2014 WIND POWER PROGRAM PEER REVIEW

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

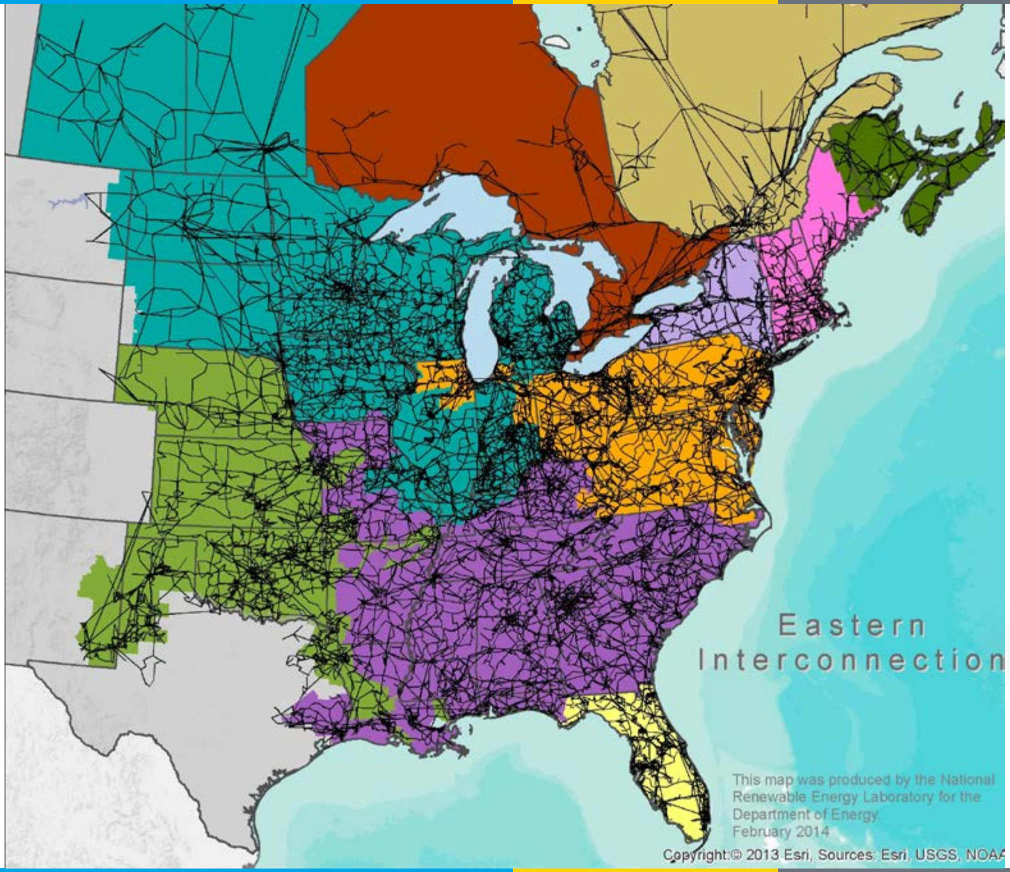
Advanced Grid Integration

March 24-27, 2014

Wind Energy Technologies

PR-5000-62152

Contents



Eastern Renewable Generation Integration Study (ERGIS)

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March 24-28, 2014

Budget, Purpose, & Objectives

Total DOE Budget[1]: $0.530M

Total Cost-Share[1]:$1.075M

Problem Statement: State renewable portfolio standards are driving utilities across the United States to adopt higher penetrations of variable renewable energy. Although power systems have been designed to handle the variable nature of loads, the additional supply-side variability and uncertainty can pose operational challenges for utilities, RTOs, and ISOs.

Impact of Project: ERGIS aims to answer critical questions about how the Eastern Interconnection could be operated by analyzing two strategies for reaching 30% combined wind and solar targets and informing stakeholders about the operational impacts of these two strategies. Among other things, the study will look at system balancing, reserve sharing, net interchange, demand response, and dispatch sequence.

This project aligns with the following DOE Program objectives and priorities

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost-effective dispatch of wind energy onto the grid
- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization
- **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

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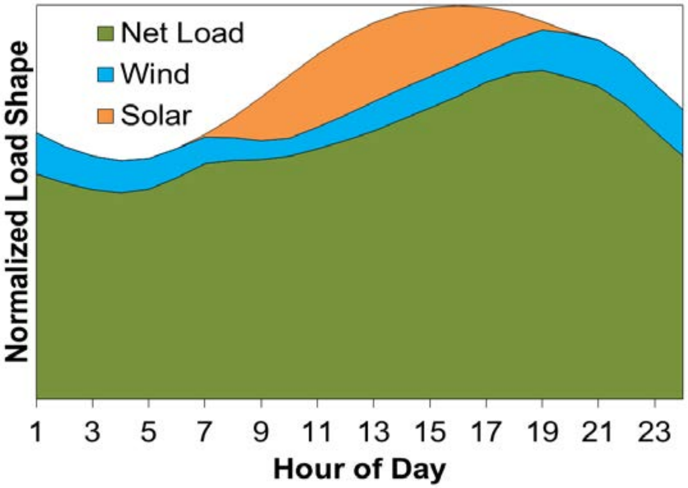

- Approach
  - Develop a 5-minute nodal model of the entire Eastern Interconnection plus Hydro Quebec
    - o 75,000 transmission elements
    - o 6,000 lines > 200 kV
    - o 60,000 buses
    - o 8,000 generation units
  - Conduct statistical analyses to characterize the variability and uncertainty in wind, solar and load data
  - Implement a reserve approach to meet system-wide variability and uncertainty
  - Incorporate datasets into model and run production cost simulations
  - Analyze operational practices and tools that impact production costs
  - Conduct sensitivity analyses

Technical Approach

- Key Issues and Solutions
  - Industry Buy-in→ Technical Review Committee
  - Wind Statistical Analysis→ Wind data fix
  - Database Creation→ Critical Energy Infrastructure Information (CEII) Clearance
  - Solar Data→ 5-minute 10-km grid Eastern Solar Dataset
  - Load Data→ Created 5-minute load data for each BA
  - Thermal Expansions→ ReEDS Capacity Expansion Model
  - Hydro Modeling→ Work with Federal and Canadian Agencies
  - Thermal Plant Assumptions→ Operational Characteristics (e.g., heat rates, ramp rates, min up and down)
  - Solve Time→ High Performance Computing (HPC)
  - Big Data → High resolution data visualization

- Wind Data Fix
  - Fix statistical outliers that occur at 12-hour intervals due to weather model initialization
- Result
  - More accurate ramp statistics
  - More realistic commitment and dispatch

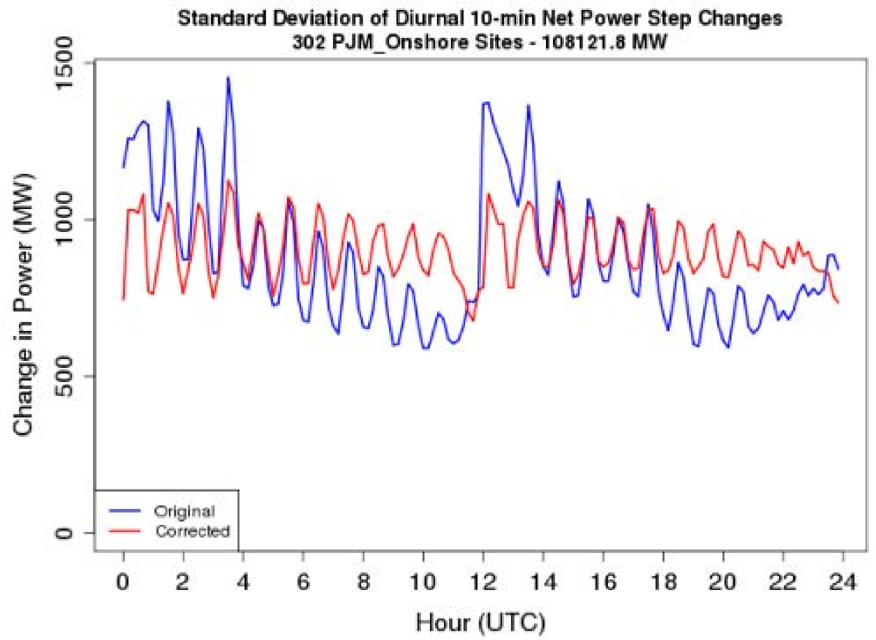

Figure 3. Diurnal mean standard deviation of 10-minute net power deltas from 302 onshore sites within the PJM region before (blue) and after (red) the diurnal correction was applied for the years 2004-2006.

Accomplishments and Progress

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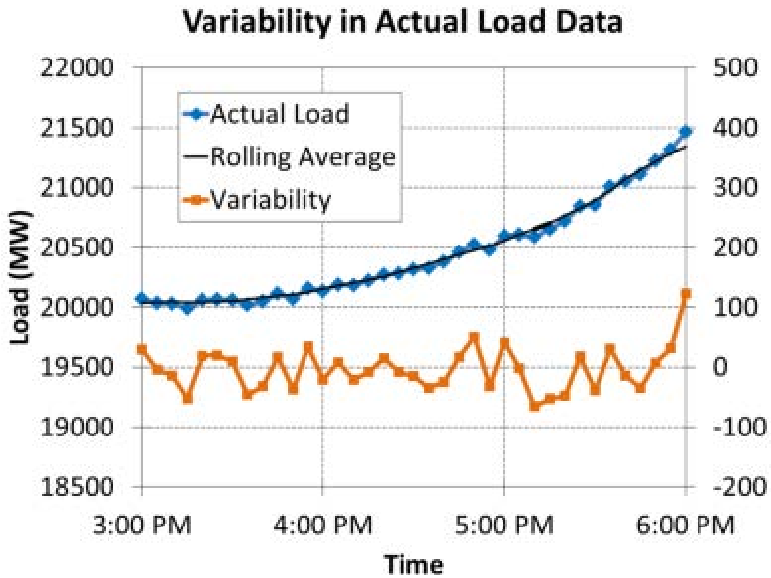
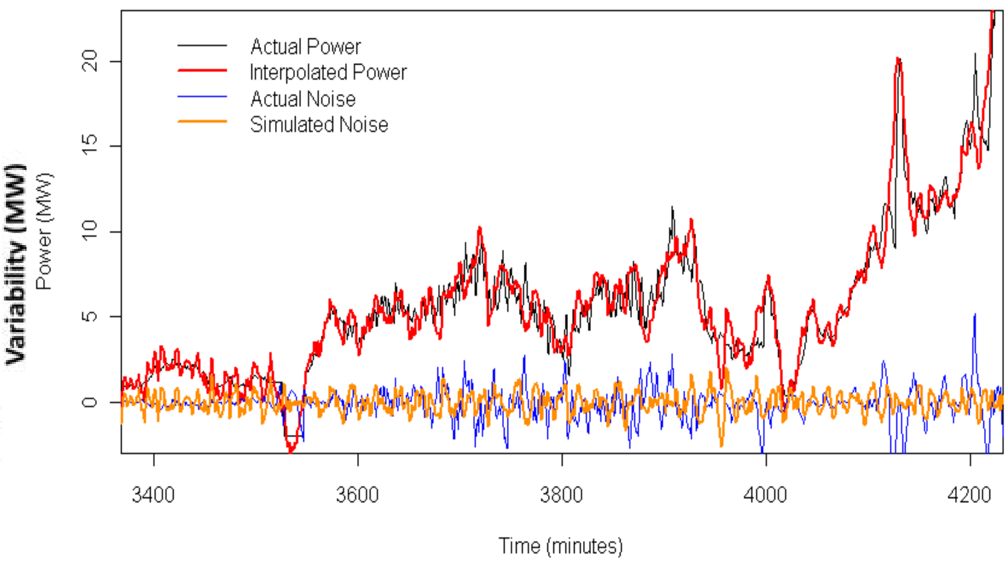
- Sub-Hourly Load Data
  - Created 5-minute load data from hourly FERC data
- Result
  - Accurately model 5-minute operation of system

- 5-Minute Wind Data
  - Created 5-minute wind data from 10-minute wind data
- Result
  - Accurately model 5-minute operation of the system





Accomplishments and Progress

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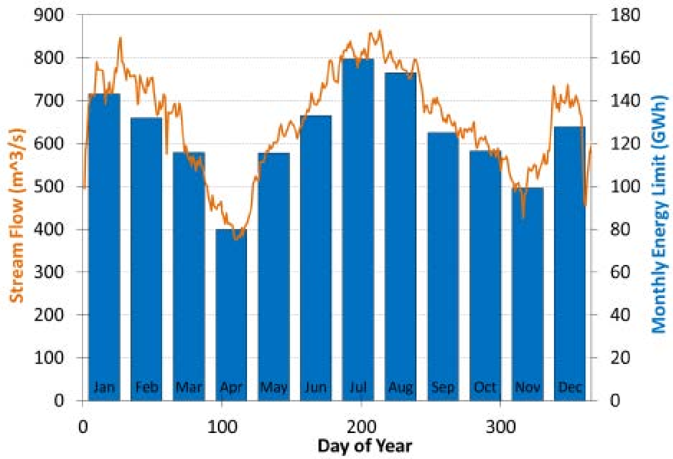
- Generator Working Group
  - Expansion and retirement
  - Ramp rates, heat rates, etc.
- Result
  - Accurate representation of actual operations
  - Options for sensitivity analyses, e.g., CC vs. CT

- Canadian Working Group
  - Significant trade between United States and Canada
  - Hydro modeling assumptions
- Result
  - Expect significant changes in flows from historical
  - Proxy generators not appropriate

Installed Capacity (GW)	Nuclear	Coal	CC	CT
Current VG	88	208	185	187
State RPS	88	195	175	198
Regional 30%	88	182	154	145
National 30%	88	171	173	153



Accomplishments and Progress

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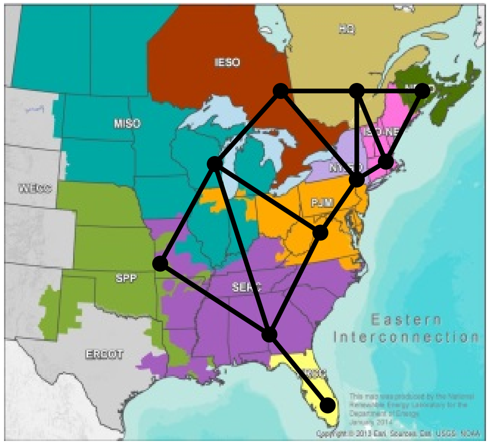
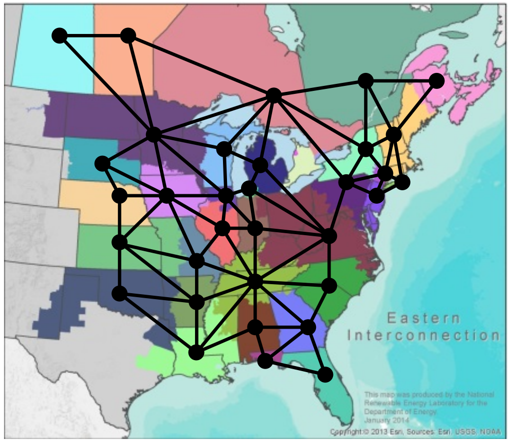
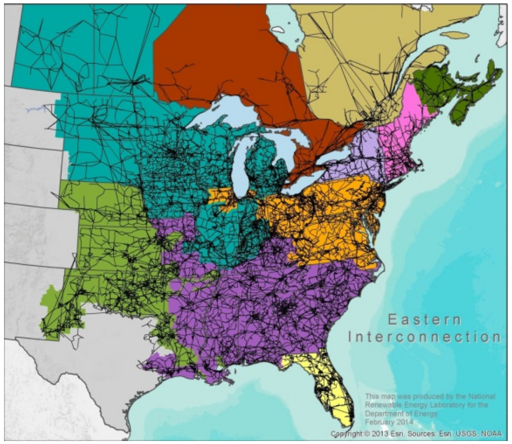
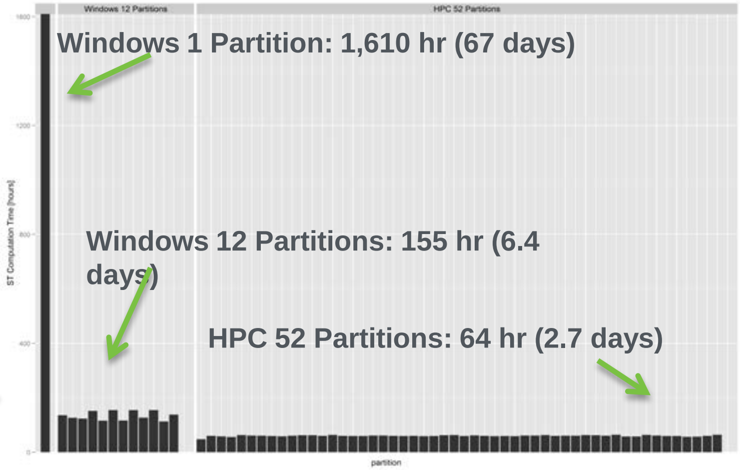
Transmission Working Group

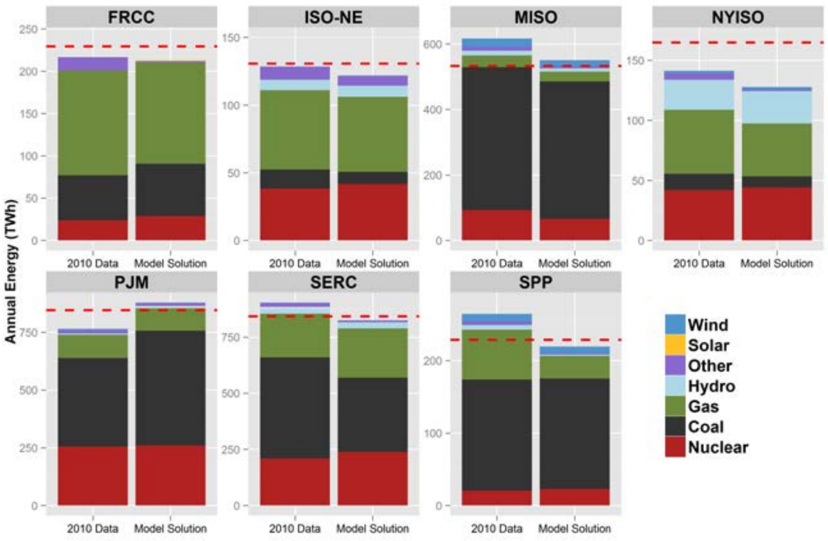


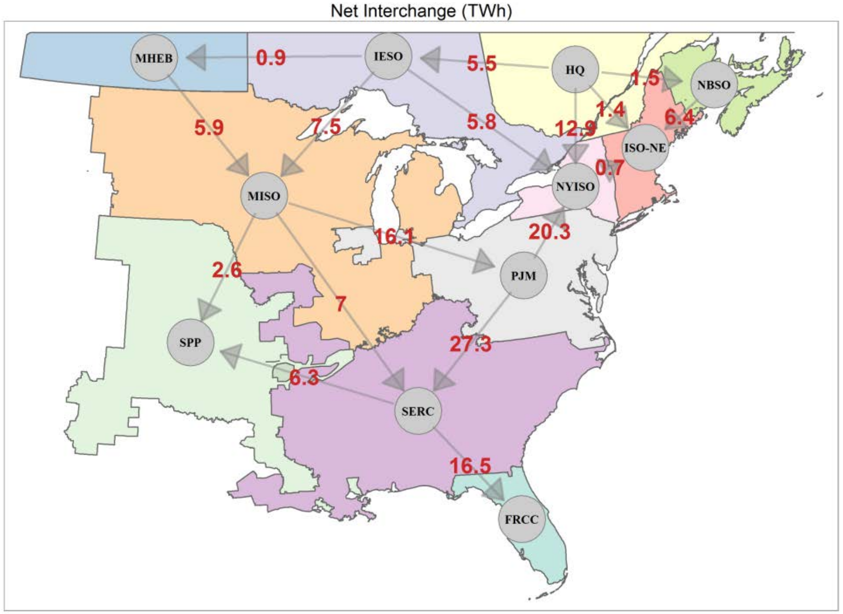




- Results
  - Accurate representation of power flows
  - Accurate generation dispatch and commitment
  - Dramatic reduction in solve time while increasing fidelity







2010 Benchmarking

- Nodal transmission
- Mixed integer programing
- Modeled results compared to historical and approved by TRC
- Generation and flows similar to available historical data

Project Plan & Schedule

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Summary		Legend	
WBS Number or Agreement Number 8			Work completed
Project Number			Active Task
Agreement Number			Milestones & Deliverables (Original Plan)
			Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)
Project Name: Eastern Renewable Generation Integration Study											
Q1 FY 13 Milestone: Interim Report on Modeling Results											
Q2 FY13 Milestone: Proposed Reserve Strategies											
Q3 FY13 Milestone: Interim Report on Modeling Results											
Q4 FY13 Milestone: Technical Paper or Presentation											
Q2 FY14 Milestone: Present Initial Modeling Results to TRC											
Q4 FY 14 Milestone: Develop Sensitivities with Mitigation Options Working Group											

Comments

- Initiation: FY 12
- Completion: FY 15
- Data errors and the lack of an EI database created substantial delays
- Project was re-scoped to reflect need to develop EI database
- Delays have largely been addressed with recently completed database and HPC

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

Subcontracts: Gary Jordan, Jack King, Brendan Kirby
Technical Review Committee: 30+ industry and research organizations:

American Public Power Association, American Wind Energy Association, Com Edison, Edison Electric Institute, Eastern Interconnection Planning Collaborative, Energy Systems Consulting, EnerNex, Electric Power Research Institute, Exelon, General Electric, GR Energy, ISO-New England, Lawrence Berkeley National Laboratory, Manitoba Hydro, Michigan PUC Midcontinent Independent System Operator, National Rural Electric Cooperative Association, Oak Ridge National Laboratory, Ontario Power Authority, PJM Interconnection, Sandia National Laboratories, Southwest Power Pool, Utility Variable Generation Integration Group, Ventyx, Western Area Power Administration, Western Farmers, WindLogics

Communications and Technology Transfer:

Events: Six TRC Meetings, five Working Group Calls, Industry Conferences
Data Transfer: Eastern Wind Dataset, Eastern Solar Dataset

Next Steps and Future Research

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FY14/Current research:

- 2010 Benchmarking (completed)
- Port database to HPC environment (completed)
- HPC simulation of 2026 scenarios
- Work with TRC to develop sensitivity analyses
  - Interchange practices
  - Reserve sharing groups
  - Demand response
  - Operations sequence

Next Steps and Future Research

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Proposed Future Research:

- Bigger and New Studies
  - New Scenarios
    - High offshore-NOWEGIS
    - Higher penetrations
  - Transmission Studies
    - HVDC overlay
    - AC transmission expansion
- Deeper Analysis
  - Market Design
    - Flexibility incentives
    - Demand response
    - Capacity markets
    - Revenue sufficiency
  - FESTIV analysis on selected ERGIS time periods

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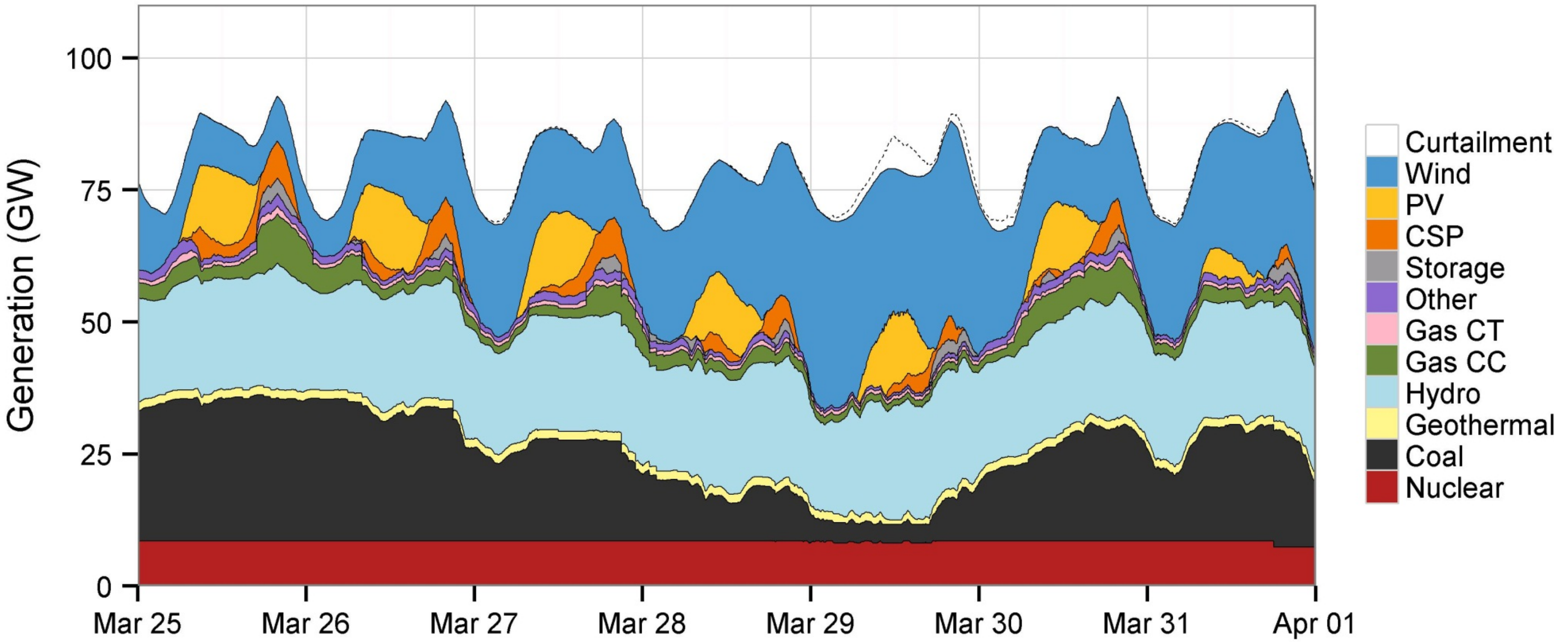

Western Wind and Solar Integration Study – Phase 2 and Phase 3

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March 24, 2014

Budget, Purpose, & Objectives

Total DOE Budget[1]: $0.630M

Total Cost-Share[1]:$0.000M

Problem Statement: Utilities, generator owners, operators, regulators and policy makers are concerned that high penetrations of renewable generation will adversely impact cycling on fossil-fueled generation and overall system reliability and stability.

