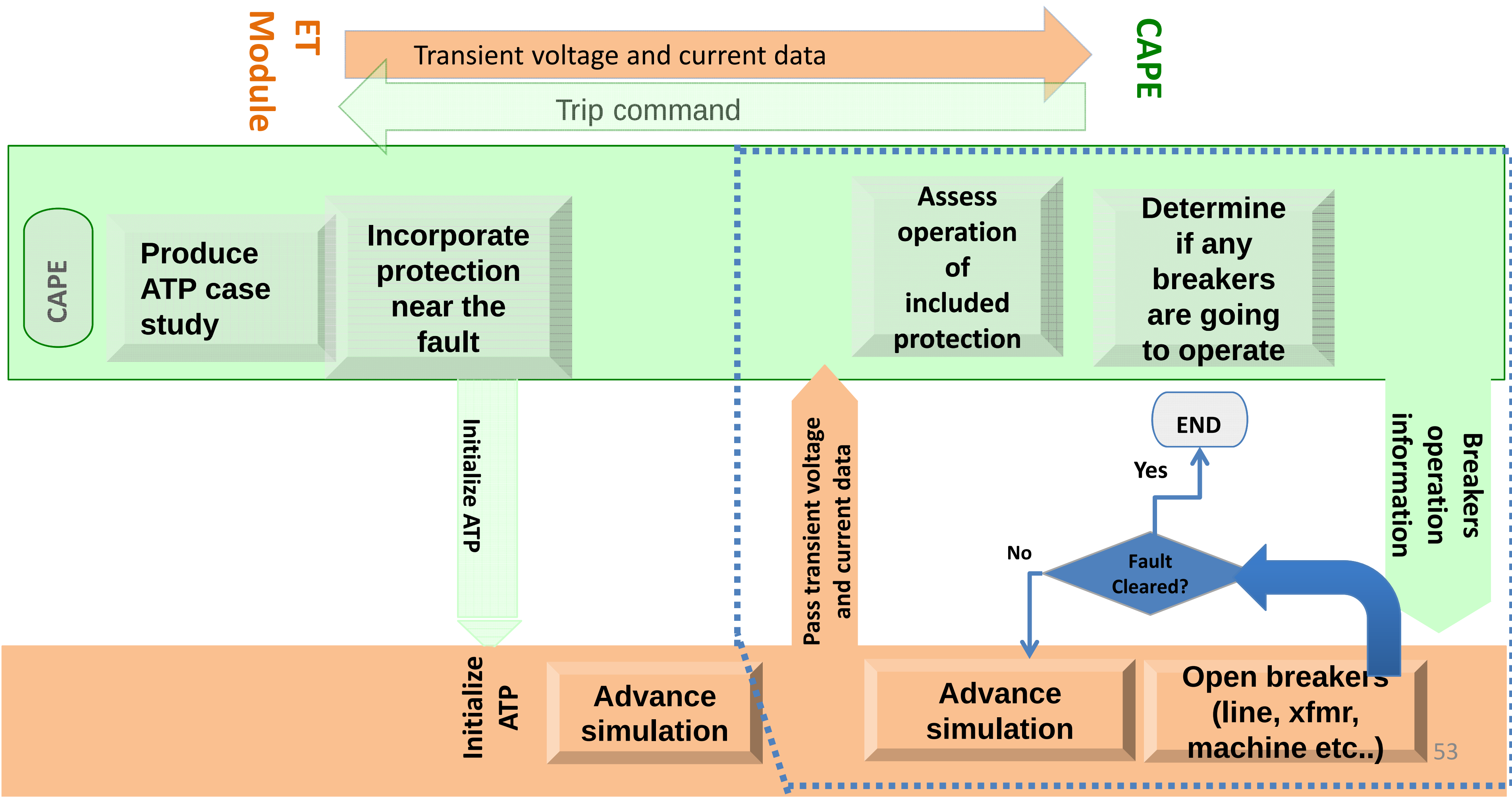
Significance for Protection

- Integrate detailed protection models in EMT studies instead of "generic" type (assumed typical protection features).
- EMT analyses can study events that other methods cannot, e.g. faults on series compensated lines, influence of system unbalances on the protection, and instrument transformer saturation.