Impact of Project: Demonstrate potential cycling impacts on fossil-fueled generators, as well as frequency response and transient stability, with high wind and solar penetration.

This project aligns with the following DOE Program objectives and priorities:

Mitigate Market Barriers: Reduce market barriers to preserve or expand access to quality wind resources

Advanced Grid Integration: Provide access to high wind resource areas, and provide cost-effective dispatch of wind energy onto the grid

Modeling & Analysis: Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization

[1]*Budget/Cost-Share for Period of Performance FY2012 – FY2013*

Technical Approach

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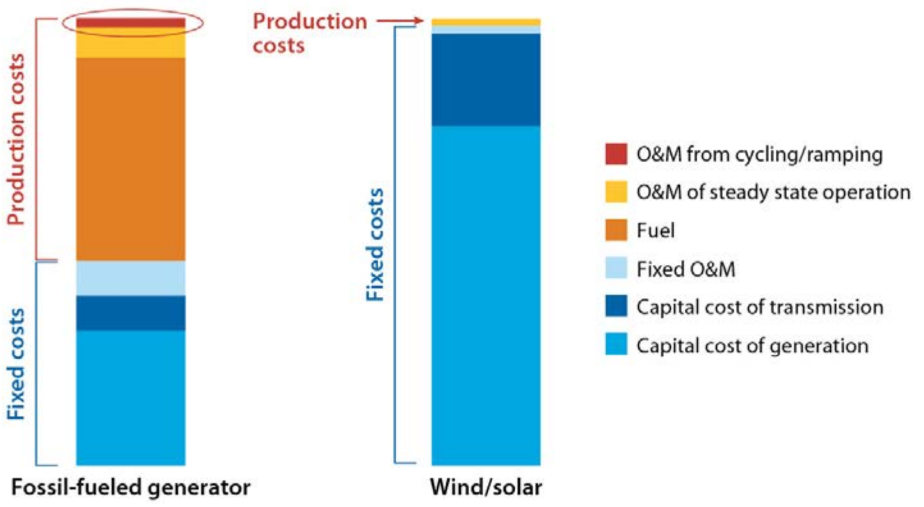
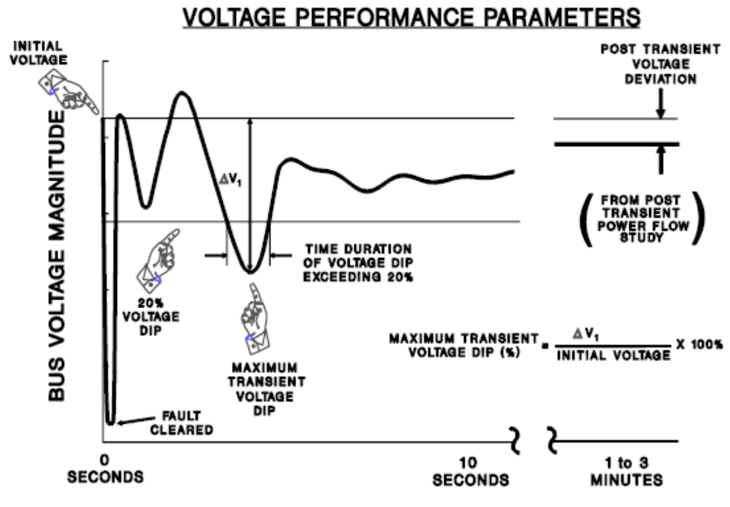
WWSIS Phase 2

- Technical Review Committee
- Develop databases & methods
- Production simulation analysis

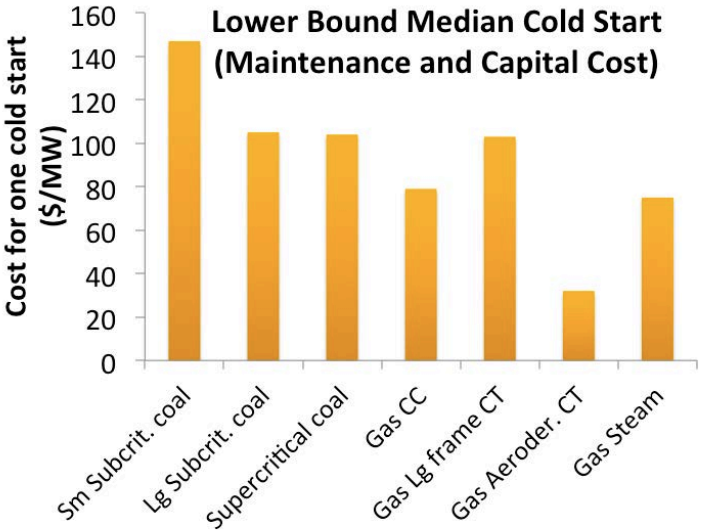


WWSIS Phase 3

- Technical Review Committee
- Develop databases and methods
- Frequency response analysis
- Transient stability performance



Note: WECC Voltage Performance Parameter figure from page XI-17 of http://www.wecc.biz/library/Library/Planning%20Committee%20Handbook/WECC-NERC%20Planning%20Standards.pdf



- WWSIS Phase 2
- Unprecedented detail
  - Subhourly solar and wind generation
  - Cycling costs (Intertek/Aptech)
  - Emissions impacts of cycling
  - Production cost modeling
- Evaluated cycling impacts from variable generation technologies
- Greg Brinkman and Debra Lew were awarded UVIG Achievement Awards for WWSIS Phase 2

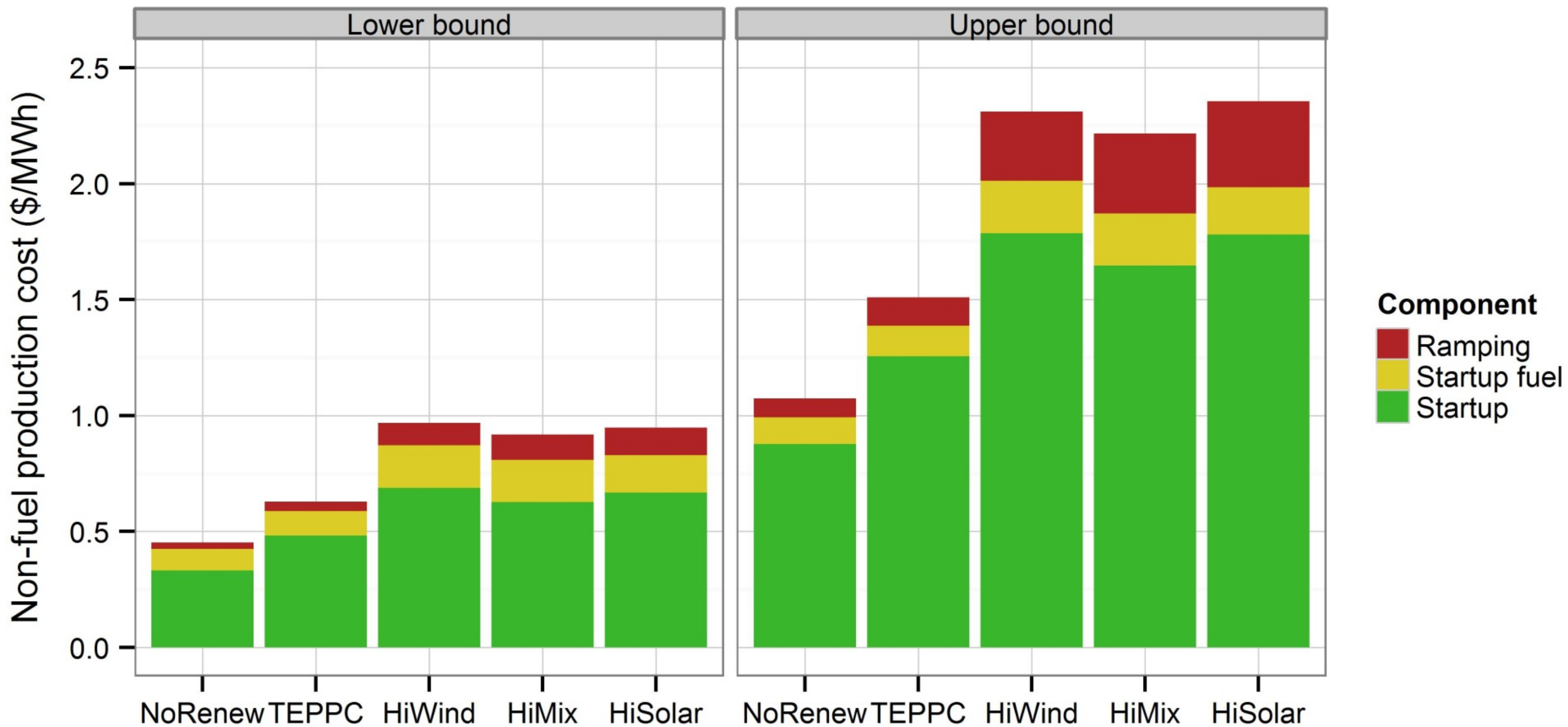
Cycling impact on emissions are relatively small with 33% renewables

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29%–34%	Negligible Impact
NO_X	170–230 million lbs 16%–22%	3–4 million lbs
SO_2	80–140 million lbs 14%–24%	3–4 million lbs

For the system, cycling costs are relatively small with 33% renewables

*High wind and solar scenarios. Capital costs are not reflected.

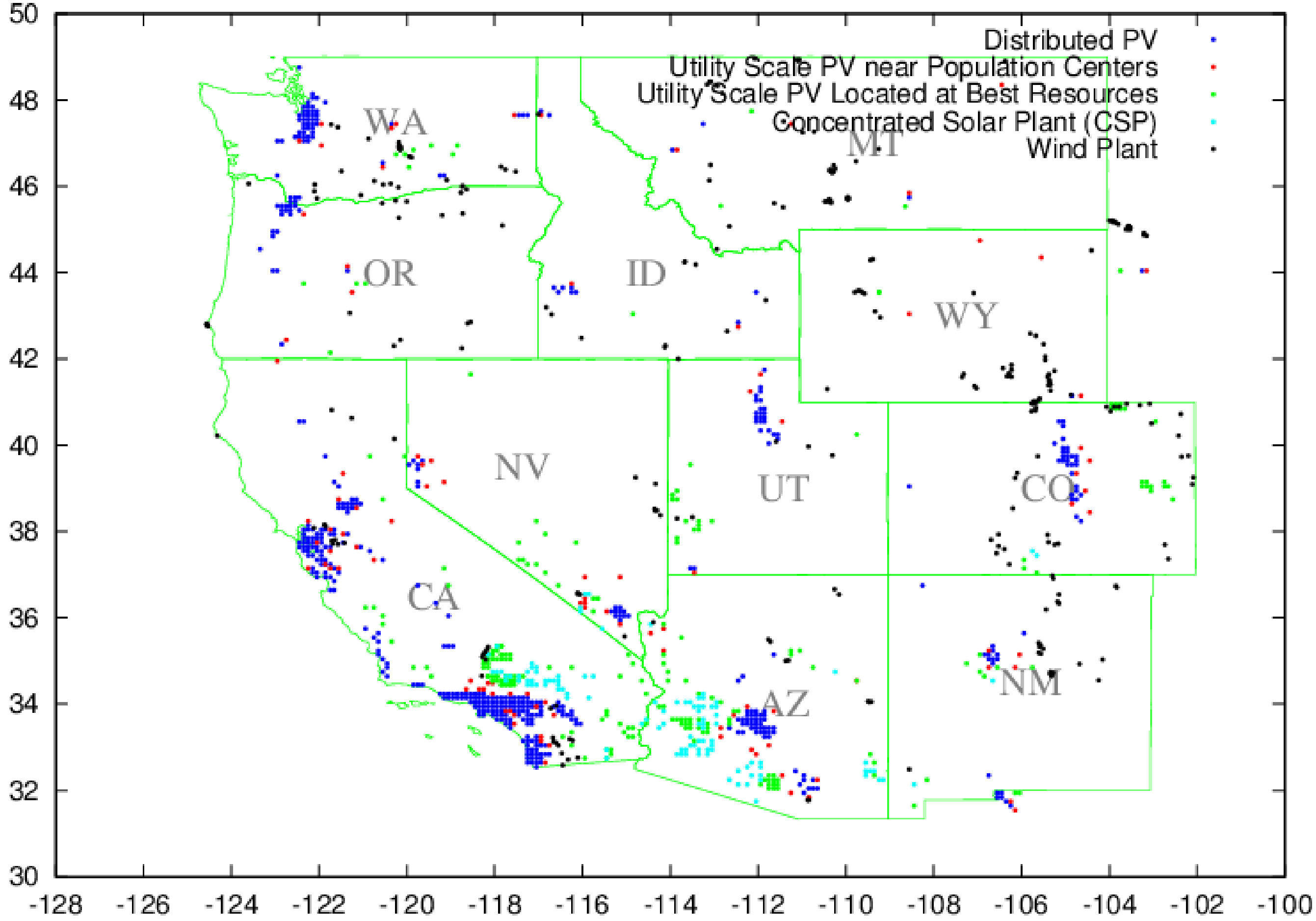
The average fossil-fueled plant sees an increase in O&M of $0.47-$1.28 per MWh generation



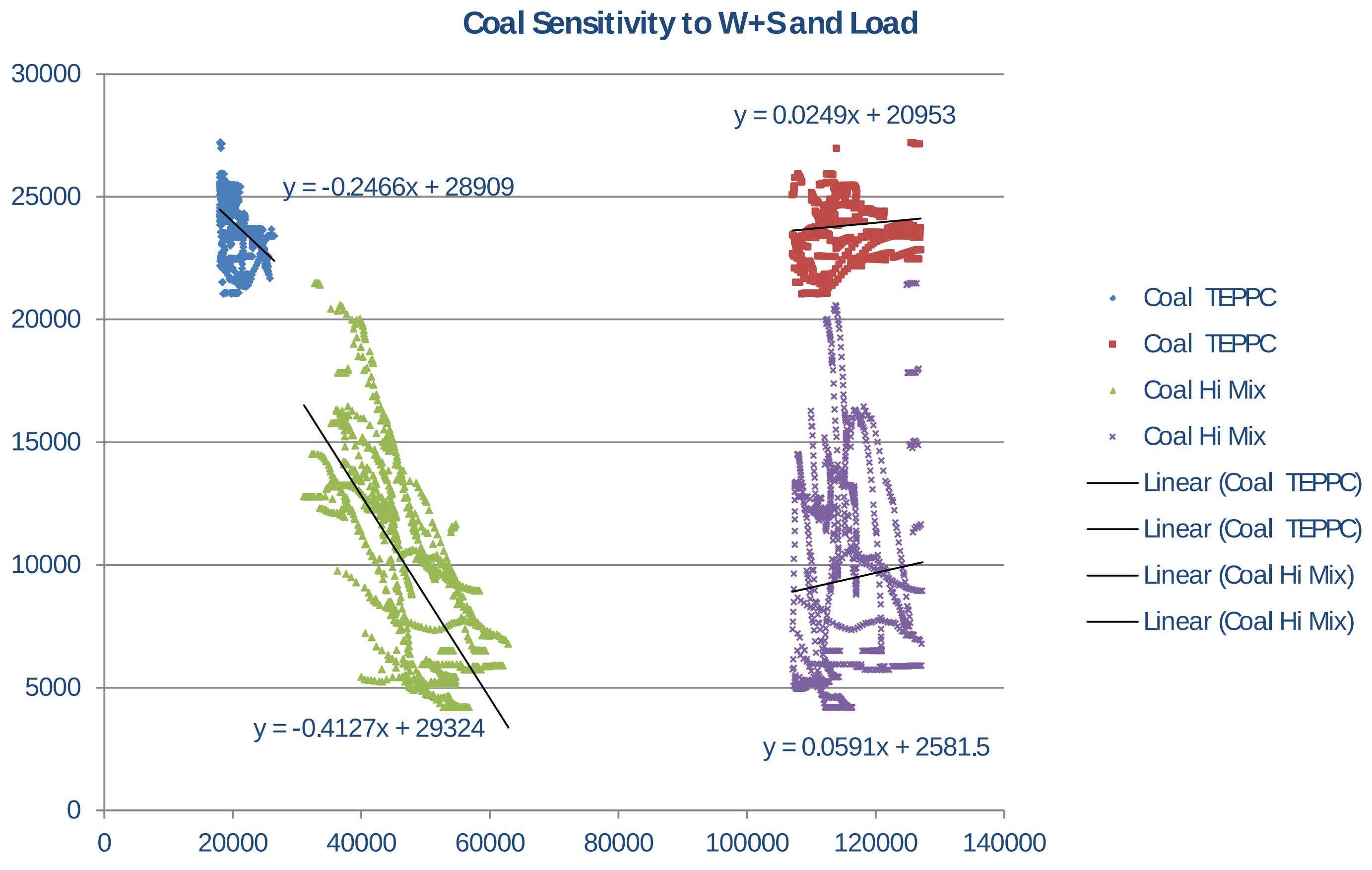
WWSIS Phase 2 Executive Summary: http://www.nrel.gov/docs/fy13osti/58798.pdf

WWSIS Phase 2 Final Report: http://www.nrel.gov/docs/fy13osti/55588.pdf

Use production simulation results to develop 33% renewable scenario (half wind, half solar)

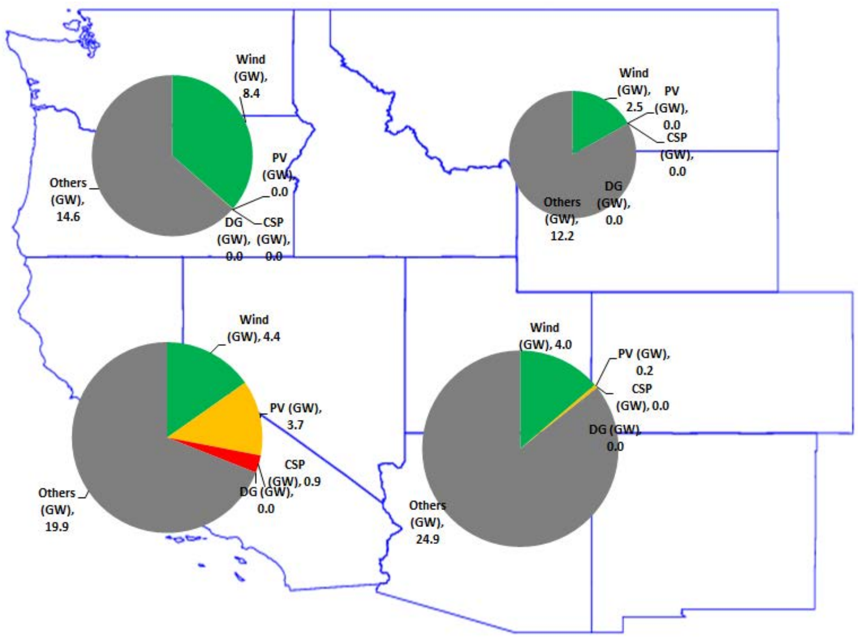


Use production simulation results to de-commit and re-dispatch thermal generation



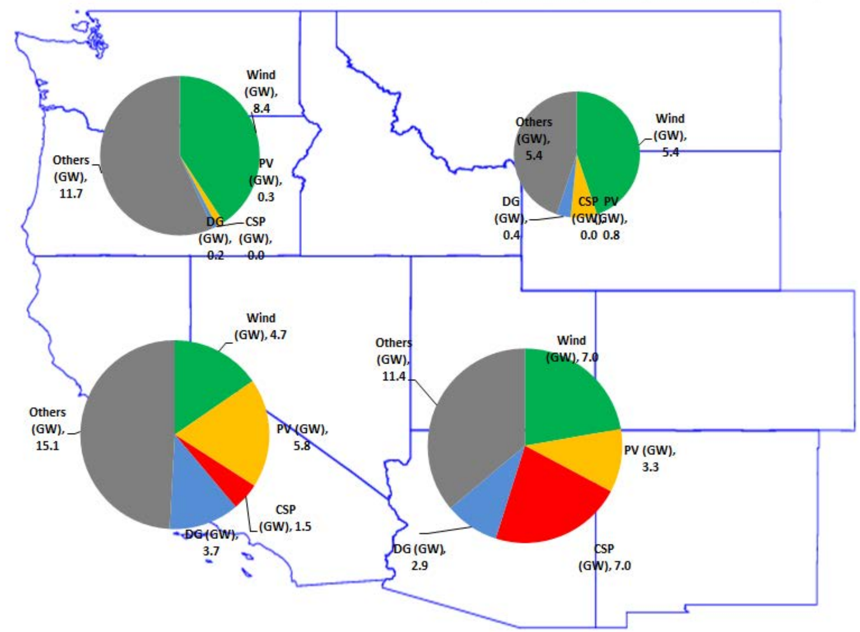
WWSIS 3 Light Spring scenarios

Reference Case



~21 GW Wind, ~5 GW Solar

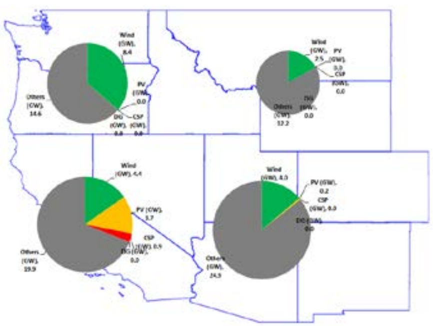
High Renewable Case



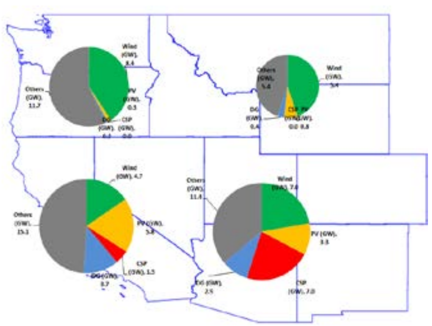
~27 GW Wind, ~25 GW Solar

WWSIS 3 Extreme Light Spring scenario

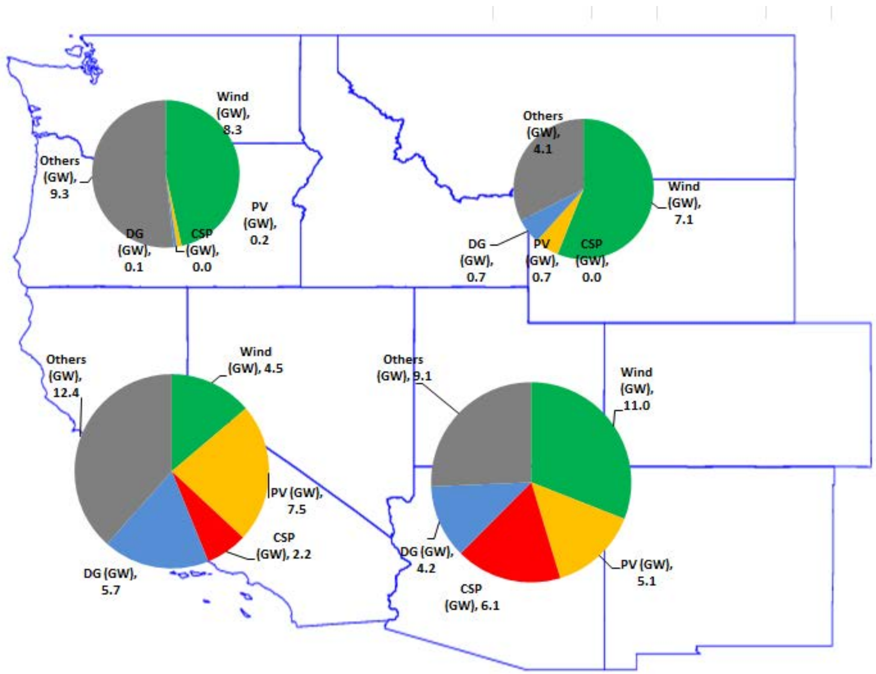
Reference Case



High Renewable Case



Extremely High Renewable Case



~33 GW Wind, ~32 GW Solar

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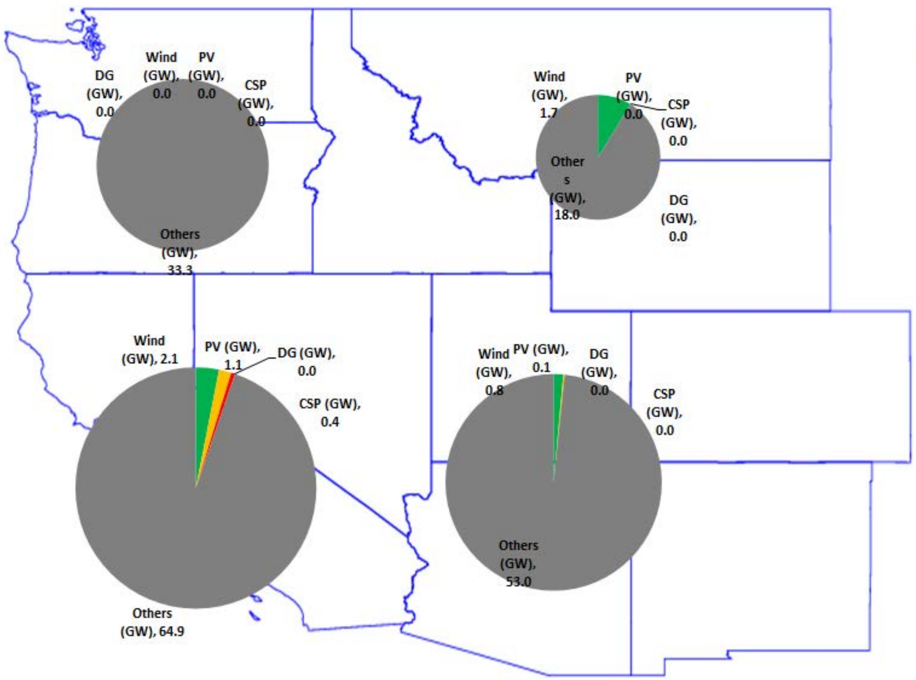
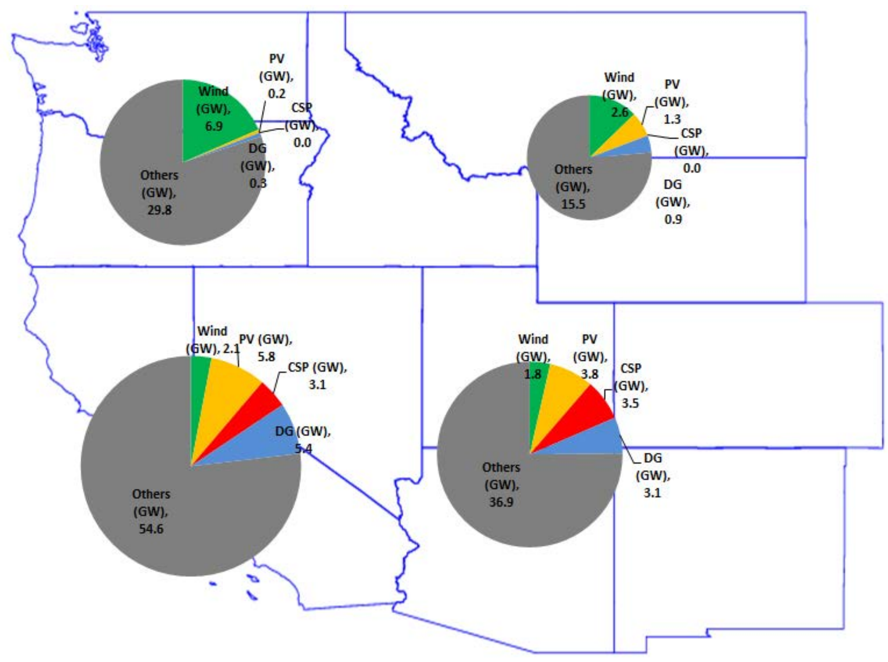
WWSIS 3 Heavy Summer scenarios

Reference Case



~5.6 GW Wind, ~1.6 GW Solar

High Renewable Case



~14 GW Wind, ~27 GW Solar

Project Plan & Schedule

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Summary		Legend	
WBS Number or Agreement Number			Work completed
Project Number			Active Task
Agreement Number			Milestones & Deliverables (Original Plan)
			Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Establish TRC to review frequency response and transient stability project and provide input and feedback												
Develop scenarios to run in PLEXOS to examine the operational strategies and retrofits												
Complete technical report discussing cost-benefit analysis of fossil fleet retrofits in the Western Interconnection.												
Presentation of transmission expansion for the Western Interconnection to TRC												
Presentation of preliminary results on production simulation modeling to stakeholders												
Report on production simulation modeling results for use in determining cycling impacts on thermal generation												
Current work and future research												
TRC meeting, results deep dives, sensitivity cases												
TRC webinar, sensitivity analysis, preliminary results memo												
Draft final report to DOE & TRC for review												

Comments

- 3-year period of performance, FY13-FY15
- No slips in milestones or schedule

Partners, Subcontractors, and Collaborators:

TRC consisted of stakeholders at utilities and industry groups, research institutions, and system operators. Subcontracts include GE Energy, Intertek/APTECH, and RePPAE.

Communications and Technology Transfer:

WWSIS Phase 2 was presented to the Utility Variable-Generation Integration Group, International Workshops on Wind and Solar Integration, Western Interstate Energy Board, Solar Power International, IEA Storage Workshop, Wind Powering America webinar, Westconnect, and other stakeholders.

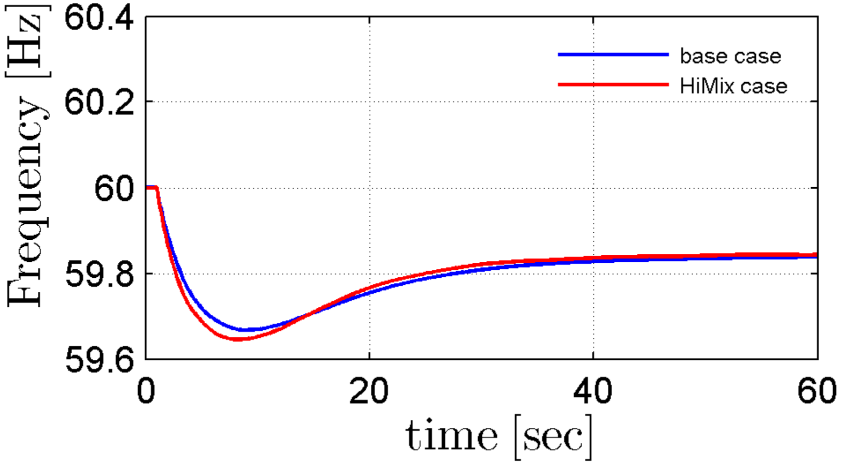
WWSIS Phase 3 will be similarly presented at workshops, seminars, and other forums in FY15, based on funding.

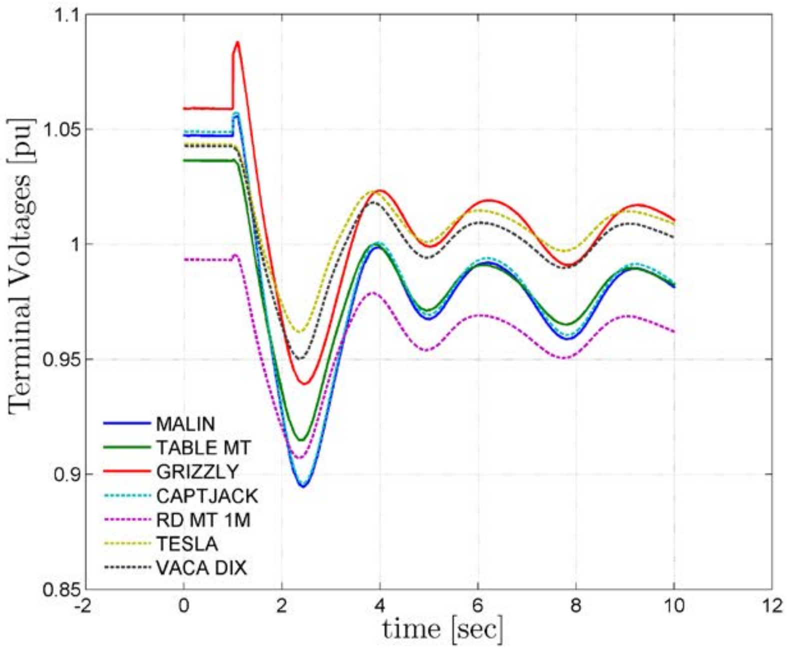
Next Steps and Future Research

FY14/Current research:

WWSIS Phase 3

- Frequency response
- Transient stability
- Sensitivity analysis
- Mitigation options
- Final report





Next Steps and Future Research

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Proposed future research:

- **Impact of load modeling on system performance.** Different load models can result in different system responses – sometimes better, sometimes worse. What are the implications for adoption of renewables with different load models?
- **Additional sensitivity analysis.** Build on the existing databases to evaluate the impact of different redispatch/decommitment approaches, different levels and/or mixes of renewable generation, etc. How sensitive is system performance to changes in the generation portfolio?
- **Impact of distributed generation on system performance.** Analyze impact of various DG generation controls in light of the desired reconciliation of Order 661 and IEEE 1547.

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Integration Support/UVIG

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2/27/2014

Budget, Purpose, & Objectives

Total DOE Budget[1]: $1.464M

Total Cost-Share[1]:$0.670M

Problem Statement: Many key stakeholders in power system planning and operations need access to best practices for integrating wind energy that result from actual practice and analysis/modeling.

Impact of Project: Analysis of value of forecasting and faster scheduling, along with NOI comments, helped spur FERC Order 764.

- Presentations of WWSIS-1 and other evaluations of BA cooperation helped inspire energy imbalance market (EIM) proposal, led to CAISO-PAC EIM in 2014, likely NV Energy in 2015, and others.
- NREL helped improve WECC modeling in transmission planning.
- Wind, solar, emissions, and wear/tear data are used by WECC and industry.
- NERC IVGTF and IEEE Capacity Value Task Force recommendations led to CA using the probabilistic method for resource adequacy/capacity value.
- NREL helped train state legislators (~40 energy committee chairs).

[1] *Budget/Cost-Share for Period of Performance FY2012 – FY2013*

Budget, Purpose, & Objectives

Impact of Project: *continued*

- CEC requested a presentation of the WGA policymaker report on mitigating integration impacts and incorporated it into its record of proceedings
- NREL worked with PacifiCorp who recently reduced integration cost estimates from $9.70 per MWh to $1.90 per MWh

This project aligns with the following DOE Program objectives and priorities:

Advanced Grid Integration: Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Objectives
  - Synthesize key results from NREL grid-integration work and that of others
  - Disseminate information, results, data, and tools to key stakeholders
  - Ensure state-of-the art results, methods, and data in wind integration reach critical decision makers
- Approach—address 3 groups
  - Regulatory and legislative
  - Technical committees (e.g., IEA Task 25, IEEE, NERC, WECC, and Technical Review Committees for integration studies)
  - Wind energy/utility forums (e.g., UVIG)
- External review
  - Integration Support Review Committee meets annually to provide input and feedback to this project

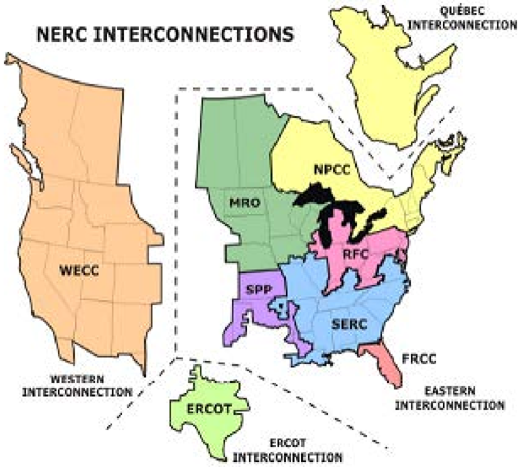
Accomplishments and Progress

- Regulatory and legislative engagement
  - Webinar series
  - FERC briefings in Jan., Feb., and May
  - NARUC meeting exhibit/participation—event at NREL July 24 for NARUC summer meetings
  - Legislative training—joint NCSL webinar
- Wind/utility forums
  - Utility Variable-generation Integration Group (UVIG) —fall and spring technical meetings, forecasting workshop, short course, and DG users groups (12 workshops/classes in 2012-2013)
  - Papers/presentations—AWEA, IEEE, and others
  - North American Wind Energy Academy
  - WAPA training

Accomplishments and Progress

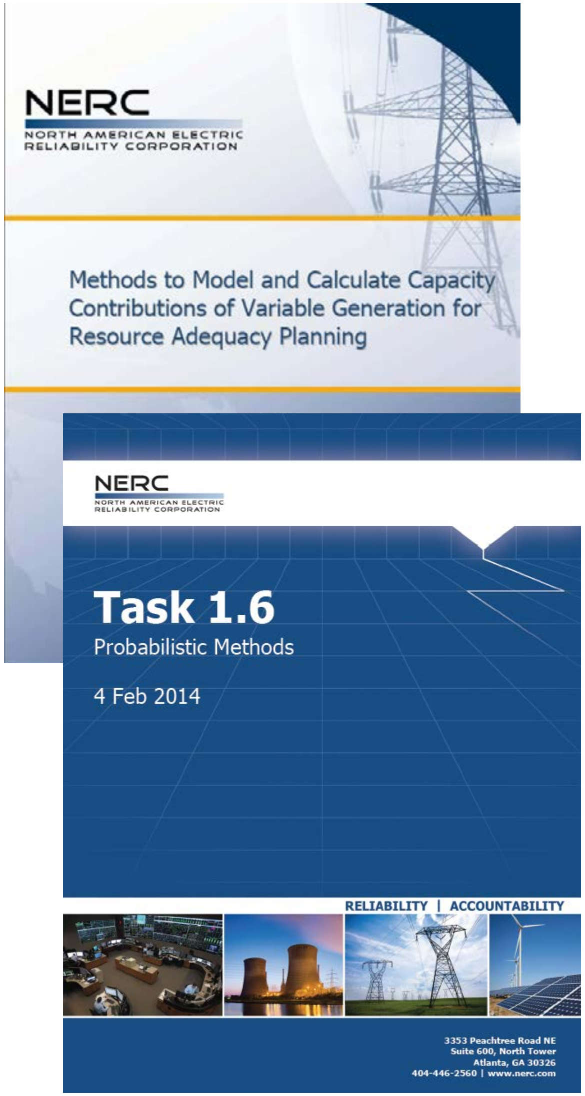
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Technical committees and task forces
  - Webinar for WECC VGS on methods for calculating flexibility reserves
  - WECC Variable Generation Subcommittee, Operating Committee, Market Committee
  - IEA Task 25—Design and Operation of Power Systems with Large Amounts of Wind Energy
  - IEEE WSPCC—sessions and super sessions
    - Presentations/papers on integration study and data requirements
  - IEEE Loss of Load Expectation Working Group
  - Technical Review Committees
    - Portland General Electric (PGE) —early phases complete, more anticipated
    - Minnesota Renewable Integration and Transmission Study (MRITS)—in process
    - PG&E Flexibility and Modeling—in process
    - Pan-Canadian Study—in process, includes some U.S. interchange and may lead to future North American study
    - PacifiCorp—completed



Accomplishments and Progress

- North American Electric Reliability Corporation (NERC): Integrating Variable Generation Task Force (IVGTF)
  - 2009—NREL contributed to “Accommodating High Levels of Variable Generation” NERC report
  - 2010-2012—NREL led Task Force 1.2 (Capacity Value), 1.4 (Flexibility), 2.4 (Operating Practice); contributed to 2.1 (Forecasting), 2.3 (Ancillary Services)
  - 2014—NREL led Task Force 1.6 (Probabilistic Methods—delayed to obtain industry review—and presented at March 2014 NERC Planning Committee Meeting), 3.1 (Reference Manual—delayed pending NERC approvals of 1.6 and 1.7)



Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Related publication

- Milligan, M.; Donohoo, P.; O'Malley, M. (2012). Stochastic Methods for Planning and Operating Power Systems with Large Amounts of Wind and Solar Power: Preprint. 8 pp.; NREL Report No. CP-5500-56208. 11th Annual International Workshop on Large-Scale Integration of Wind Power, Nov. 2012

Significance of IVGTF Effort

- NERC is the reliability organization for North America and sets rules and best practices
- Recognition of the role of variable generation in the future generation mix
- Next phase of work will establish a combination of NERC-recommended best practices and reliability rules
- Will set the reliability framework for integrating large amounts of wind energy on the bulk power system

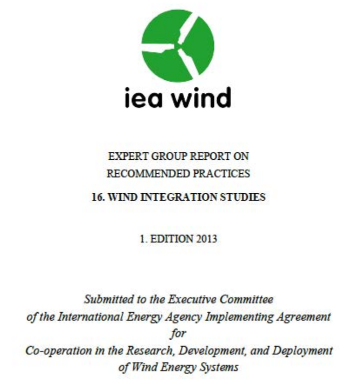
International Energy Agency (IEA) Task 25: Design and Operation of Power Systems with Large Amounts of Wind Energy

- Convene international experts on wind integration and hold bi-annual meetings
- Objectives
  - Share best practices in wind integration and study methods
  - Provide an international forum for exchange of knowledge
  - Recommend methods and guidelines
- 15 Countries
  - Canada, China, Denmark, Finland, Germany, Ireland, Italy, Japan, Norway, Netherlands, Portugal, Spain, Sweden, United Kingdom, United States

Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- IEA Task 25: Design and Operation of Power Systems with Large Amounts of Wind Energy
  - Attended bi-annual meetings in 2012-2013 (excludes fall 2013 cancellation due to U.S. government shutdown)
  - Selected IEA publications with NREL participation
- IEA Wind Recommended Practice 16. Wind Integration Studies (2013)
- Short-Term Energy Balancing with Increasing Levels of Wind Energy, IEEE Transactions on Sustainable Energy (2012)
- The Flexibility Workout: Managing Variable Resources and Assessing the Need for Power System Modification. IEEE Power and Energy (2013)
- Wind Integration Cost and Cost-Causation. 12th Wind Integration Workshop on Large-Scale Integration of Wind Power into Power Systems (2013)
- Wind and Solar Curtailment, 12th Wind Integration Workshop on Large-Scale Integration of Wind Power into Power Systems (2013)

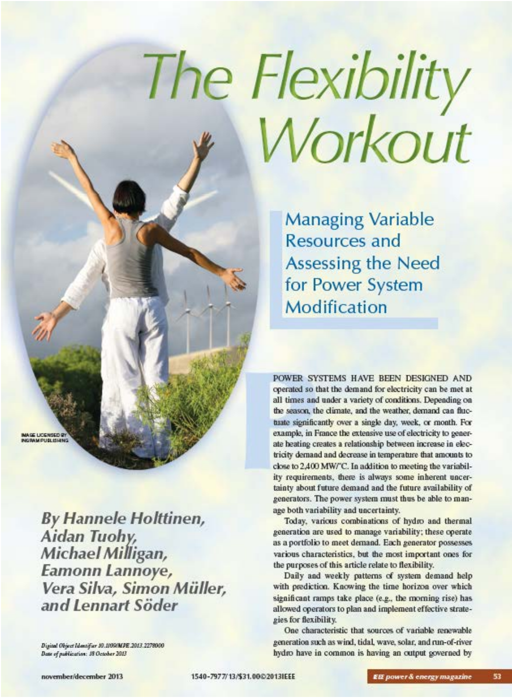


iea wind

EXPERT GROUP REPORT ON
RECOMMENDED PRACTICES
16. WIND INTEGRATION STUDIES

1. EDITION 2013

Submitted to the Executive Committee
of the International Energy Agency Implementing Agreement
for
Co-operation in the Research, Development, and Deployment
of Wind Energy Systems



The Flexibility Workout

Managing Variable Resources and Assessing the Need for Power System Modification

IMAGE LICENSED BY INGRAM PUBLISHING

By Hannele Holttinen, Aidan Tuohy, Michael Milligan, Eamonn Lannoye, Vera Silva, Simon Müller, and Lennart Söder

Digital Object Identifier 10.1109/MPE.2013.2278000
Date of publication: 18 October 2013

POWER SYSTEMS HAVE BEEN DESIGNED AND operated so that the demand for electricity can be met at all times and under a variety of conditions. Depending on the season, the climate, and the weather, demand can fluctuate significantly over a single day, week, or month. For example, in France the extensive use of electricity to generate heating creates a relationship between increase in electricity demand and decrease in temperature that amounts to close to 2,400 MW/°C. In addition to meeting the variability requirements, there is always some inherent uncertainty about future demand and the future availability of generators. The power system must thus be able to manage both variability and uncertainty.

Today, various combinations of hydro and thermal generation are used to manage variability; these operate as a portfolio to meet demand. Each generator possesses various characteristics, but the most important ones for the purposes of this article relate to flexibility.

Daily and weekly patterns of system demand help with prediction. Knowing the time horizon over which significant ramps take place (e.g., the morning rise) has allowed operators to plan and implement effective strategies for flexibility.