Integration Process: CAPE/EMT

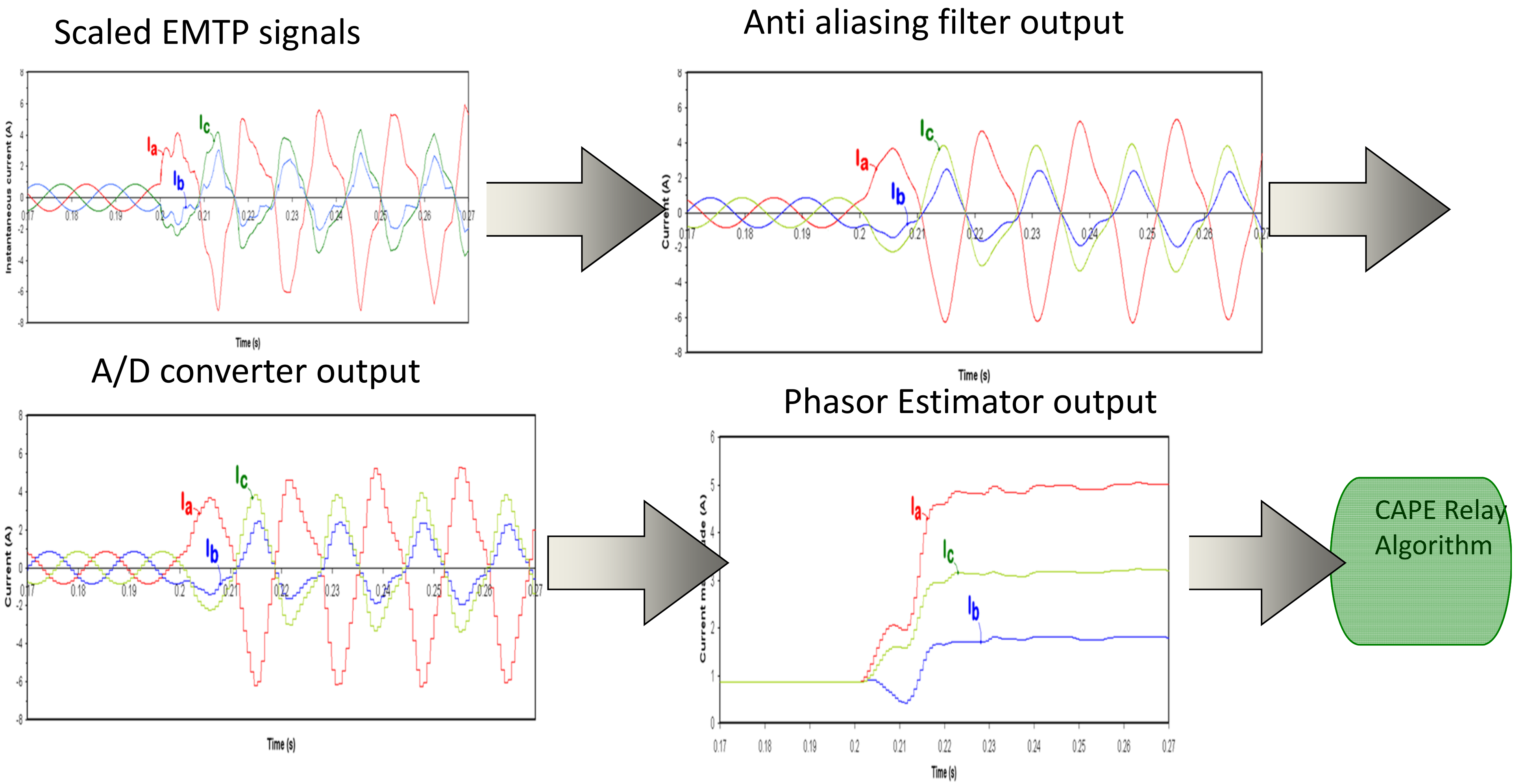
EMT → Models the electromagnetic dynamics of the system

CAPE → Models the response of the protection system



CAPE/EMT

Transient Numerical Relay Model



Next Steps: Address Challenges

- Computing Speed/Database size
- Manufacturer-specific relay models
  - Filter parameters
  - Sampling frequency
  - Algorithms
- Dynamic parameters:
  - PSSE user-defined dynamic models
  - EMTP specific models
    - Frequency dependent, constant parameters

Conclusions

- CAPE/PSSE Integration provides an robust interface between detailed protection models and operation and power system dynamic behavior at the quarter cycle resolution
- CAPE/ET Integration provides the capability to further investigate in a specific area at the micro-second resolution to better predict real system behavior.

Selected Publications

- Technical papers:

  - Yong Liu; Joe R. Gracia, Thomas J. King, Yilu Liu, "Construction of the United States Eastern Interconnection (EI) Planning Model with High Penetration of Renewable Energy Resources," IEEE Transactions on Power Systems, Special Section on Power System Planning and Operation towards a Low-Carbon Economy, under review.
  - Yong Liu; Joe R. Gracia; Thomas J. King; Yilu Liu, " Contribution of Variable-speed Wind Generation to Frequency Regulation in Eastern Interconnection (EI)," 2014 IEEE PES Transmission & Distribution Conference & Exposition.
  - Yong Liu; Joe R. Gracia; Thomas J. King; Yilu Liu, " Contribution of Variable-speed Wind Generation to Frequency Regulation and Oscillation Damping in Eastern Interconnection (EI)," IEEE Transaction on Sustainable Energy, to be published.
  - Yong Liu; Joe R. Gracia; Thomas J. King; Yilu Liu, " Contribution of Variable-speed Wind Generation to Frequency Regulation and Oscillation Damping in Eastern Interconnection (EI)," CURENT 2013 Annual Meeting, April 2013.
  - *G. Kou, S. Hadley, Y. Liu, and P. Markham, "Developing Generic Dynamic Models for the 2030 Eastern Interconnection Grid," Oak Ridge National Laboratory (ORNL) Report, Oak Ridge, TN, USA, Dec. 2013.*
  - *G. Kou, S. Hadley, Y. Liu, T. King, J. Culliss, J. Stovall, "Developing Generic Dynamic Models for the 2030 Eastern Interconnection Grid," in Proc. 2014 IEEE PES Transmission and Distribution Conference and Exposition (T&D).*
  - *G. Kou, S. Hadley, Y. Liu, T. King, "Developing Dynamic Models for the 2030 Eastern Interconnection Grid," in Proc. 2014 IEEE PES General Meeting.*
  - *G. Kou, S. Hadley, Y. Liu, "Dynamic Model Validation with Governor Deadband on the Eastern Interconnection," Oak Ridge National Laboratory (ORNL) Report, Oak Ridge, TN, USA, Feb. 2014.*

- Book chapter:

  - Yong Liu; Joe R. Gracia; Thomas J. King; Yilu Liu, Large Scale Renewable Power Generation: Advances in Technologies for Generation, Transmission and Storage by Springer.

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