One characteristic that sources of variable renewable generation such as wind, tidal, wave, solar, and run-of-river hydro have in common is having an output governed by

november/december 2013 1540-7977/13/$31.00©2013IEEE IEEE power & energy magazine 53

IEA Task 25: Design and Operation of Power Systems with Large Amounts of Wind Energy

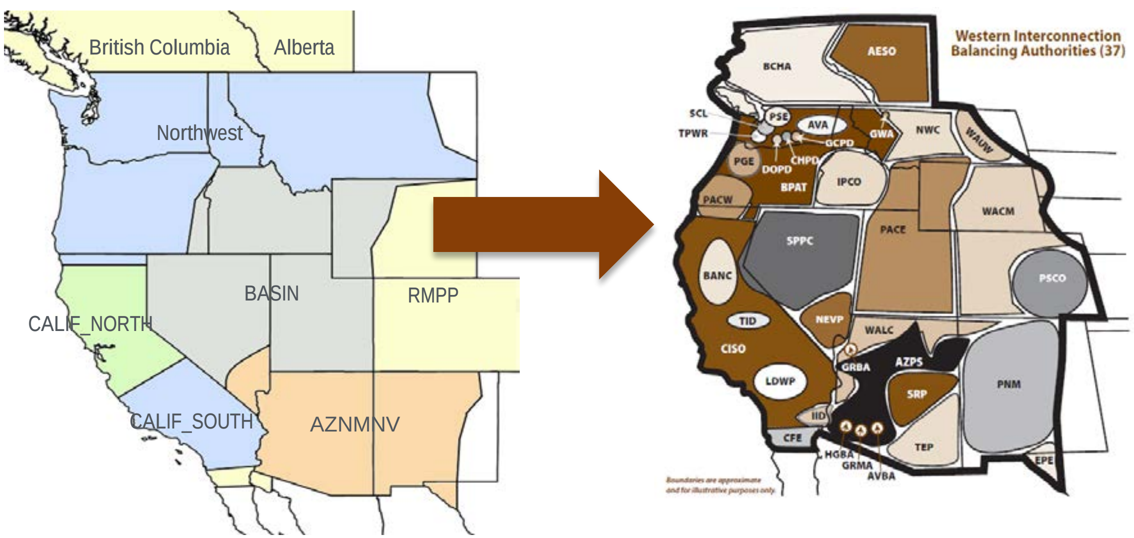
- "Best papers" at recent wind integration workshops
  - Markets to Facilitate Wind and Solar Energy Integration in the Bulk Power Supply: An IEA Task 25 Collaboration. 11th International Workshop on Large-Scale Integration of Wind Power. Lisbon, 2012.
  - Flexibility Chart—Evaluation on Diversity of Flexibility in Various Areas,12th Wind Integration Workshop, London, 2013. http://www.windintegrationworkshop.org/best_papers.php

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- WECC now uses NREL's flexibility reserve method in its transmission expansion modeling
- Presented integration cost methods to the Committee for Regional Electric Power Cooperation
- Helped persuade WECC to adopt a more granular approach to interconnection modeling

Geographic/electric areas

Balancing Authority Areas (BAAs)



Testimonials/Awards

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- M. Milligan presented to PUC Commissioners and staff at EIM meetings in Boise, Idaho
  - PUC EIM Chair said, "Your ability to break down the essential components of each (of the EIM) analyses and offer valuable comparisons and contrasts … was of particular value to the PUC EIM Group and its stakeholders."
- Integration Support Review Committee Comments (2013)
  - NERC IVGTF was an "unprecedented opening of the door" to start resolving integration issues. "Being at the table is critical to influence the long-term direction and thinking … "
  - What NREL has been doing in the west is just right
  - NREL has been "essential to the process" of the EIM development
- L. Bird delivered a presentation to a webinar co-hosted by NREL and NCSL on methods of managing integration challenges
  - ~50 participants, ~25 representing state legislators or staff.
  - Participant feedback included: "Great webinar, congratulations."
- B. Kirby (consultant to NREL) and M. Milligan: UVIG Achievement Awards for Sustained Advances in Wind Integration Study Methodology (2012)
- 2 "best papers" at recent Wind Integration Workshops
  - http://www.windintegrationworkshop.org/london2013/best_papers.php
  - http://www.windintegrationworkshop.org/best_papers.php

Project Plan & Schedule

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Integration Support, UVIG, IEA												
FY 12 Q1 Milestone: UVIG Fall Technical Workshop												
FY 12 Q2 Milestone: Disseminate lessons learned at Ackermann Conference												
FY 12 Q3 Milestone: Dissemenate Results to IEA Task 25												
FY 12 Q4 Milestone: Participate in NERC IVGTF												
FY 13 Q1 Milestone: UVIG, IEA, WECC Reserves presentations												
FY 13 Q2 Milestone:Support Ackerman and CREPC, TEPPC, SPSG and WREZ, IEA Task 25												
FY 13 Q3 Milestone: IEA Task 25 Spring meeting and presentation												
FY 13 Q4 Milestone: Host 2 webinars, present reserve method to WECC												
FY 14 Q1 Milestone: UVIG Fall Workshop and DG User Group												
FY 14 Q2 Milestone: WECC Operating Reserves Task Force												
FY 14 Q3 Milestone: Host IEA Task 25 in Colorado												
FY 14 Q4 Milestone: NCSL Legislative Horizons and NARUC												
Current work and future research												

Comments

- FY09-FY15, all milestones completed on schedule

Project Plan & Schedule

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Additional Details on FY 14/FY 15 plan

- Minnesota Renewable Integration and Transmission Study TRC – thru FY 14
- Pan-Canadian TRC – thru FY 15
- NCSL: Upcoming webinars and speaking FY14
- IEA: NREL hosting next international meeting Apr 2014
- NERC: Receive NERC comments and finalize report summer 2014
- UVIG: Help organize/participate in Spring meeting and teach at short course FY14
- IEEE: Attend Power and Energy Society GM, Wind/Solar Power Coordinating Committee meeting Summer 2014
- IEEE: Attend LOLEWG meeting Summer 2014
- Present papers at WindPower 2014

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators: Brendan Kirby, IEA Task 25, UVIG, WECC, NERC, IEEE Wind/Solar Power Coordinating Committee, IEEE LOLEWG, National Conference of State Legislatures (NCSL), National Association of Regulatory Utility Commissioners (NARUC), AWEA, Minnesota Department of Commerce, PGE, PG&E, Western Interstate Energy Board (WIEB), WAPA, Canadian Wind Energy Association

Communications and Technology Transfer

- Multiple publications, conference presentations, fact sheets, etc.
- Website: http://www.nrel.gov/electricity/transmission
- Selected webinars: http://www.nrel.gov/electricity/transmission/webinars.html
- Selected publications: http://www.nrel.gov/electricity/transmission/publications.html
- NREL publications website: www.nrel.gov/publications

Next Steps and Future Research

FY14/Current research

- Various papers, webinars, conference presentations, meetings and meeting presentations as described in slide 14

Proposed future research

- Continue engaging with legislators, regulators, and policy groups to ensure research results are accessible (membership changes every 2 to 4 years)
- Continue collaboration with NERC as the next phases of the IVGTF develop
- Continue developing Web, fact sheet, and other summaries of research for online access
- Continue to support UVIG, IEEE, and the power system at large by providing data and research results in appropriate forums

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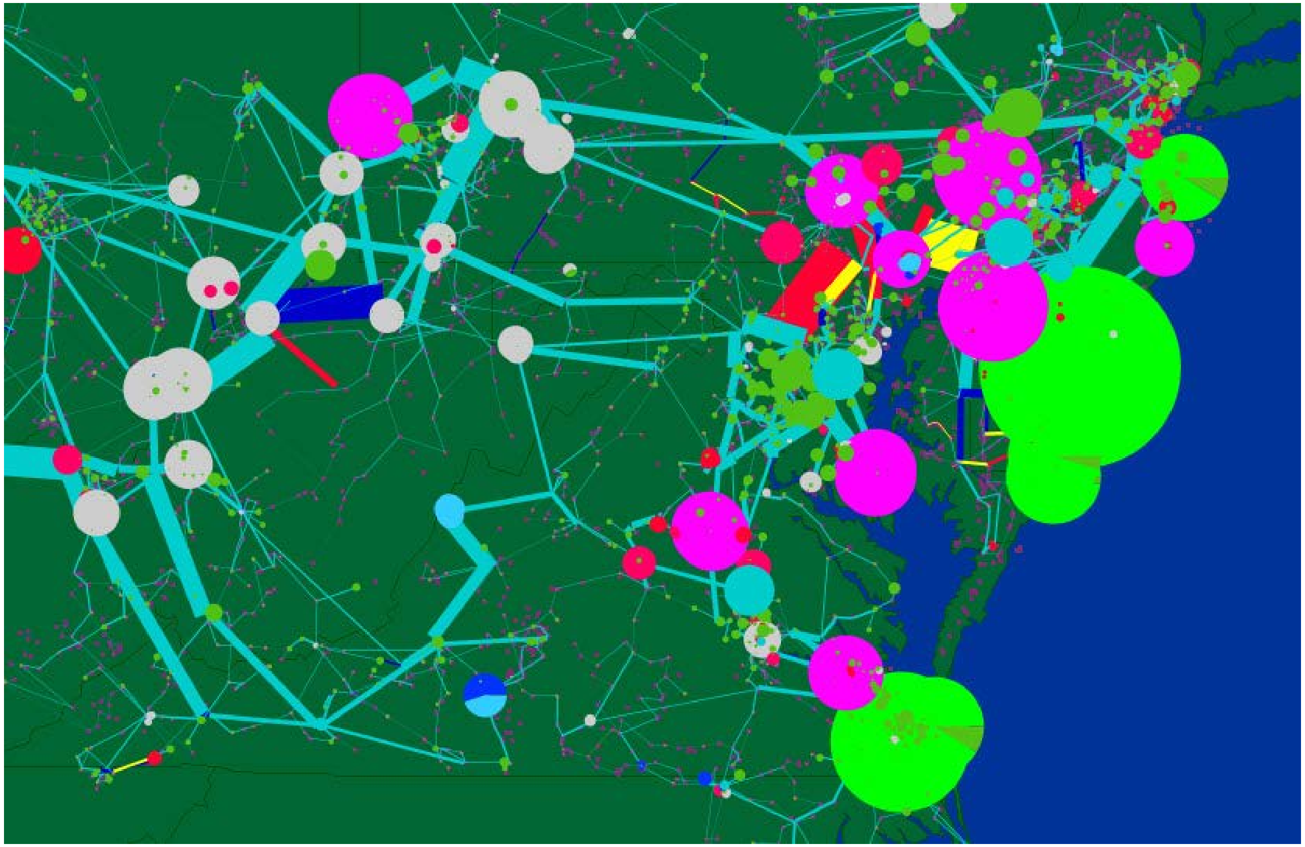


Mid-Atlantic Offshore Wind Integration and Transmission

Willett Kempton

The University of Delaware

willett@udel.edu 302-831-0049[

3/25/2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.211M

Total Cost-Share[1]:$0.106M

- ## Problem Statement:
  1. Examine offshore wind consistent with calculated resource size
  2. Compare piecemeal radial connections to the ISO (PJM) with connections via a HVDC offshore network similar to a team partner
  3. Examination of power fluctuations at each node due to wind energy variability
  4. Analyze wind power production profiles over Eastern offshore region of the regional ISO to assess effectiveness of long-distance, North-South transmission for leveling offshore wind energy output
  5. How power fluctuations and wind leveling affect the need for ISO grid upgrades, congestion management, and demand for A/S
  6. Analysis of forecasts to solve unit commitment problems and determine optimal mix of generators.

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Impact of Project:

- **Evaluate the pros and cons of offshore transmission**
  - Radial versus an HVDC backbone to decrease offshore wind farm costs and permitting time
- **Address questions about:**
  - Adequacy of existing transmission infrastructure
  - Ability of existing generating resources to provide A/S support in ISO territory

This project aligns with the following DOE Program objectives and priorities:

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

Technical Approach

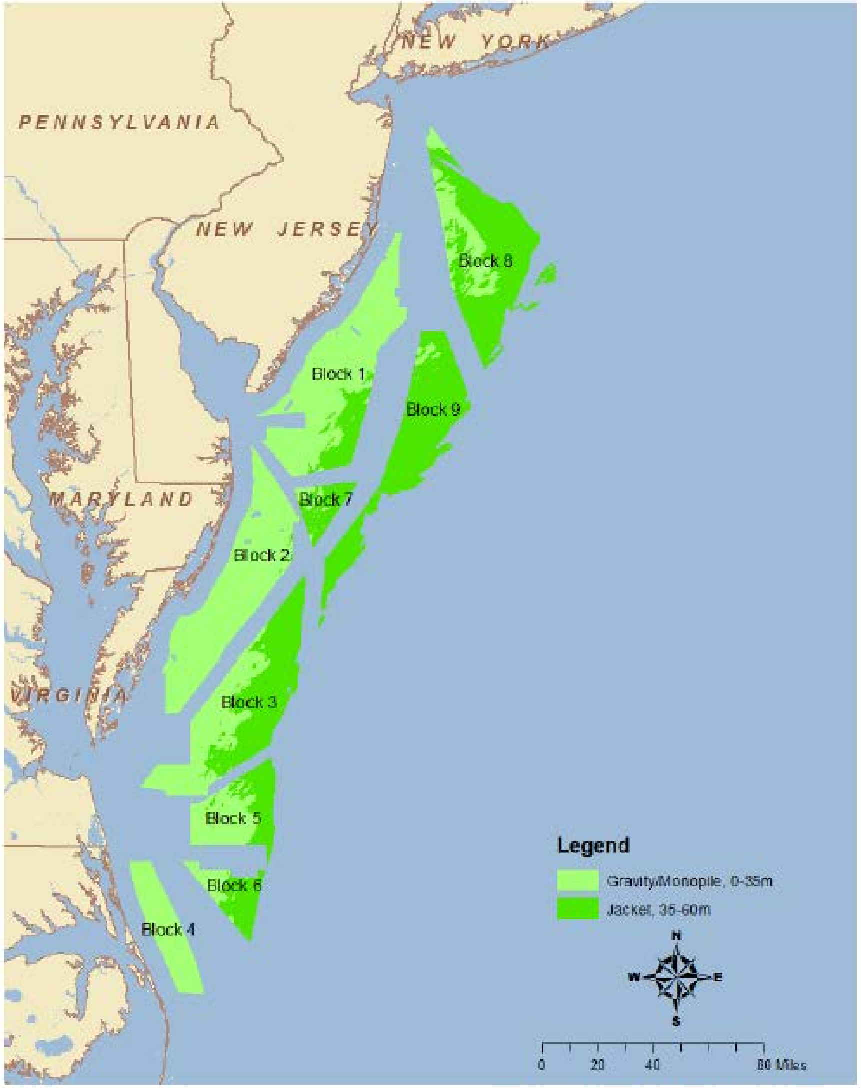
- WEAs used as Level 1, additional levels based on ocean space adjacent to PJM, minus clear exclusions;
- Result: Five “buildout levels” of capacity & generation
  – Determined how much the regional ISO, PJM, load would be

Build Level	Rated Capacity (GW)	Average Output (GW_a)	Percentage of Average PJM Load
1: *Wind Energy Areas*	8.3	2.9	3.6%
2: *15% PJM Load*	39.4	13.8	17.3%
3: *25% PJM Load*	57.8	20.2	25.4%
4: *35% PJM Load*	80.6	28.2	35.4%
5: *Complete Buildout*	117.0	40.9	51.4%

Technical Approach

- POI's were determined for HDVC
  - Transmission losses were calculated

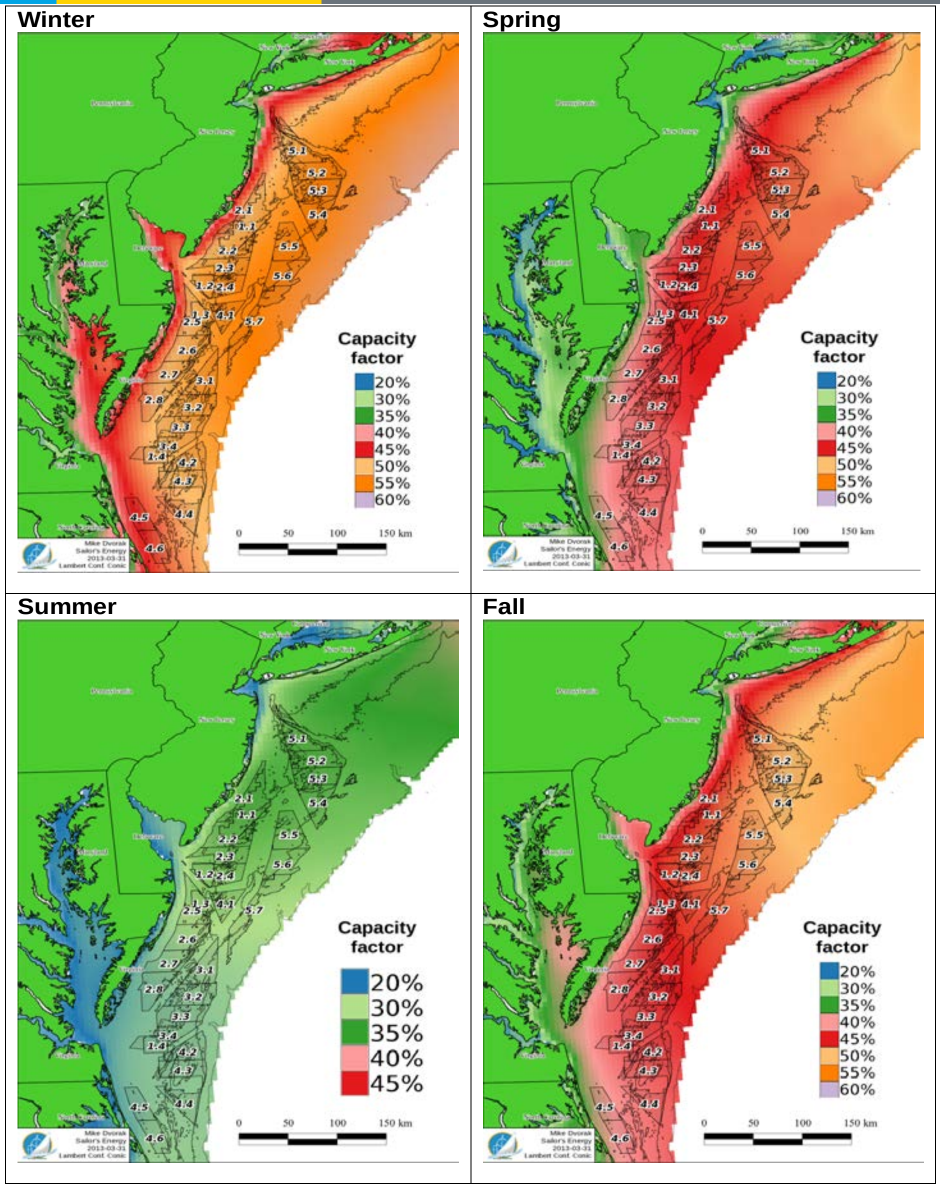
- Build-out levels determined by
  - BOEM WEA areas
  - Conflict Zones
    - Shipping Lanes
    - Military Zones
    - Fish Havens
    - Explosives
    - Etc.



Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

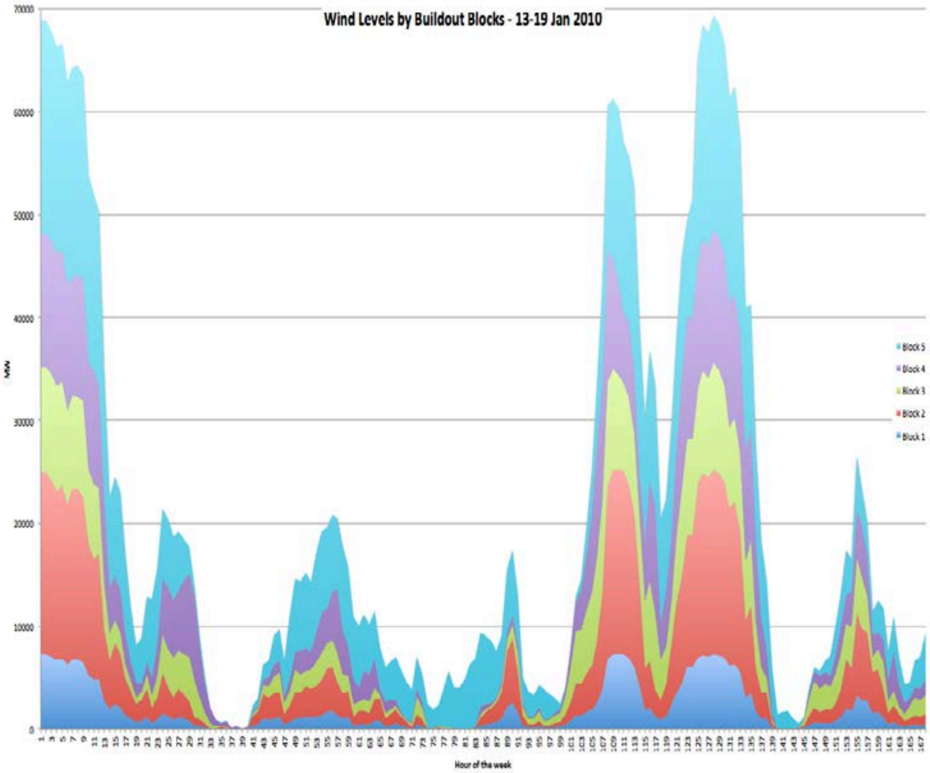
- Weather Forecasting Model (WRF)
  - Model wind speed for five years
    - Using buoy data and the log-law to calculate hub-height wind speeds
  - Produce seasonal wind resource maps
  - Calculated Power

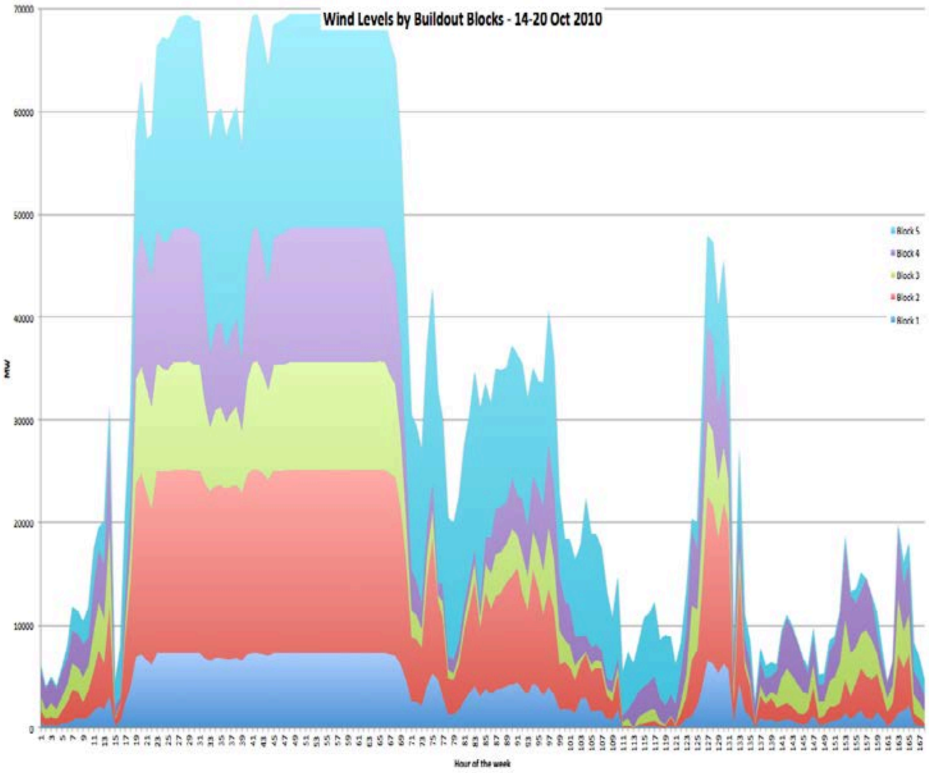


Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Analyzed Offshore Wind Leveling

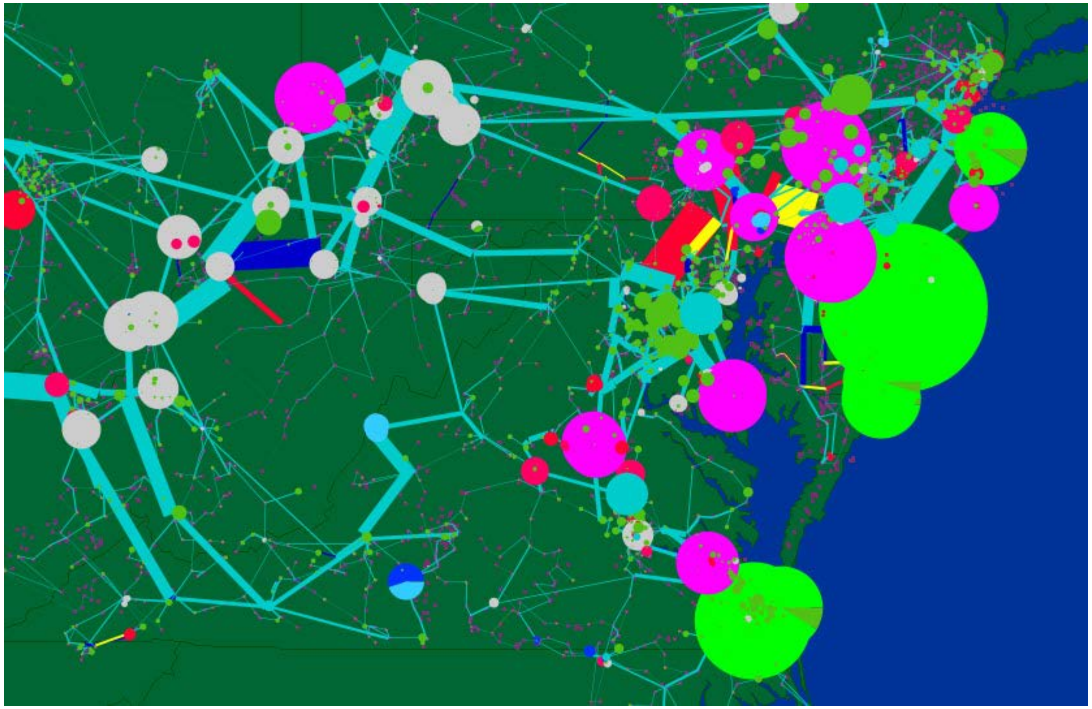




Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Created combined power flow and unit commitment model, “SMART-ISO”
  - Simulated Grid based on PJM data
    - Day ahead and hour ahead commitment models



Accomplishments and Progress

- Developed “build-out blocks” for offshore wind areas
- Optimized site lay-out to reduce transmission costs
- Created seasonal wind resource maps using WRF
- Analyzed Wind Leveling
- Created a SMART-ISO model
  - Simulates unit commitment and power flow models

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number: DE-EE0005366	
Project Number: 5484	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Mid-Atlantic Offshore Wind Integration and Transmission												
Task 1.3: Model First-Cut Loses												
Task 2.1: Develop Maps												
Task 3.1: Run WRF and Develop Wind Maps												
Task 5.2: Report on Wind Leveling Results												
Task 6.3: Report about Unit Commitment Results												
Current work and future research												
Task 4.5: Report about Congestion Impact												
Task 6.5: Report on High Frequency Impacts												
Submit journal articles for publication												
Hold Workshops about Project												

Comments

- Project Period: October 1, 2011 to September 30, 2014
- Some milestones were slipped due to new data/ vital changes that needed to be made to our models.
- Go/ No Go Decisions-
  - Calibrate WRF Model was replaced with Error Analysis
  - Validate the Power Flow Model with the Regional ISO was completed through Subtask 6.2
  - Validate the Combined Unit Commitment and Power Flow Models with the ISO- Go Decision

Project Budget

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$124,641	$1,637	$159,988	$80,460	$53,327	$23,887

Partners, Subcontractors, and Collaborators:

Cristina Archer, University of Delaware
Jeremy Firestone, University of Delaware
Michael Dvorak, Sailor's Energy
Warren Powell, Princeton University
Hugo Simao, Princeton University
Boris Defourny, Princeton University
Deniz Ozkan, Atlantic Grid Development
Mohamed El-Gasseir, Atlantic Grid Development
Paul McGlynn, PJM Interconnection
Scott Baker, PJM Interconnection

Communications and Technology Transfer:

Summary of Power Flow models available at http://energysystems.princeton.edu/smartiso.htm
Summary of Buildout levels: http://www.sailorsenergy.com/maowit-build-blocks
Posters presented at: AWEA Offshore (October 2013) and University of Delaware's "Coast Day."

Next Steps and Future Research

FY14/Current research:

- Congestion Impact
- High Frequency Variation Runs
- Holding Workshops

Proposed future research:

- Looking more at forecast distribution error
- Using minute forecast versus actual data

Carolinas Offshore Wind Integration Case Study

Spencer Hanes

Duke Energy Business Services, LLC

Spencer.Hanes@duke-energy.com

March 2014

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE EE0005368
Initiated in 2011
Phase I efforts Feb 2012-March 2013
Phase I and Phase II combined under a single Assistance Agreement
Remaining Schedule through 6/1/2015

Carolinas Offshore Wind Integration Case Study

Spencer Hanes
Duke Energy Business Services, LLC
Spencer.Hanes@duke-energy.com
March 2014

Purpose & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.355M

Total Cost-Share[1]: $0.000M

Problem Statement:

The project's objective is to provide a thorough and detailed analysis of specific issues, impacts, and costs associated with integrating various amounts of offshore wind generation into the Duke Energy Carolinas system. The study's authors expect the information provided by the study to inform policy decision-makers, industry participants, and utility planners as they evaluate the positives and negatives of offshore wind development.

Impact of Project:

This project will issue 2 reports informing the industry on findings concerning Siting, Capacity and Energy Profile, Interconnection and Delivery, Dynamic Stability Analysis, Operating Reliability Impacts, Production Cost Impacts.

This project aligns with the following DOE Program objectives and priorities

- **Optimize Wind Plant Performance:** Reduce Wind Plant Levelized Cost of Energy (LCOE)
- **Accelerate Technology Transfer:** Lead the way for new high-tech U.S. industries
- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

[1]*Budget/Cost-Share for Period of Performance FY2012 – FY2013*

Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

A Variety of technical approaches were/are required to for this project.

- Produced wind plant output data set spanning 1999-2008 at 10 minute temporal resolution
- Optimized siting on cost estimates for interconnection proximity, water depth, and wind regime
- Sites selected were modeled using AWSTrupower weather prediction and power output models
- Wind estimates correlated against known offshore elevated platforms and adjusted for seasonal characteristics
- 3 scenarios considered at 1,000MW, 3,000MW and 5,600MW total output
- The siting study demonstrated there is abundance of high quality development areas offshore in the Carolinas at manageable depths(i.e<30 m) to meet the DOE study target of 17,000 GWH annual production for offshore wind resources.

Accomplishments and Progress

- Carolinas Offshore Wind Integration Case Study Phase 1 Final Technical Report (DOE –EE0005368.001) was submitted March 2013
- Study completed and report published on time and under budget
- Phase II Assistance agreement received 6/17/2013
- Initiated construction of model for interconnection and delivery analysis

Project Plan & Schedule

DOE EE0005368
- Initiated in 2011
- Phase I efforts Feb 2012-March 2013
- Phase I and Phase II combined under a single Assistance Agreement

Remaining Schedule through 6/1/2015

• Task 1 Site Selection	Complete
• Task 2 Capacity and Energy profile analysis	Complete
• Task 3 Interconnection and Delivery Study	Complete
• Task 4 Dynamic Stability Analysis	April 2014
• Task 5 Operating Reliability Impacts	April 2014
• Task 6 Production and Operating Cost Impact Analysis	Nov 2014
• Final Report	June 2015

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:

Principal Investigators

Christopher Fallon
Jeff Peterson
Orvane Piper
Rebecca Ashby
William Hazelip
Bob Pierce
Lisa Salvador
Bob Burner
Yishan Zhao
Tom Pruitt

AWS Truepower

Ken Pennock
Jaclyn Frank

ABB

John Daniel
Shu Liu
Jinxiang Zhu

NREL

Eduardo Ibanez
Dennis Elliott
Aaron Bloom

UNC-Chapel Hill

Harvey Seim

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research:

Dynamic Stability Analysis
In addition to the steady-state assessment of the system's ability to accept large-scale offshore wind, a dynamic evaluation will also be performed. This assessment will be made using the MMWG dynamic models. They include a library of standard wind turbine models which will be used to represent the offshore wind plants in the studies. A broad selection of contingencies will be studied that include known stability issues as well as anticipated new issues based on the results observed in the SSA. Up to four different wind and thermal generation dispatch scenarios will be constructed to allow an assessment of the sensitivity of the dynamic stability of the system to generation dispatch. Dynamic stability cases of particular interest are the high wind generation, low thermal generation scenarios in which the interconnected system loses significant inertia due to the offline thermal generation plants.

Operating Reliability Impacts
Using the wind production sets in sub-hourly timeframes developed by the capacity and energy profile team and transmission study (both steady state and dynamic) and production costing results, the system operation impacts team will assess the expected reserve requirements and other reliability impacts. The team will evaluate the level and types of reserves needed to maintain system balance and account for the variability and technical limitations of the wind developments such as ramping, voltage support, etc. The analytic process will be similar to that done for the Eastern Wind Integration and Transmission Study (EWITS) where a statistical analysis of 10 minute variability for the various sites will be conducted and reflected to a revised reserve level for production modeling. Potential ramping issues and the means of addressing them will be identified.

Production Cost Impacts
Once the system operation team has performed its analysis, the production cost team will evaluate the impact of offshore wind development on average production cost for the system. The variability of wind generation is known to have significant impacts on the dispatch and operation of the existing generation fleet including unit ramp rates and operating reserve requirements. It is important to assess the impact on baseload (coal and nuclear) units. In order to evaluate that impact and to determine the expected impact on system operation costs, a production cost analysis will be performed using the wind variability, reserve changes and other system parameters determined from the wind resource analysis efforts.

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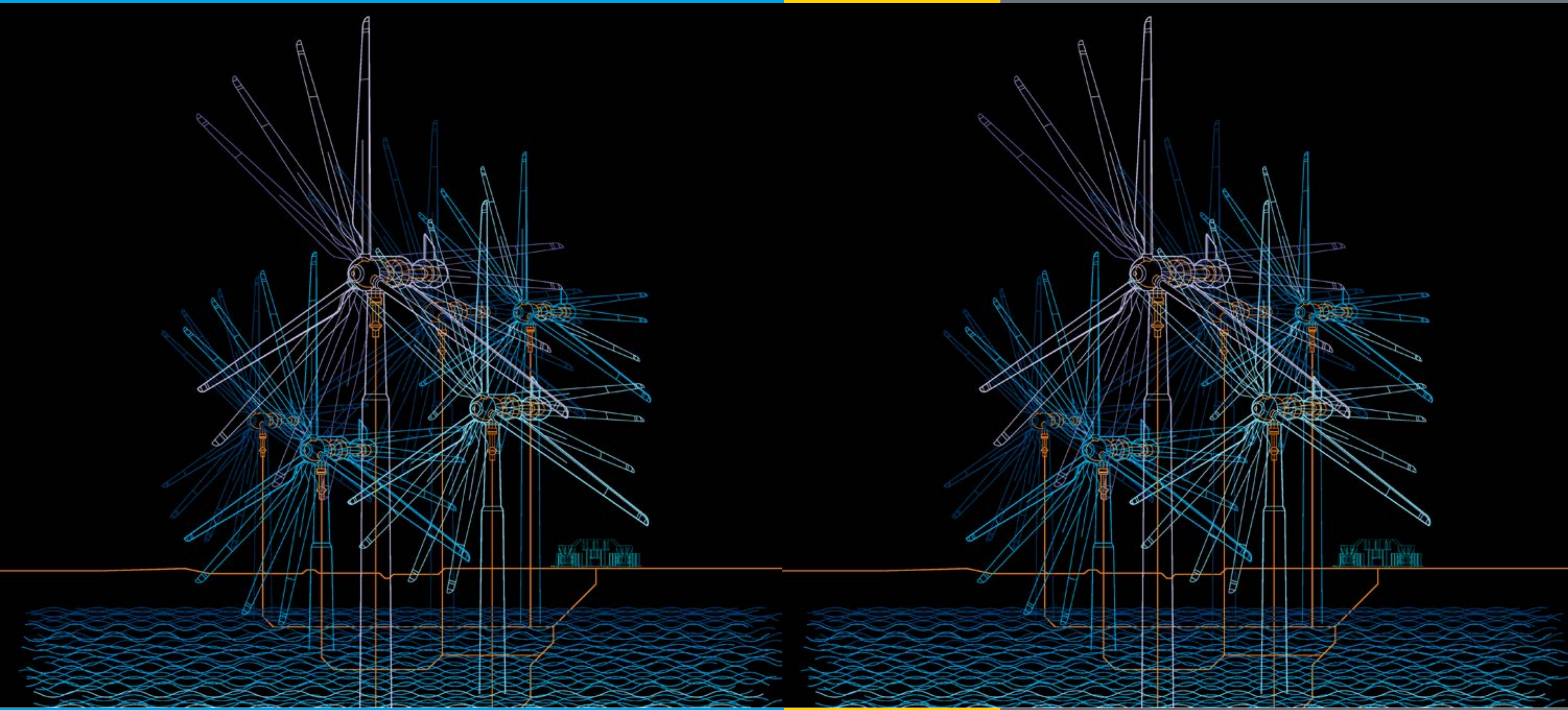


National Offshore Wind Energy Grid Integration Study (NOWEGIS)

John P. Daniel
ABB Inc
john.daniel@us.abb.com 919-856-3306

March 26, 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.13M

Total Cost-Share[1]:$0.00M

Problem Statement: Define technical and economic viability data toward achieving the "20% Wind Energy by 2030" offshore goals of 54GW by 2030, through

1) offshore wind staging assessment;
2) production profile development;
3) study technique assessment;
4) technology evaluations;
5) regulatory trend assessment

Impact of Project: A data set of the potential build-out, interconnection sites, offshore production profiles, technology benefits and limitations, and regulatory recommendations and impediments.

This project aligns with the following DOE Program objectives and priorities:

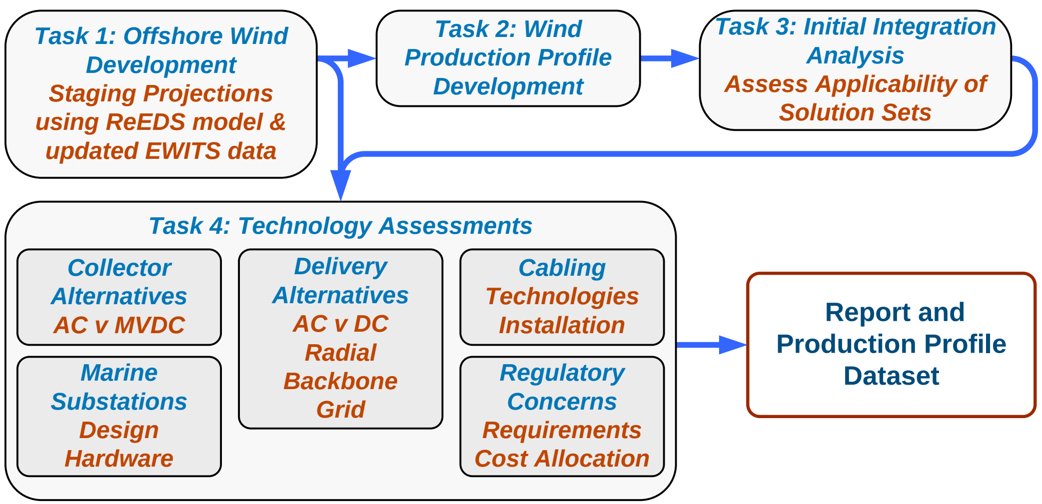
- **Optimize Wind Plant Performance:** Reduce Wind Plant Levelized Cost of Energy (LCOE)
- **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources
- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid
- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization

[1] *Budget/Cost-Share for Period of Performance FY2012 – FY2013*

Technical Approach

- Siting and staging for 54 GW of offshore capacity using NREL's Regional Energy Deployment System
- Refined siting based on development of high-resolution resource data
- Development of 10-minute resolution power production profiles for selected sites
- Technology review and assessment through steady-state simulations, reliability analysis and production-cost simulations using industry standard programs such as PSS/E, Power Factory, and Gridview
- Vetting of accomplishments by a Technical Review Committee comprised of members from industry, system operators and government

Technical Approach



2012-2013:

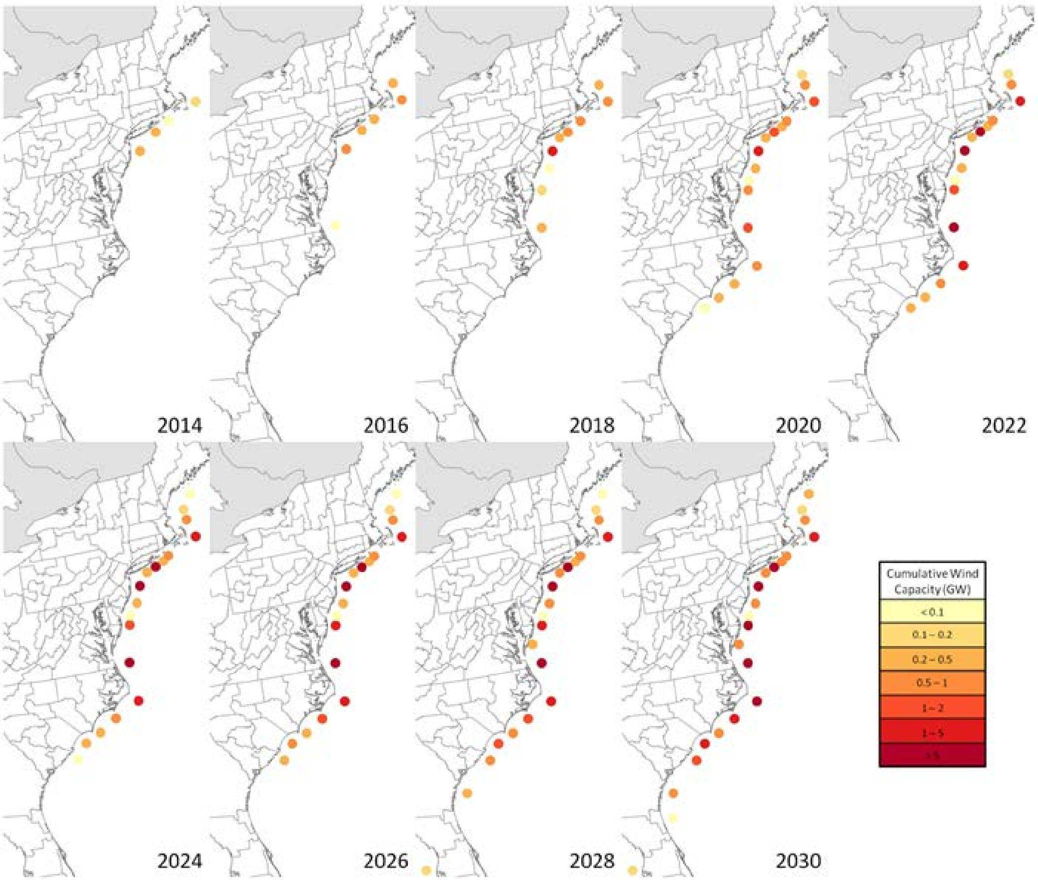
Task 1 – Offshore Wind Development Staging : Complete

Task 2 – Wind Production Profile Development : Complete

Task 3 – Initial Integration Analysis : In Progress, complete by March 2014

Task 4 – Technology Assessment : In Progress, complete by April 2014

Task 1: Offshore Wind Development Staging



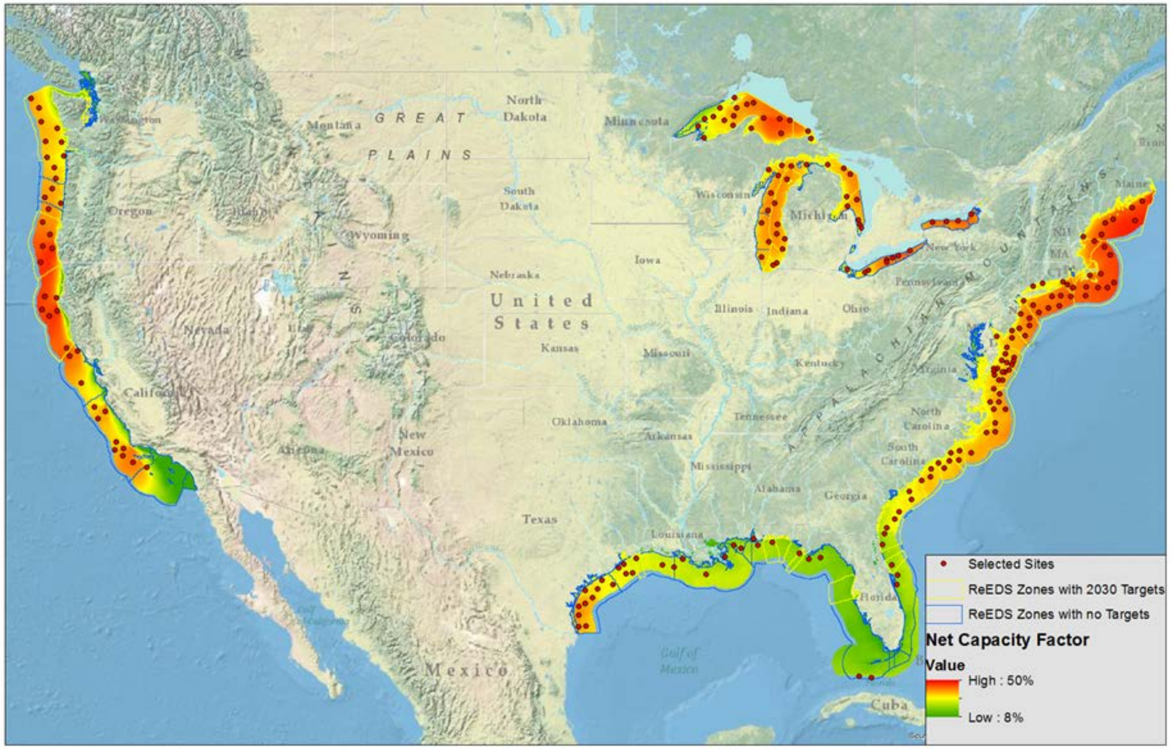
Example ReEDS results

Great Lakes, Gulf Coast and West Coast similarly considered

East Coast showed largest concentration due to load centers, resources, and potential interconnection costs based on current technologies

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Task 2 Wind Production Profile Development



209 sites, 134+ GW

10-min profiles of wind speed, wind direction and net power for 2004-2006

Summarized capacity factor and losses for each site

Profiles enhance EWITS data and synthesized following EWITS, PRIS, ERGIS

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	DE-EE0005365

Legend	
	Work completed
	Active Task
◇	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: National Offshore Wind Energy Grid Interconnection Study												
Task 1 - Offshore Wind Staging												
Task 2 - Wind Production Profile Development												
Task 4 - Technology Assessment - Technology Review, Start Simulations												
Interim Report												
Current and future work												
Task 3 - Initial Integration Analysis												
Task 4 - Technology Assessment - Technology Simulations												
Final Report												

Comments

- Project initiated Oct 2011 with anticipated completion Sep 2013
- DOE delay in authorizing reimbursement with one contractor delayed critical path work by approximately 5 months
- Recognized data quality issue caused additional delay
- No cost extension granted by DOE Sep 2013 moving end date to April 30, 2014

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:

AWS Truepower: Ken Pennock, Jaclyn Frank

NREL: Eduardo Ibanez, Trieu Mai, Michael Heaney, Aaron Bloom, Dennis Elliott, Lynn Coles

Duke Energy: Spencer Hanes

U. of Pittsburgh: Gregory Reed, Brandon Grainger, Matt Korytowski

TRC: DOE, AWEA, BOEM, ERCOT, ISO-NE, NREL, OWDC, PJM, XeroEnergy (UK)

Communications and Technology Transfer:

Conferences: AWEA Offshore 2012; Clemson Power Conference 2012; U. Pittsburgh Power Conference 2011, 2012, 2013; NCSEO SEC 2012; 12th Wind Integration Workshop, London, UK 2013

Papers: Ibanez, E.; Mai, T.; Coles, L. (2012). "Analyzing the Deployment of Large Amounts of Offshore Wind to Design an Offshore Transmission Grid in the United States." 11th Annual International Workshop on Large-Scale Integration of Wind Power,13-15 November, 2012. Lisbon, Portugal.

Korytowski, M.J., Fodiak, J., Daniel, J., Reed, G.F., Scott, N., "Integration of Offshore Wind Power to the U.S. Grid," Wind Integration Workshop – International Workshop on Large-Scale Integration of Wind into Power Systems and Transmission Networks for Offshore Wind Power Plants, London, UK, October 2013.

Next Steps and Future Research

FY14/Current research:

- Complete Task 3 integration study method assessment based on power production curves of Task 2
- Complete Task 4 technology assessment simulations, technology reliability assessments, production cost assessments and regulatory evaluations
- Complete Final Report

Proposed future research:

Many examples exist where technology developments such as GIS HVDC converters, alternate generation-collection topologies, etc. could substantially decrease capital, maintenance and operational costs. Government/Industry/Academic collaboration may accelerate development of such technologies.

Great Lakes Offshore Wind: Utility and Regional Integration Study

Kenneth A. Loparo

Case Western Reserve University

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.324M

Total Cost-Share[1]:$0.280M

- Problem Statement: Address technical questions and planning needs related to the integration of large-scale offshore wind into utility service areas

- Impact of Project: Develop general guidelines and recommendations for the interconnection of offshore wind projects that include transmission system upgrades and operational impacts

- This project aligns with the following DOE Program objectives and priorities:

  - **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources
  - **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

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Use *Lake Erie Case Study* of offshore wind integration into the FirstEnergy/PJM service territory to develop a general set of guidelines for offshore wind integration from the Great Lakes. The approach is based on: (1) the development of an appropriate system model, (2) data on offshore wind profiles, (3) transmission and generation system conditions, and (4) methods for evaluating the wind resource and interconnection. Schedule

- Year 1: Baseline (completed)
- Year 2: Impact-identify utility integration needs relative to Lake Erie and recommend appropriate system upgrades including capacity and storage (80% complete)
- Year 3: Develop General Recommendations for Interconnecting Large Great Lakes, and potentially National, Wind Energy Plants to the Grid

Year 1 Baseline (FirstEnergy/PJM) System Analysis (5/2012-4/2013) (100% Compete)

Task 3.1: Generate Operating Scenarios

(1) Steady-state models include recent public announcements of generation retirements and associated transmission system reinforcements, (2) PJM's Load and Generator Deliverability analysis is used for integrating the proposed 1GW of offshore wind generation on Lake Erie, (3) Impact analysis w/wo Perry.

Scenarios chosen include:

•1 GW at Perry 345kV substation

•200 MW each at: Avon 345kV, Lakeshore 138kV, Eastlake 345kV, Perry 345kV, and Ashtabula 138kV s

•500MW at Avon 345kV and 500MW at Avon 138kV substation

Task 3.2 Acquire Simulation Data for Operating Scenarios (100% Complete)

•Contingencies include critical 345kV and 138kV NERC Category B (n-1) outages near the Cleveland area including: local 345kV lines, local 345/138kV transformers, critical generating units, 138kV tie-lines Wind capture modeling using NREL Eastern Wind Integration and Transmission Study (EWITS

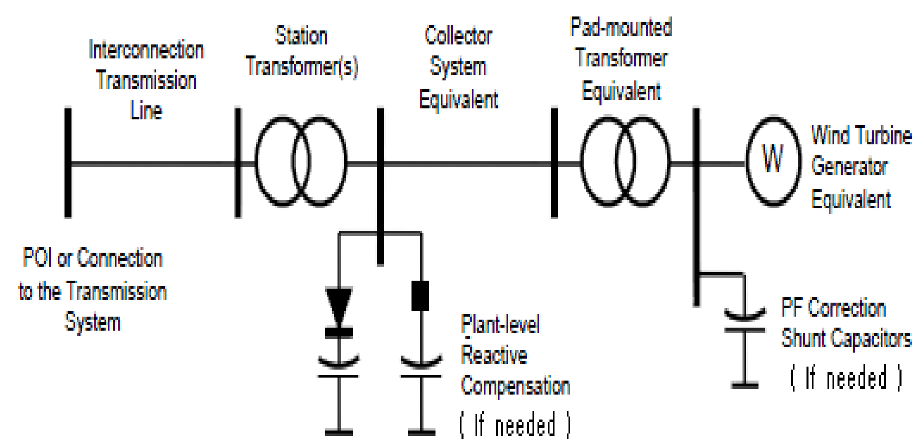
•2015 summer peak steady-state

•Eastern Interconnect Frequency Study light load dynamics. ATSI includes applicable PJM Regional Transmission Expansion Planning (RTEP) projects.

Year 2 Great Lakes Impact Analysis

(5/2013-4/2014) (80% Complete)

•Offshore wind plant model - conventional equivalent generator connected to a (PV) bus



Accomplishments and Progress

Year 2 Great Lakes Offshore Wind Impact Analysis (5/2013-4/2014) continued

Task 3.3 Steady State Analysis (90% Complete)

•Use traditional contingency and PV analysis to determine impact of wind generation on Qreserves, voltages, line loadings, LTC and SVC operation. 345kV POI at Perry is completed, other scenarios in process.

Task 3.4 Dynamic Analysis (50% Completed)

•Dynamic analysis uses Eastern Interconnect Frequency Study light load dynamics dataset, one selected offshore wind scenario used for this case. Dynamic analysis will include three to five representative contingencies, including a normally-cleared fault, a stuck breaker fault and a generation trip. Small signal stability will be assessed using eigenvalue/eigenvector modal analysis and Prony analysis.

Task 3.5 Energy Storage Modeling (50% Competed)

•Optimal Power Flow model is adapted to Integrate wind energy and energy storage. Model includes two different cases of wind farm allocation:

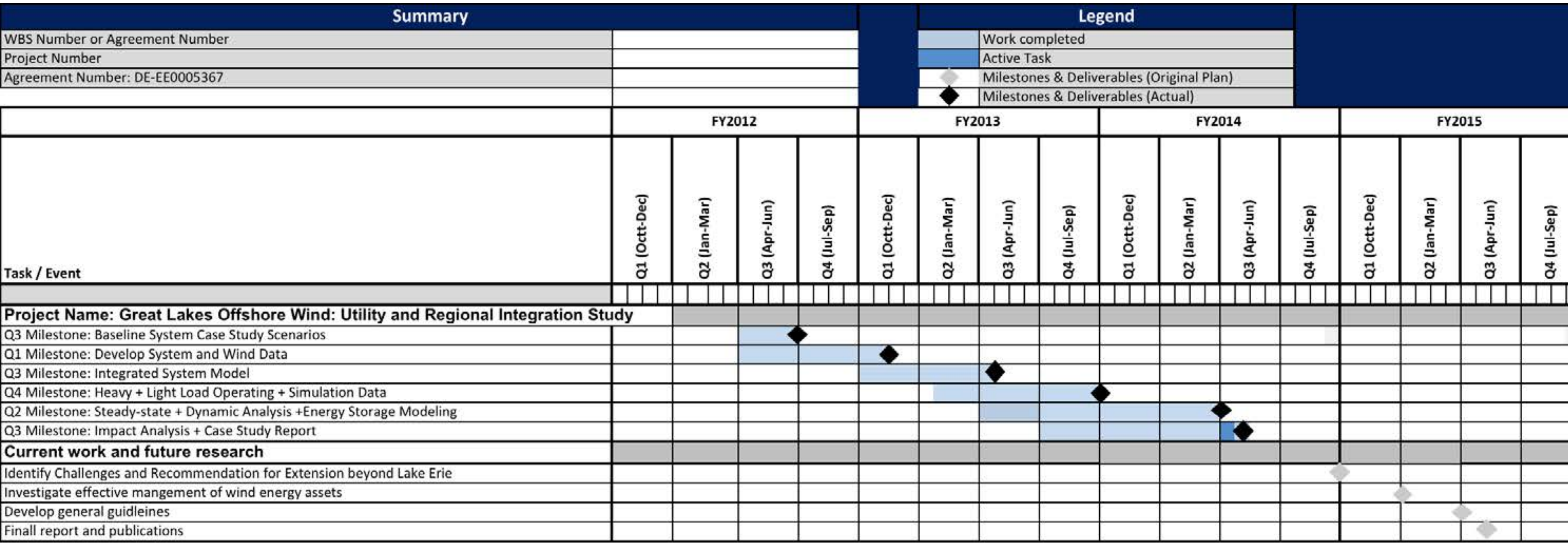
•Wind energy integration in combination with expanding transmission capacity

•Wind energy and energy storage integration avoiding additional investments into transmission modernization

Task 3.6 Analyze Data and Suggest Options (50% Complete)

Year 3 General Guidelines for Offshore Wind Impact Analysis (5/2014-4/2015)

Project Plan & Schedule



Comments

- May 1, 2012 to April 30, 2015
- Go/no-go decision point for FY12 occurred on April 30, 2013, project was completely funded as of June 2013, no other go/no go decision points.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

General Electric Energy: Steven Barnes and Robert D'Aquilla
National Renewable Energy Laboratory: Kara Clark
FirstEnergy Technologies: Johnny Gest and Joe Waligorski
PJM Interconnection: Scott Bakers and Paul McGlynn

Communications and Technology Transfer:

Workshop planned at the conclusion of the project to disseminate the general guidelines for Great Lakes Offshore Wind Energy Impact Analysis, Lake Erie impact analysis with FirstEnergy/PJM model will be used as a case study

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research: Plan for 2014-15 is to develop a set of general guidelines for Great Lakes Wind Integration Impact Studies using the lessons learned from the Lake Erie study.

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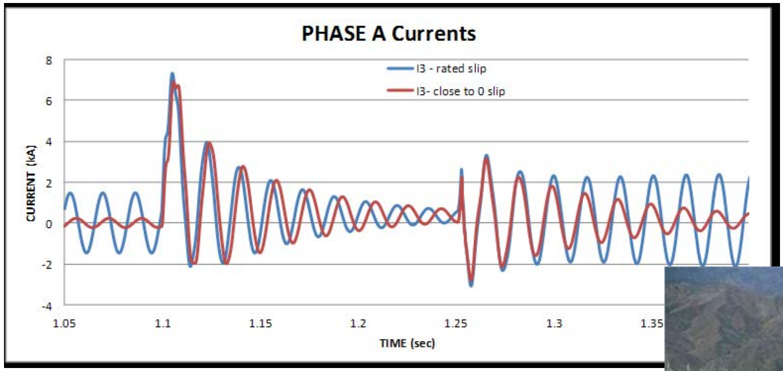
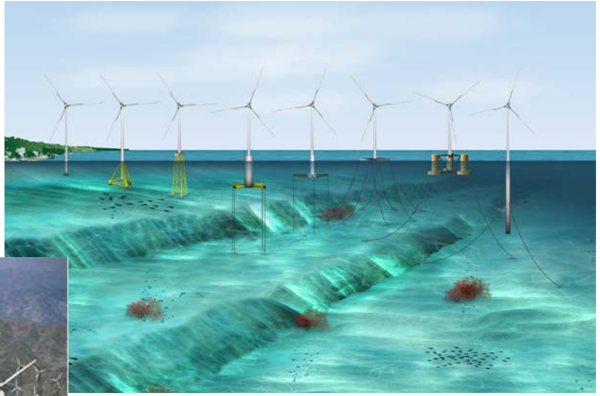
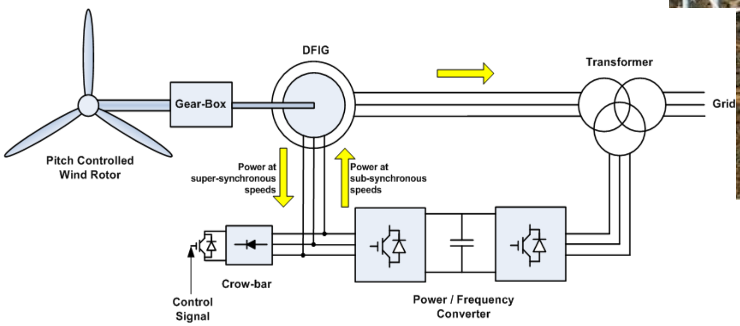






Principle Investigator:
Eduard Muljadi

Key Staff:
Vahan Gevorgian
Mohit Singh
Y.C. Zhang

Generator Modeling

Eduard Muljadi
NREL
Eduard.muljadi@nrel.gov; (303) 384-6904
March 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.480M

Total Cost-Share[1]:$0.000M

Problem Statement:

- ***Problem:*** High penetration wind generation increases the challenges in power system planning, operation, and reliability.
- ***Presently:*** Many of the WTG dynamic models are developed as a black-box positive sequence software platform.
- ***Challenges:*** Hundreds of 3- to 5-MW turbines based on power electronics will be installed onshore and offshore as opposed to a synchronous generator conventional plant (single land-based 1000-MW steam turbine installed close to load).
- ***Opportunities:*** The extensive deployment of synchrophasors (PMUs) has provided opportunities previously not available to plant operators and power systems engineers. We should build our WPPs within this new paradigm.
- ***Proposed:*** An open source, three-phase architecture (positive, negative, zero sequence), designed to include power electronics and PMUs with easy adaptation to change control strategies.

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Impact of Project:

- NREL's work on dynamic modeling has benefited the wind industry, utility industry, and universities.

- NREL in collaboration with Sandia, EPRI, UVIG, WECC, CEC, and software vendors has developed and performed:
  - 4 types of dynamic models of WTGs in detailed representation (PSCAD, Matlab/Simulink)
  - Dynamic model validation of wind turbine models.

- NREL's collaborations with IEC, IEA , and IEEE have produced standards or recommended practices and guidelines in the area of wind turbine generation.

- Various topics of investigations in the area of generator modeling are disseminated via technical journals, conferences, seminars, and university lectures.

This project aligns with the following DOE Program objectives and priorities:

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost-effective dispatch of wind energy onto the grid.
- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities, and identify key drivers and hurdles for wind energy technology commercialization.

Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- In-house dynamic modeling of wind turbines in 3-phase (positive, negative, and zero sequences) in an electromagnetic transient (EMT) platform to include fault ride-through and ancillary services.

- Dynamic model validation efforts using field data collected in collaboration with WAPA, BPA, ERCOT, etc.

- Collaboration with the IEEE, IEC, IEA, WECC, UVIG, NERC and universities in the area of dynamic modeling and standard/guide development.

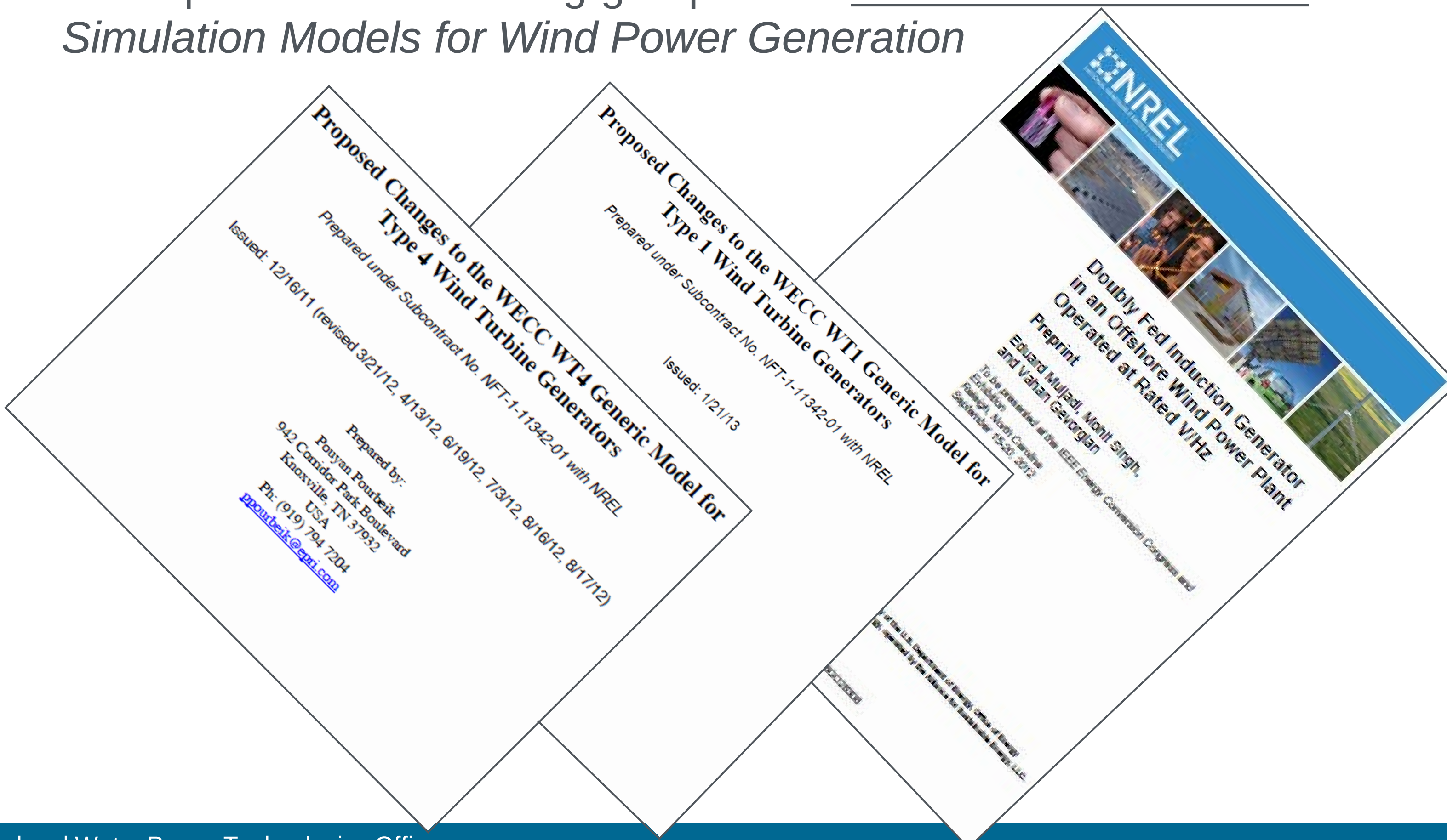
- Public dissemination and outreach via technical papers, reports, seminars, lectures, and tutorials presented at conferences or in technical journals.

Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Publication of EPRI reports on proposed changes to the WECC WTG Generic Model for four different types of models.

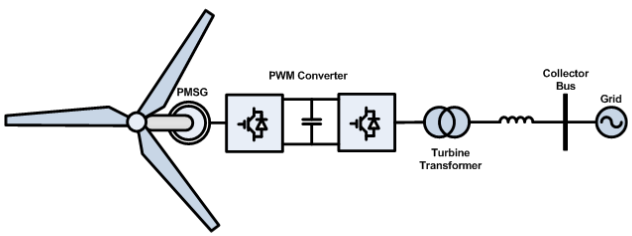
- Participation in the working group for the **IEC- TC 88 - 61400-27** *Electrical Simulation Models for Wind Power Generation*



Accomplishments and Progress

- Participation in the user group/task force **UVIG, WECC, IEEE** on dynamic modeling of wind turbines and other committees

- Public dissemination as technical papers (10+) in the IEEE journals and conferences, NREL reports, book chapters in the area of wind modeling including:
  - Short Circuit Current Contribution of four different types of turbines
  - Fault current limiter
  - Dynamic model validation for wind turbine generation
  - HVDC for offshore wind power plants
  - Stress reduction of gearbox by power electronics control.



V(t)

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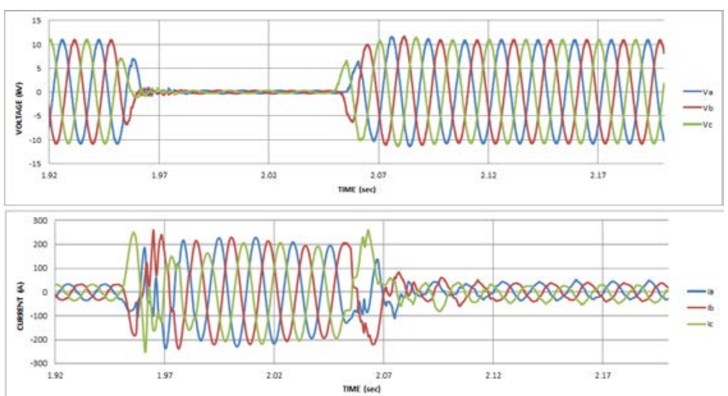
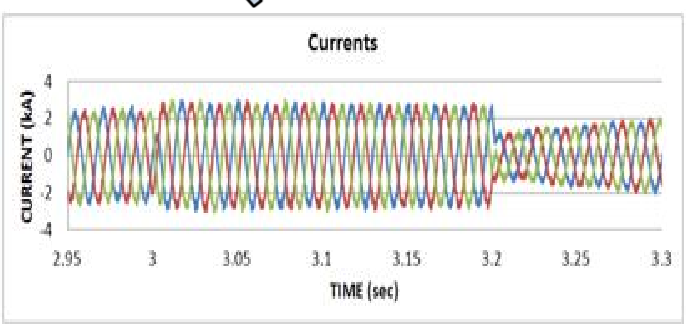
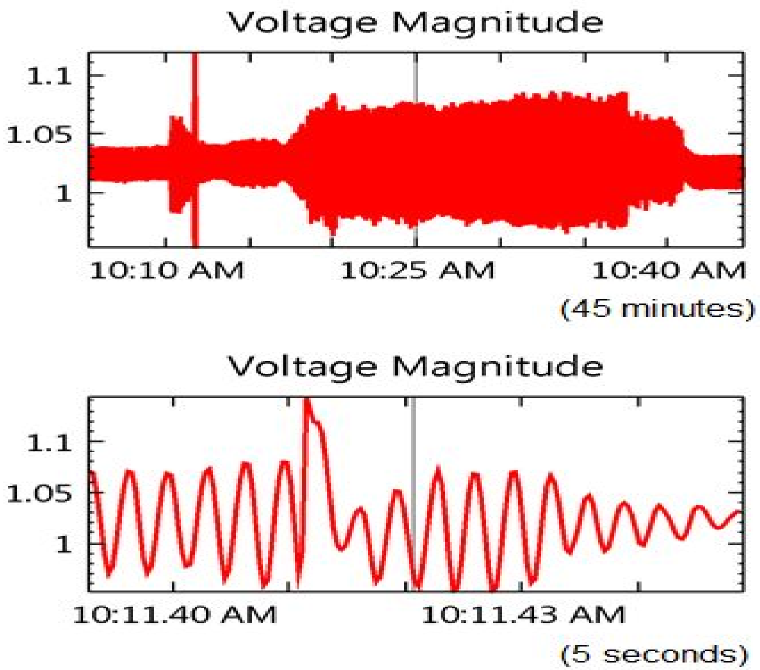


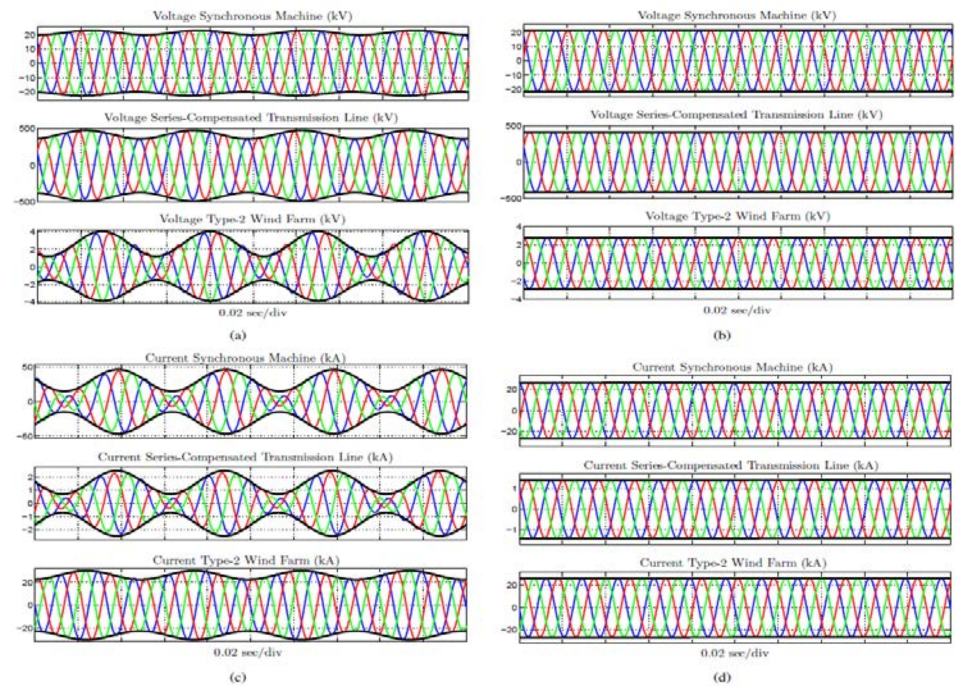
Short Circuit
(Recorded)



Short Circuit
(Simulated)

Accomplishments and Progress





No Controller **With Controller**

Subsynchronous Resonance at a Wind Power Plant (Recorded)

Subsynchronous Resonance at a Wind Power Plant (Simulated)

Credit: Austin White – OG&E

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2012				FY2013				FY2014			
	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Wind Generator Modeling												
Q2 Milestone: Produce draft report on PSCAD wind turbine modeling to allow frequency droop, inertial response response, real and reactive poewr control for use by industry to assess modern wind turbine capabilities												
Q4 Milestone: Produce a draft report on the WECC generic dynamic model for wind turbine type 1 and type 2.												
Q1 Milestone: Develop and implement PMU based control strategies on different types of WTGs using PSCAD software platform by December 31, 2012												
Q2 Milestone: Investigate the use of WTG to provide oscillation damping in the power system.												
Q3 Milestone: draft report on PMU based WTG controls												
Q4 Milestone: draft report summarizing the modifications proposed and implemented in the next generation WECC generic models												
Current work and future research												
Control algorithms for wind turbines and wind plants to provide oscillation damping												
Document in a letter report the wind power plant oscillation damping control algorithms utilizing PMU signals as feedback												

Partners, Subcontractors, and Collaborators:

Subcontracts:

1. Subcontract with EPRI on Specification of the Second Generation Generic Models for Wind Turbine Generators (subcontract No. NFT-1-11342-01 with NREL)

2. Subcontract with the University of Texas at Austin on algorithm development for synchrophasors.

Partners, Subcontractors, and Collaborators:

Collaborations and Technology Transfer:

1. Southern California Edison (SCE) on WECC Wind Models on RTDS, funded by SCE perform at NREL - 2012
2. EPRI, WECC, and software vendors
3. Sandia, Pacific Northwest National Laboratory, Brookhaven National Laboratory
4. Collaboration with Universities:
   1. Ph.D. internships funded by home institutions: 2 students in FY 2012 and 2 students FY 2013
   2. University of Denver
   3. Universidad de Castilla-La Mancha, Spain
   4. University of Colorado-Denver,
   5. IREC (Renewable Energy of Catalonia)
   6. University of Colorado-Boulder
   7. Nanyang Technological University Singapore
   8. University of Wisconsin
   9. Ohio State University
   10. University of Texas

Next Steps and Future Research

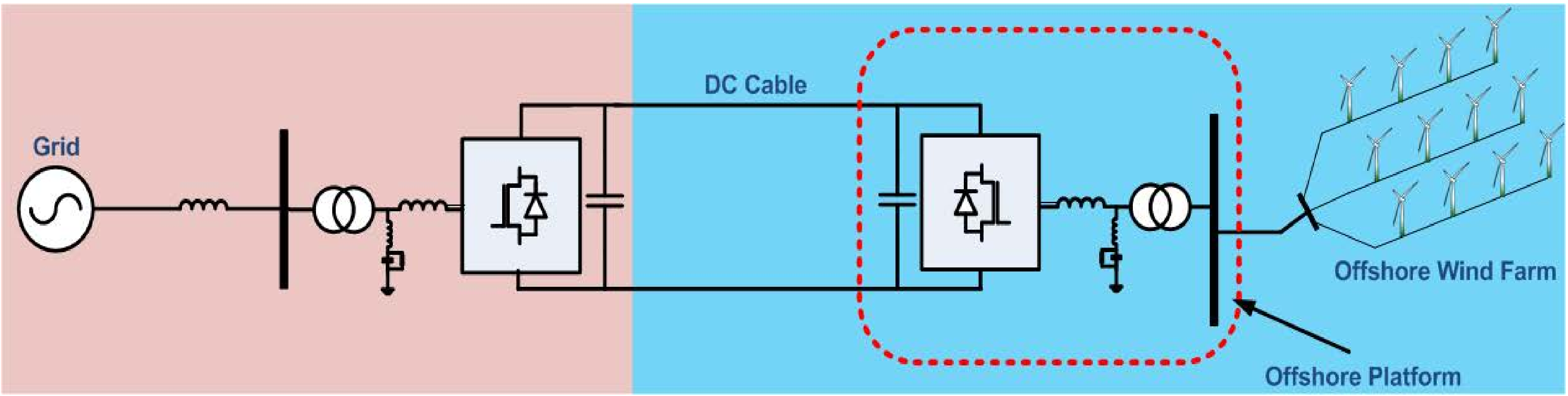
FY14/Current research:

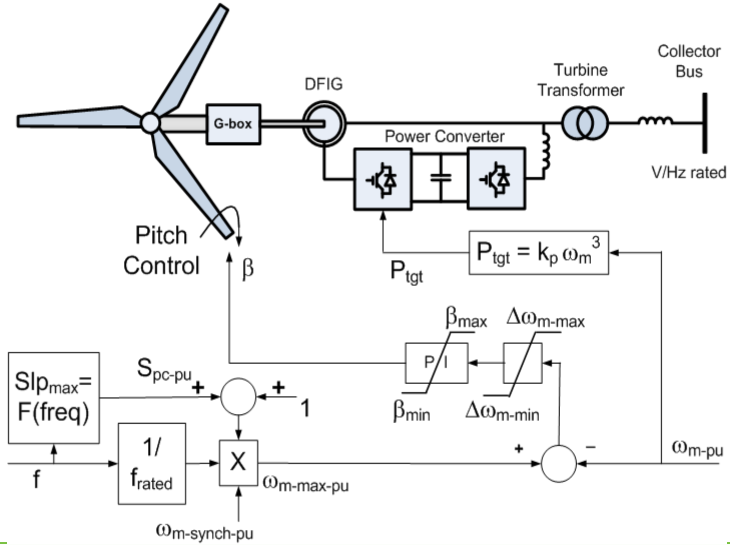
Current research is a progression of the past work and projects with the emphasis on utilizing the flexibility of power electronics at the turbine and wind plant level, based on modern power system control with the scope on wide area monitoring, protection and control perspectives.

Proposed future research:

- Stability and reliability enhancement by WPPs
- Synchrophasors for monitoring and control implementation
- Ancillary services functionalities
- Offshore and HVDC R&D
- Supervisory control for plant and zonal based control
- Utilizing available FACTS devices and energy storage
- Coordination among renewables, coordination between distribution and transmission system networks
- Wide Area Monitoring for Protection and Controls (WAMPAC)
- Adopt successful smart grid technologies

Proposed future research:





Example of a modern offshore WPP utilizing HVDC-VSC

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Wind Turbine Generator Modeling

Grid System Planning for Wind

Benjamin Karlson, P.E.

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(505) 377-3774

March 26, 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $.650M

Total Cost-Share[1]:$.0M

- ## Problem Statement:

  Generic, standard and publicly available models have not been readily available to the regional reliability organizations and grid operators who are responsible for maintaining the grid.

- ## Impact of Project:

  NERC has clearly stated that developing and improving access to validated, non-proprietary planning models is a pre-requisite for large-scale integration of variable generation.

  Planning of wind energy can be accomplished in a manner that allows for reliable power without an overbuilt system.

This project aligns with the following DOE Program objectives and priorities:

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

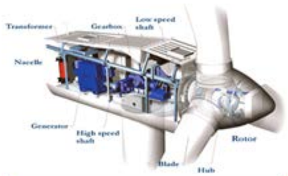
[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

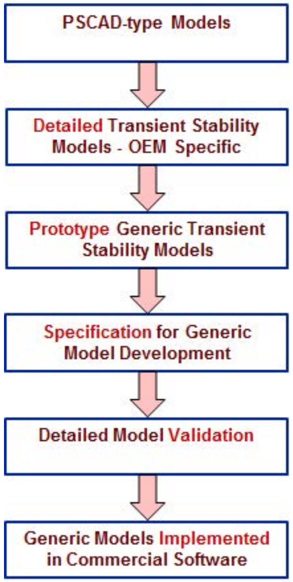
Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Key Issues:

- Historically, most WTG models are proprietary user-defined models developed by manufacturers
  - Prevents the exchange of data and the validation of models
- Generic, standard, publicly available models should:
  - Allow for easy exchange of model data;
  - Facilitate comparisons of system dynamic performance between different simulation programs;
  - Allow for implementation of WTG models in different simulation programs; and
  - Provide a mechanism for parameter tuning.





Technical Approach:

Coordination and participation in industry efforts is paramount

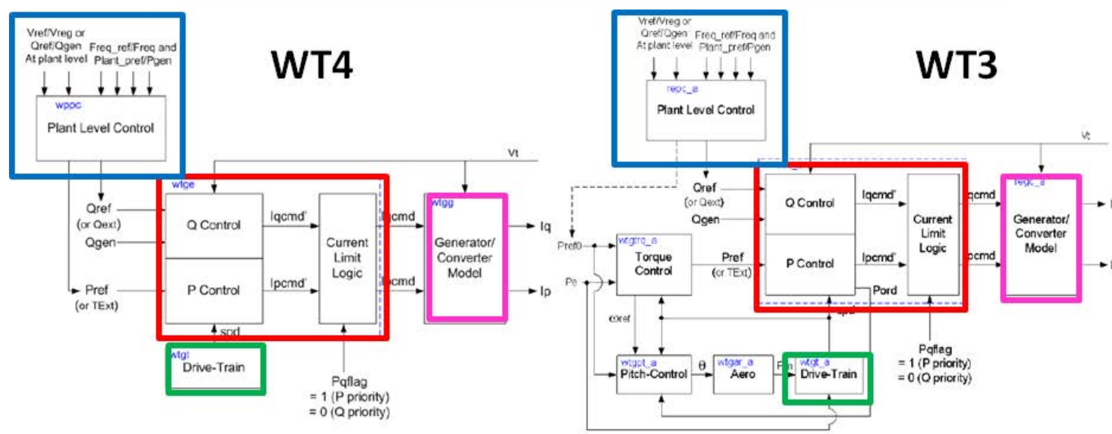
- The WECC Renewable Energy Modeling Task Force
  - Sandia is the Chair of the REMTF leading the efforts for continued improvements of WTG models
- The NERC Integration of Variable Generation Task Force
  - Sandia contributed to the NERC IVGTF guidelines
- The International Electrotechnical Commission TC 88 WG27
  - Sandia is the U.S. delegate to the IEC TC88 WG27

- Second generation WTG models have been developed
  - Models have been updated with improved capability (inertial response, governor control, reactive compensation)
- Models are available in power system simulation software
  - PSS®E
  - PSLF™
  - PowerWorld
- Model guideline published

Modular structure for wind and PV models
- Easier to implement and maintain models

Module	Use
REPC_A	Wind/PV plant controller
REE_A, REE_B	Wind /PV electrical controls
REGC_A	Generator/Converter model
WTGT_A	Drive Train
WTGAR_A	Aerodynamic Model
WTGPT_A	Pitch Control Model
WTGTQ_A	Torque Control Model
lhvrt	Voltage/current Protection Model

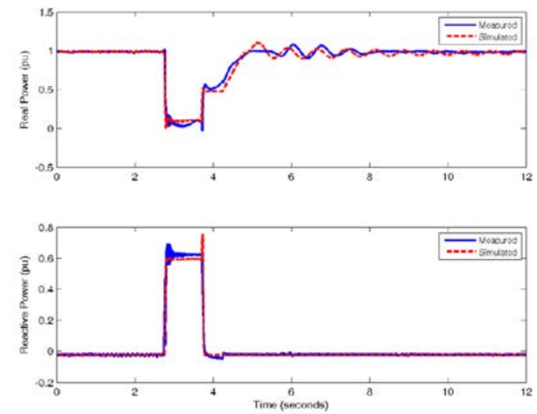
PV Plants
WT4 Plants
WT3 Plants



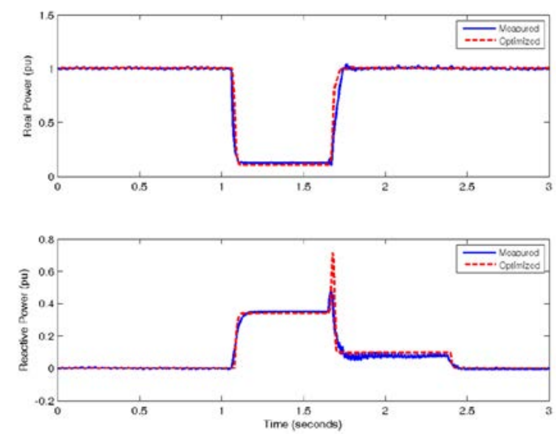
Block diagram of type 3 and type 4 WTG models

WTG models have been improved and implemented in power system simulation software

- Model validation methodology has been developed
  - EPRI's Wind Turbine Generator Model Validation Software, Version 1.0
  - Allows users to validate models using measured system disturbance data
- Collaborative effort between EPRI, NREL, and Sandia
- A range of operating conditions has been analyzed for validation
- Simulation fits are quite good and reasonable for the purposes of large scale power systems simulation studies



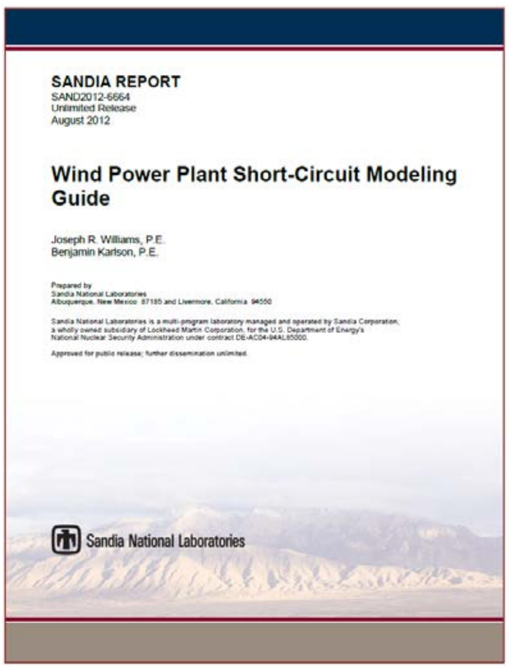
Modeled and measured comparison of a type 3 WTG response to a voltage dip at high side of step-up transformer.



Modeled and measured comparison of a type 4 WTG response to a voltage dip at high side of step-up transformer.

Tool available for download at:
http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001021763

- Conventional generators are typically modeled on an individual basis
- Wind farms employ many machines that make modeling individual generators not practical



SANDIA REPORT
SAND2012-6664
Unlimited Release
August 2012

Wind Power Plant Short-Circuit Modeling Guide

Joseph R. Williams, P.E.
Benjamin Karlson, P.E.

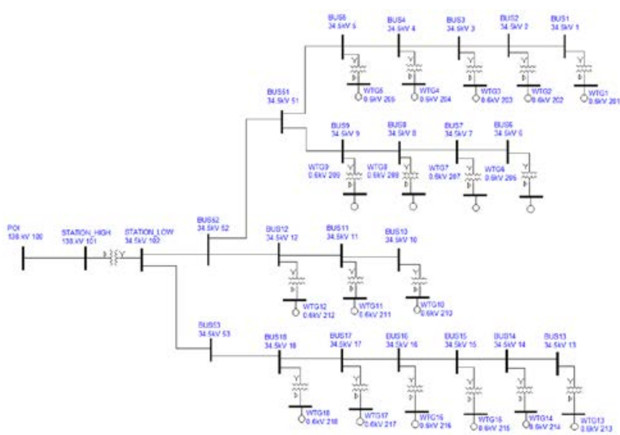
Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

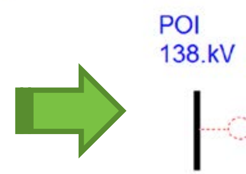
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

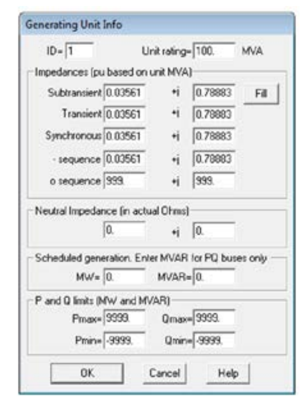
Approved for public release; further dissemination unlimited.

Sandia National Laboratories

- Presented a method for determining the maximum short-circuit contribution from a wind power plant







Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	8.1.1
Project Number	
Agreement Number	22925

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Q2 Milestone: Report with EPRI documenting wind turbine generator model validation												
Q3 Milestone: Wind turbine generator short-circuit whitepaper												
Q4 Milestone: Year end report on WTG modeling and validation												
Q1 Milestone: Implementation of 2nd generation WTG models												
Q3 Milestone: Report on the WTG model validation effort												
Q4 Milestone: Updated of the WECC Wind Power Plant Dynamic Modeling Guide												
Current work and future research												
WTG model improvements whitepaper: Renewable Energy Plant Controller Capabilities												
Finalize WT4 and WT3 model improvements and verify functionality of models												
Technical report detailing WTG model improvements												

Comments

- This effort requires significant coordination and collaboration among National Labs, industry organizations, power system simulation software developers, wind turbine manufacturers, and transmission owners and operators to develop and validate models.

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- The WECC Renewable Energy Modeling Task Force
  - Abe Ellis from SNL is the Chair of this task force
  - This Task Force includes partners like GE, Siemens, and PowerWorld
- The NERC Integration of Variable Generation Task Force
  - SNL has actively participated IVGTF tasks
- The International Electrotechnical Commission TC 88 WG27
  - SNL is the delegate from the US
- Ed Muljadi from NREL
  - SNL coordinates efforts with Ed Muljadi
- EPRI
  - Contracted to develop validation methods
- BEW Engineering
  - Contracted to improve modules on the type 3 and 4 WTG
- UVIG

Communications and Technology Transfer:

This work has been presented at numerous conferences and workshops including, but not limited to:

- WECC Modeling Webinars and Workshops
- IEEE Power & Energy Society General Meetings
- UVIG Technical Conferences
- IEC Meetings
  - Sandia hosted the 13th meeting of the IEC TC88/WG27 in September 2012

Papers include:

- EPRI, *Generic Models and Model Validation for Wind and Solar PV Generation: Technical Update*, Report under Sandia Contract 1180611.
- A. Ellis, R. Nelson, E. Von Engeln, R. Walling, J. MacDowell, L. Casey, E. Seymour, W. Peter, C. Barker, B. Kirby, J. R. Williams, *Review of Existing Reactive Power Requirements for Variable Generation*, IEEE Report.
- A. Ellis, R. Nelson, E. Von Engeln, R. Walling, J. MacDowell, L. Casey, E. Seymour, W. Peter, C. Barker, B. Kirby, J. R. Williams, *Reactive Power Performance Requirements for Wind and Solar Plants,* IEEE Report.
- J. Williams, B. Karlson, *Modeling Wind Plants for Short-Circuit Transmission Studies,* Whitepaper.
- Modeling Chapter of "Wind Power in Power Systems," Wiley Publication
- V. Zheglov, R. Zavadil, J.C. Smith, E. Muljadi, A. Ellis, *UVIG – Documentation, User Support, and Verification of Renewables Plant Models,* IEEE Publication
- P. Pourbeik, A. Ellis, R. Zavadil, J. Fortmann, P. Sorernsen, E. Muljadi, Y. Chi, *Dynamic Models for Wind Turbine Generators*, IEC Report
- P. Pourbeik, A. Ellis, J. Sanchez-Gasca, Y. Kazachkov, E. Muljadi, J. Senthil, D. Davies, *Generic Stability Models for Type 3 & 4 Wind Turbine Generators for WECC*, Working Group Joint Report – WECC REMTF
- NERC Special Reliability Assessment: Interconnection Requirements for Variable Generation, Lead author for Report Chapter, A. Ellis
- WECC REMTF Report, *Pseudo Governor Model for Type 1 and Type 2 Generic Turbines*

Next Steps and Future Research

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FY14/Current research:

- Efforts are on-going to improve on current WTG models. The second generation of dynamic models include a plant controller module responsible for voltage (reactive power) and frequency (active power) control. The module lacks capability to:
  - Supervise multiple WTG units in wind power plant
  - Coordinate with wind power plant shunt compensation devices
- Sandia is working with Siemens to begin module improvements necessary to fully capture the operating characteristics of wind power plants.
  - Improved module is expected to be complete by end of FY14 Q3.

Proposed future research:

- Model validation against a range of system events remains a high priority. Challenges remain in obtaining good data.
- Future revisions of the models are inevitable as new features are added and grid codes are adopted.

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INL Wind Program
FY12-13 Peer Review

Grid System Planning for Wind: Concurrent Cooling Model and Beta System

Kurt S. Myers
INL Wind and Power Systems Program
(208) 526-5022, Kurt.Myers@inl.gov
March 26, 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.800M

Total Cost-Share[1]:$0.00M

Problem Statement: Transmission line ampacity ratings, traditionally limited by conductor thermal capacity, are defined by a static rating using predetermined environmental conditions. Without accurately measuring environmental conditions and their effects, existing transmission lines can be significantly underutilized. Using dynamic line ratings will lead to improved line ampacity ratings and better knowledge of operational/reliability issues.

Impact of Project: Wind power production stands to directly, and most immediately benefit from increased transmission capacity through improved dynamic line rating systems, due to environmental effects. The system being developed and tested improves overall dynamic line rating quality and leads to average capacity improvements of 10-30%, or more in certain areas.

This project aligns with the following DOE Program objectives and priorities:

- **Optimize Wind Plant Performance:** Reduce Wind Plant Levelized Cost of Energy (LCOE)
- **Accelerate Technology Transfer:** Lead the way for new high-tech U.S. industries
- **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources
- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

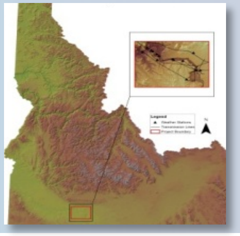
[1] *Budget/Cost-Share for Period of Performance FY2012 – FY2013*

Budget, Purpose, & Objectives

In FY 2013, INL supported the Wind and Water Power Technologies Office with these objectives:

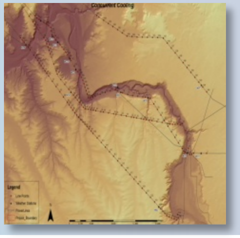
- The Concurrent Cooling Project will continue modeling, software and hardware development, and field testing to accurately determine dynamic line ratings (DLRs) with given loading and weather conditions.
- Analyze and compare with other DLR and measurement systems, continue system validation.
- Continue development of ideas for improving existing technologies through application of the weather station/model based system being developed by this project.
- Expand interaction with other utilities and industry to advance DLR technology and application potential, and support related wind integration and transmission activities.

New or better use of existing, power system infrastructure to help source 20% of nations wind energy by 2030.



Develop and improve partnerships with external stakeholders, including regulators, state governments, system operators, and utility and transmission planners.

Continue development of the INL-Idaho Power concurrent cooling transmission line analysis to include assessment of DLR procedures, development of potential regulatory guidelines, and publishing of results.



Increase deployment of wind energy through systems integration, interconnection, and technical outreach to promote education for private, Native American, and government entities.

Technical Approach

Refine weather station placement/spacing technique on transmission line corridors, and improve system technology, station architecture and communication integration to utility.

Test CFD model and calculation software results with comparison to field devices. Improve modeling software and begin process automation.

Continue improvement of system costs. Plan for utility operational use, system programming linkages, and future application uses and improvements (forecasting and analytics).

This system is unique due to significant increase in line data points, accuracy, and lower system costs. Application of CFD and other uses for the data add to system uniqueness and value.

Budget, Accomplishments, and Progress

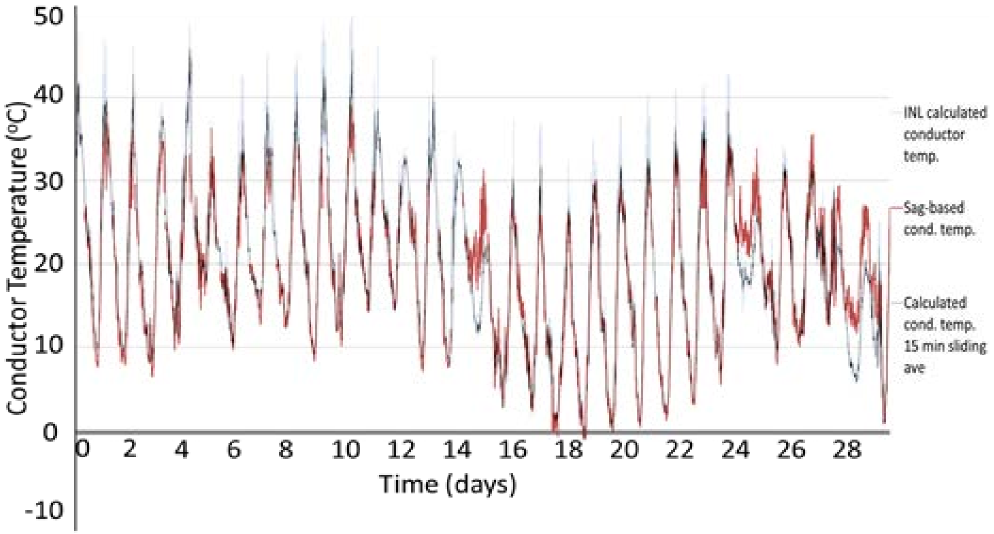
Grid Systems Planning for Wind

- INL continues to develop a methodology to dynamically rate transmission lines by taking advantage of concurrent cooling potential.
- With support from DOE's EERE Wind and Water Power Program, INL and Idaho Power Company are implementing use of climatology data to calculate DLRs.
- Key accomplishments in FY 2013 :
  - Executed data analysis and field validation efforts with Promethean Devices, LLC.
  - Removed Promethean Devices, LLC's equipment from the test location and analyzed 3 months of transmission line conductor temperature and available ampacity data.
  - Developed an operation DLR test area and fully characterized a 120+ mile section of line and surrounding 600+ square miles of terrain.
  - Initiated development of a custom Idaho Power wind data logger with a board-level cell modem to minimize communications error, reduce cost, and reduce power consumption.
  - Made advances in development of an INL custom DLR calculation software package using IEEE-738 and written in Java.

Field Validation Results: Conductor Temperature

Completed 3-month field demonstration using INL's DLR methodology coupled with Promethean Devices, LLC's non-contact IR based transmission line monitoring system.

- Achieved +0.968 correlation coefficient between the thermal conductor temperature measurements and estimates, an average 1.1° C difference.
- Identified geographic dependencies on ambient air temperature, affecting calculated conductor temperature and available ampacity.
- Investigated IEEE-738 impacts due to zero wind speeds.



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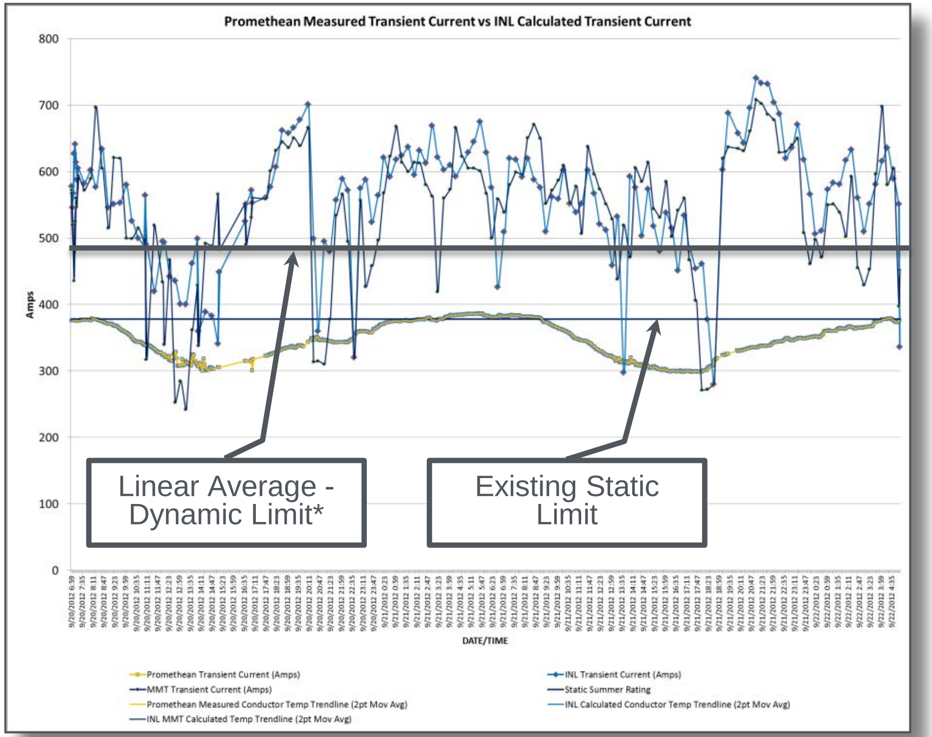
Field Validation Results: Available Ampacity

- Calculated conductor temperature using collected weather data, CFD-based lookup tables from models, and the IEEE steady-state conductor temperature equations.
- Calculated the maximum available ampacity over a 60-minute time period using the IEEE transient current rating function.
- Determined that high-resolution weather data needs to be collected at critical locations with modeling in between.
- Determined that using mesoscale climatology data without local measurements and sophisticated CFD modeling for areas between actual measurements often leads to minimal thermal and ampacity improvements above the static IEEE standard ratings, with large uncertainties.



IDAHO POWER An IDACORP Company | Promethean Devices | windsim

Accomplishments and Progress

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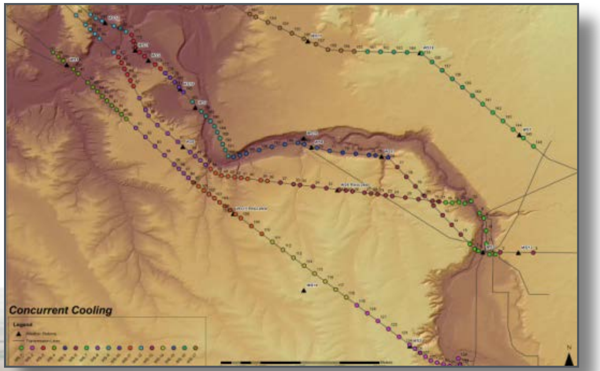
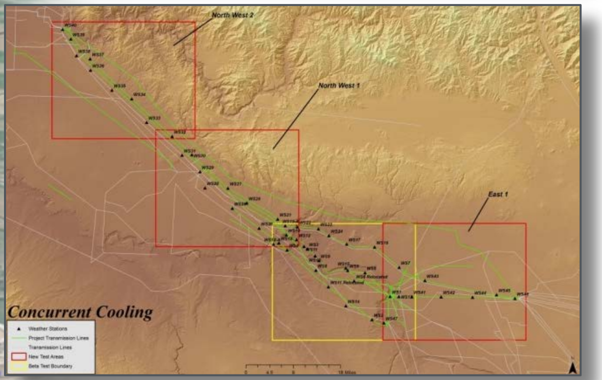
Wide Area Terrain Modeling: High-Resolution CFD

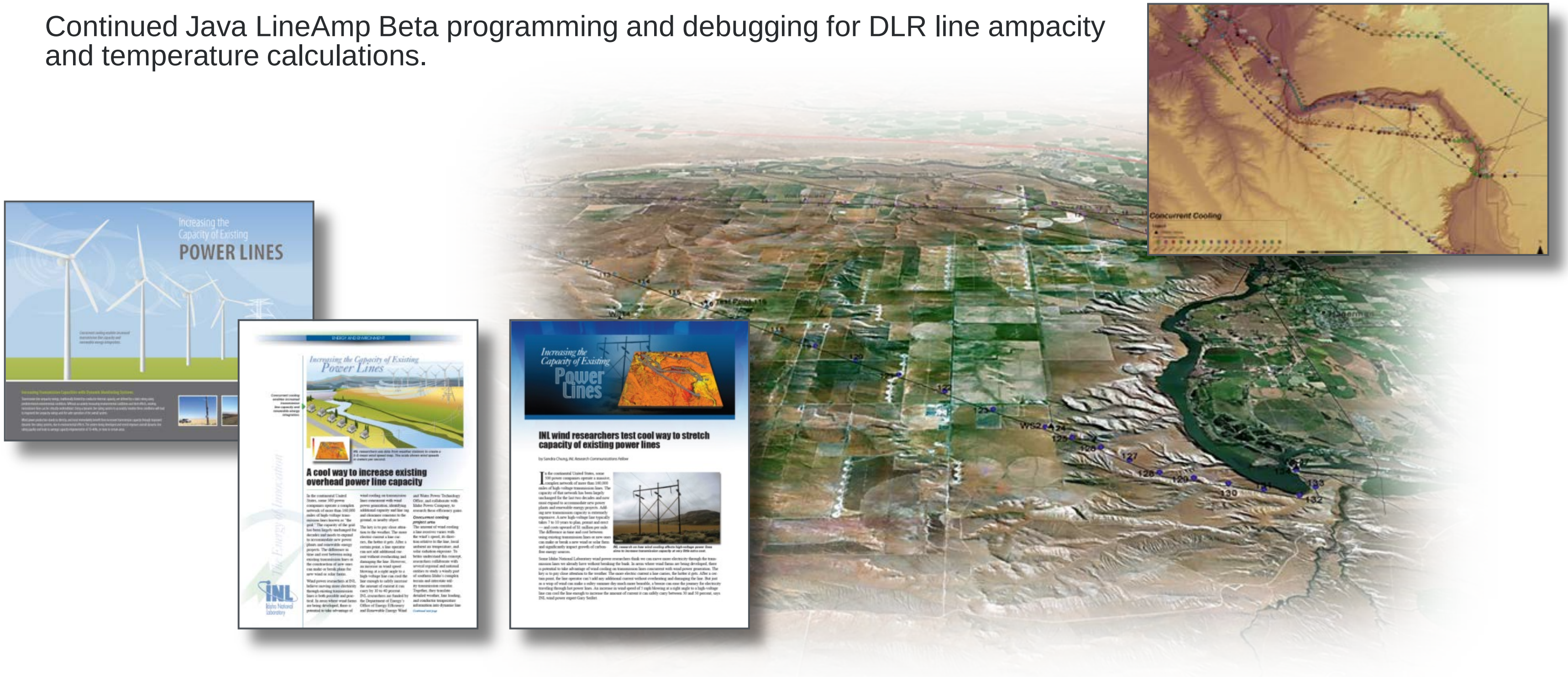
- Completed CFD model updates, including new weather stations.
- Expanded area includes the same four transmission lines modeled in the alpha phase, but it incorporates an end-to-end solution for testing and validation at an operational scale.
  - Modeled terrain area increased from about 600 to 6,600 mi^2
  - INL identified 47 total weather station locations needed to support a DLR of more than 450 line miles: two lines at 230 kV and two lines at 138 kV.





INL Software Development for DLR

- Developed beta programming/software with databasing of historical trends and patterns for validation and comparison.
- Attended and presented at IEEE and UVIG conferences.
- Work with Idaho Power continued on programming developments and databasing of historical trends and patterns and software programming for line ampacity calculations
- Reported IEEE and UVIG conference meeting attendance.
- Continued Java LineAmp Beta programming and debugging for DLR line ampacity and temperature calculations.



INL and Idaho Power Equipment Tests

- INL and Idaho Power worked together to design, build, test, and implement multiple versions of wind data loggers.
  - Version one included all “off-the-shelf” hardware integrated to create a customized working system.
  - Version two integrated custom communications and improved battery and solar panel sizing for added reliability.
  - Version three is a fully redesigned logger system with custom enclosure and mounting hardware, Idaho Power designed board-level wind data logger and chipset cellular communications hardware to reduce equipment costs and improve installation efficiencies.
- Initiated battery failure analysis/replacement and logger upgrades.
- Designed integrated system with on-board diagnostics.
- Field validation tests.

Rev 1

Rev 2

Rev 3

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	08.01.01
Project Number	21118
Agreement Number	22496

Legend	
(light blue)	Work completed
(blue)	Active Task
◇	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Grid System Planning For Wind: Concurrent Cooling Model and Beta System												
Q1 Milestone: Error band/derating limits analysis	◆											
Q2 Milestone: Methodology development for wind-cooling correlation		◆										
Q3 Milestone: Concurrent cooling model development and improvements			◆									
Q4 Milestone: Validate concurrent cooling models with CFD analysis				◆								
Q4 Milestone: Field validation with Promethean Devices				◆								
Q1 Milestone: Data analysis and field validation, communications upgrades					◆							
Q2 Milestone: CFD model updates and weather station build-outs (25)						◇			◆			
Q3 Milestone: Beta programming and Java system testing again historical data							◆					
Q4 Milestone: INL to host industry workshop/seminar								◆				
Q1 Milestone: Beta software development and GUI interface linkage with CFD auto									◆			
Q2 Milestone: Evaluate system costs and market analysis initiated										◆		
Q3 Milestone: Roadmap for integration of DLR analysis into planning and routing											◆	
Q4 Milestone: Investigate existing GIS planning and routing tools wint industry feedback												◆
Q4 Milestone: Update to test area progress and system integration efforts												◆

Comments

- Project is an ongoing effort with multiple tasks associated to the development of each milestone with various industry support over multiple years.
- Slipped milestone in Q2 of FY13 due to industry partner equipment installation delay. Did not cause setback to DOE-INL portion of the project, and project did not see a financial impact.
- Project has leveraged investment from utility partner to equip lines with INL specified and designed equipment.

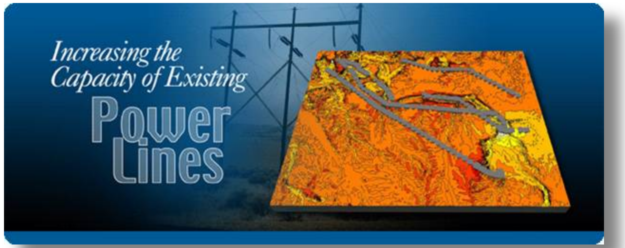
Partners, Subcontractors, and Collaborators:

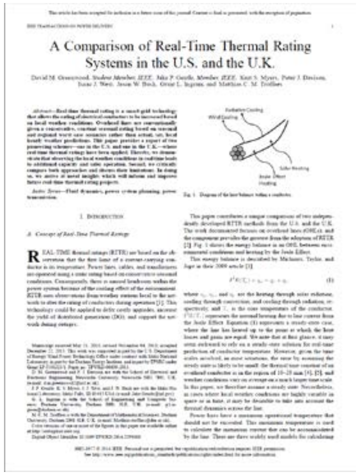
- **Boise State University – Boise, ID**
  - Graphical processing units CFD research (GIN3D)
  - Masters student thesis work related to DLR standard development
- **Durham University – Durham, UK**
  - Research collaborator and methodology validation and comparison
  - Joint publications
- **Idaho Power Company – Boise, ID**
  - Test area
  - Equipment funding and installation
  - Engineering support
- **Idaho State University – Pocatello, ID**
  - Graduate student intern (1.5 years) – full-time position hire
  - 2010 to 2011 Senior Design Project (4 students)
  - 2011 to 2012 Senior Design Project (4 students)
- **Montana Tech of the University of Montana – Butte, MT**
  - Undergraduate student intern (4 years)
  - Graduate student intern (2 years)
- **Promethean Devices, LLC – Fort Mill, SC**
  - Field validation subcontract (3 months)
- **University of Idaho – Moscow, ID**
  - PhD student intern supporting multiple publications
  - Undergraduate student intern (3 years)
- **WindSim AS – Tonsberg, Norway**
  - Computational fluid dynamics (CFD) software collaborator and development partner
  - Subcontracts
  - Joint publications

BOISE STATE UNIVERSITY | Durham University | IDAHO POWER An IDACORP Company | Idaho State University | MontanaTech THE UNIVERSITY OF MONTANA | Promethean Devices | University of Idaho | windsim

Communications and Technology Transfer:

- Publications – Presentations: IEEE PES Transactions, DistribuTECH, and IEEE PES T&D, UVIG Fall Technical Workshop, Western Energy Policy Conference.
- Senior design – capstone projects with Idaho State University.
- Masters thesis with Boise State University.
- Masters thesis project with University of Idaho
- PhD Dissertation with Durham University – UK.
- Additional discussions, collaborations and workshops with Idaho Power, Southwest Power Pool, ERCOT, PJM, and Electric Power Research Institute regarding DLR projects and technology/methodology validation and industry acceptance.





A Comparison of Real-Time Thermal Rating Systems in the U.S. and the U.K.

IEEE PES Power & Energy Society™

UWIG Utility Wind Integration Group

Boise State University | Durham University | EPRI Electric Power Research Institute | ERCOT | Idaho Power An IDACORP Company | Idaho State University | SPP Southwest Power Pool | University of Idaho

Communications and Technology Transfer: Continued

- INL 1st Annual DRL Workshop an industry conference/seminar to receive focused feedback from existing and potential collaborators, which included utilities, universities, and other commercial entities interested or involved with DLR.
- It provided INL and DOE EERE better exposure to research and an opportunity to receive feedback from interested parties regarding the validity of the beta system.
- INL and Idaho Power's 1st Annual DLR Workshop was completed successfully with **20+** attendees.
- A 2nd annual workshop is highly desired by attendees.
- Discussions were held with the Alberta Electric System Operator, AltaLink, ATCO Electric, and University of Calgary about DLR project support in Alberta.
- A similar workshop was requested to be hosted in Calgary in FY 2014.

INL Idaho National Laboratory

INL - IPCo 1st Annual Dynamic Line Rating Workshop

'Increasing Transmission Capacities with Dynamic Monitoring Systems'

11th September 2013, Boise, ID

INVITATION

Dear Madam or Sir,

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research: Evaluate Java based Beta software and continue improvements, begin CFD software automation improvements with commercial software vendor, improve evaluation of system costs and initiate market analysis, investigate GIS planning and routing integration feasibility, evaluate potential GIS and line design platforms, analyze and report on large area modeling efforts and automation.






Proposed future research: Additional commercial product testing and validation with other line measurement technologies; develop system improvements to communications, loggers, and instrumentation; improved uncertainty and error analysis; integration of wind and solar generation forecasting developments with transmission capacity forecasts; exploit weather station data from transmission level for use in severe weather event forecasting and system readiness; planning and routing tool development, system integration and operational acceptance; policy and regulatory.

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Operational Impacts of a Large-Scale Wind Power Expansion

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Argonne National Laboratory

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March 27 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $.450M

Total Cost-Share[1]:$0.00M

Problem Statement: The characteristics of the wind resource create challenges for the electric power grid. The project investigates how to best address uncertainty and variability in *operational decisions*, related *planning problems*, and how to improve *price incentives* in electricity markets with wind power.

Impact of Project: The methods and insights from this project contribute to *more efficient grid operations, better price incentives*, and *lower wind integration costs* in electricity markets with wind power.

This project aligns with the following DOE Program objectives and priorities:

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

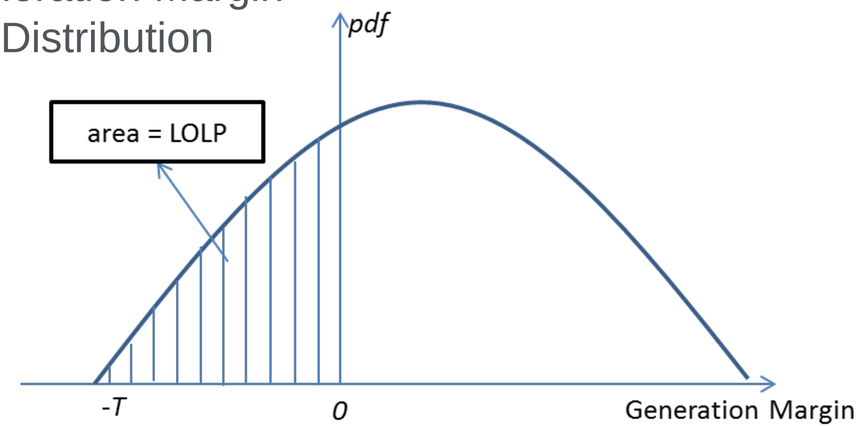
[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach - Dynamic Operating Reserve Demand Curves

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Demand for reserves should depend on probability of supply shortfalls
  - Proposed in (Hogan 2005), under implementation in ERCOT
- Estimate the risk of supply shortfall *considering impact of wind power*
- Represent the main uncertainties from load and supply
  - Forced outages of thermal power plants
  - *Probabilistic forecast for wind power*
  - Load forecasting errors

Generation Margin Distribution



LOLP: Loss of load probability
VOLL: Value of loss load

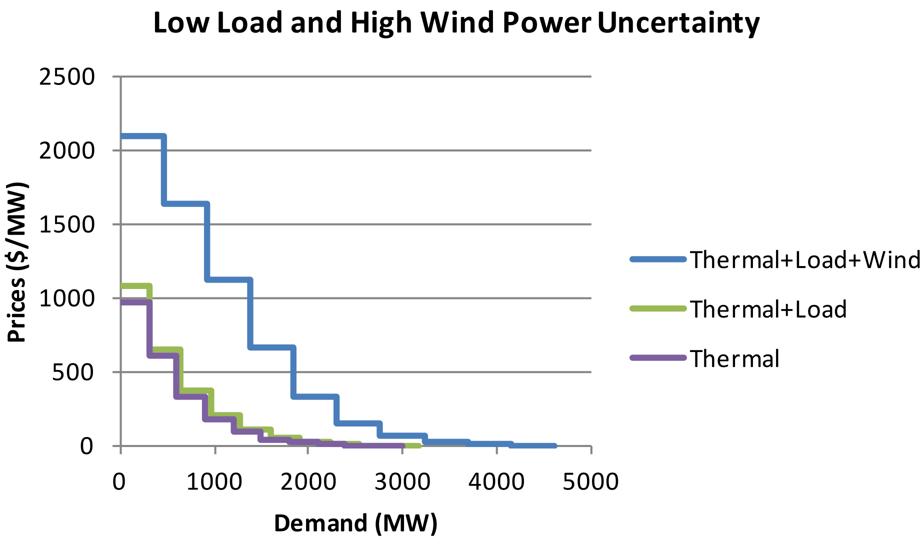
Price(reserve) = LOLP(reserve) * VOLL

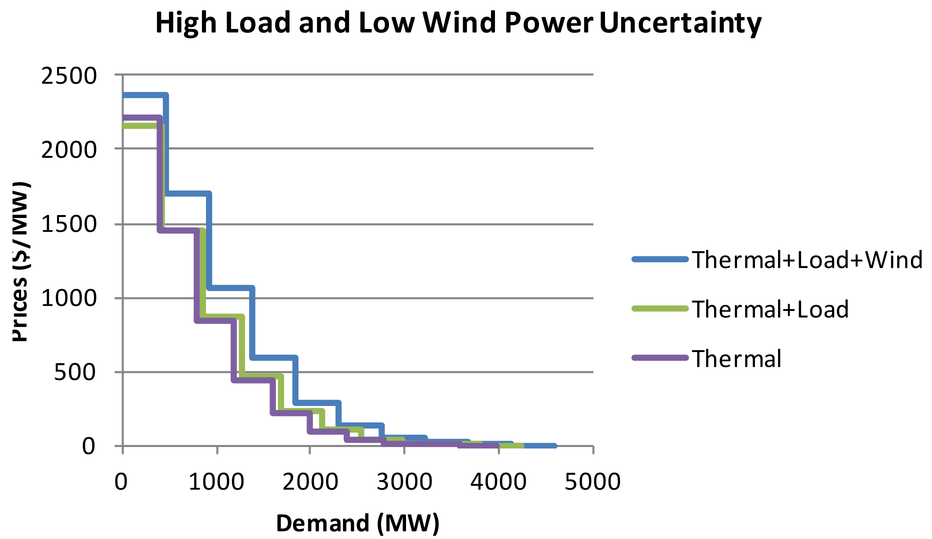
Zhou and Botterud (2014)

Accomplishments and Progress –
Dynamic Operating Reserve Demand Curves

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Numerical analysis of generator/ load dataset for Illinois with 20% wind
  - Hourly demand curves for sum of spinning and non-spinning reserves
  - Contributions to operating reserve demand for two selected hours:

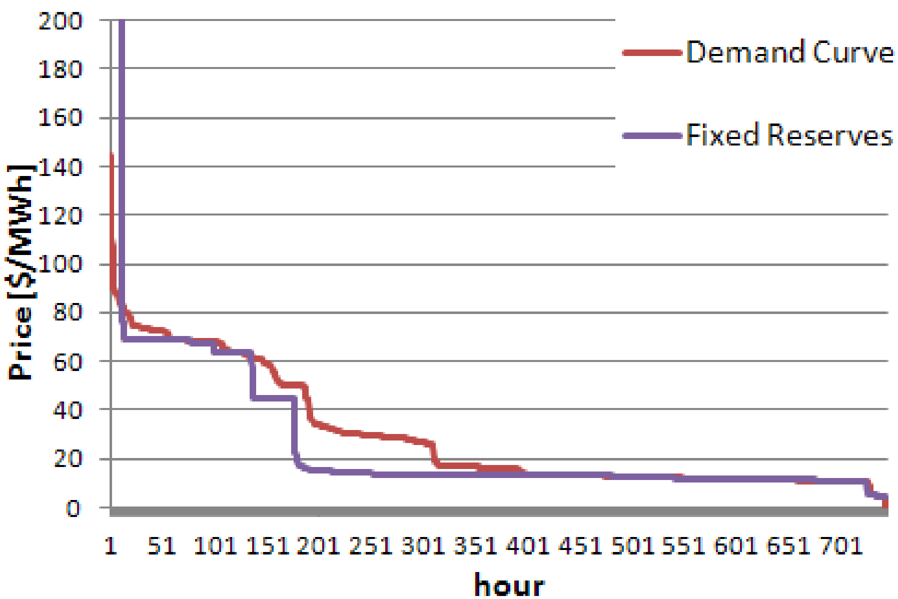




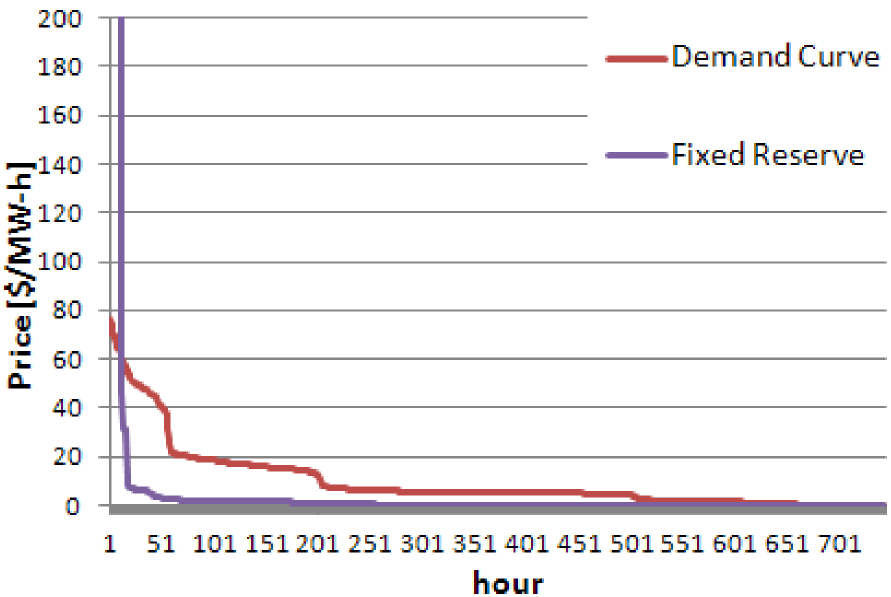
- *The amount of reserves scheduled will depend on the cost of providing them*
- *The price responsive reserves add flexibility to scheduling and dispatch*

- Simulation of electricity market with co-optimization of energy and reserves
- Price duration curves for day-ahead market, month of July:

Energy



Reserves

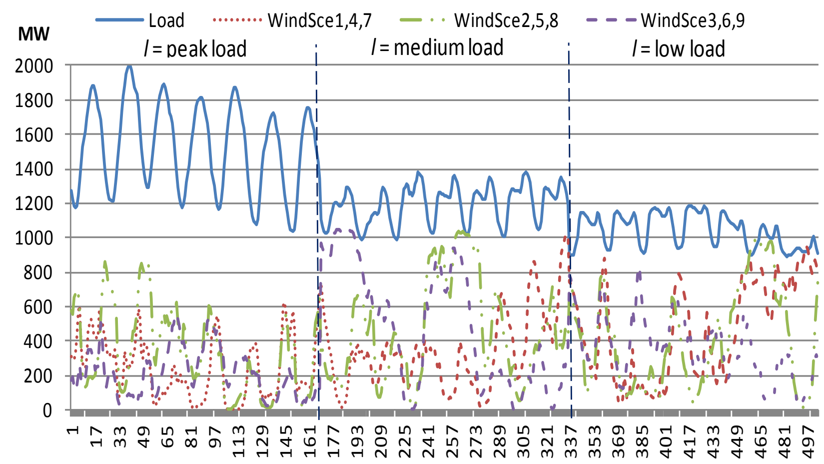


- The proposed demand curve for operating reserves
  - *Gives higher prices for energy and reserves in most hours, fewer price spikes*
  - *Stabilizes revenue stream for thermal generators; alleviates "missing money"*
  - *Better reflects wind power forecast uncertainty in prices*

Technical Approach -
Long-Term Market Implications of Wind Power

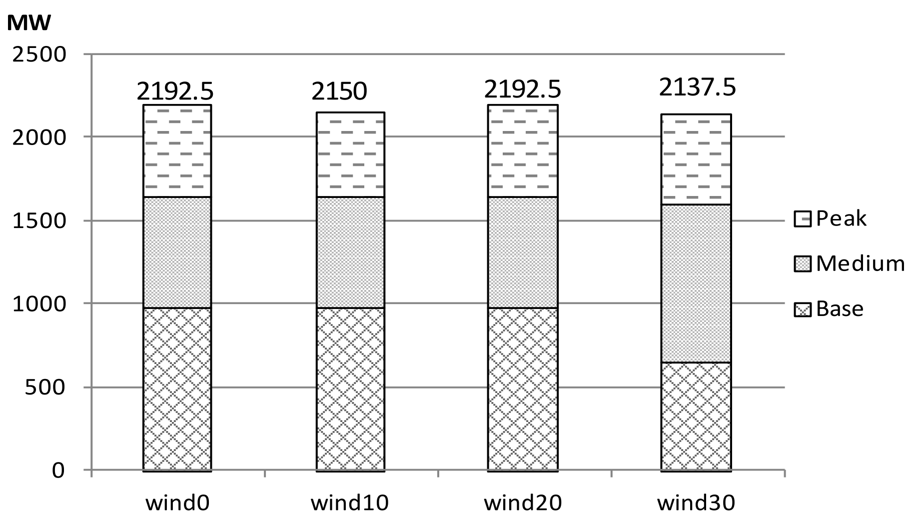
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

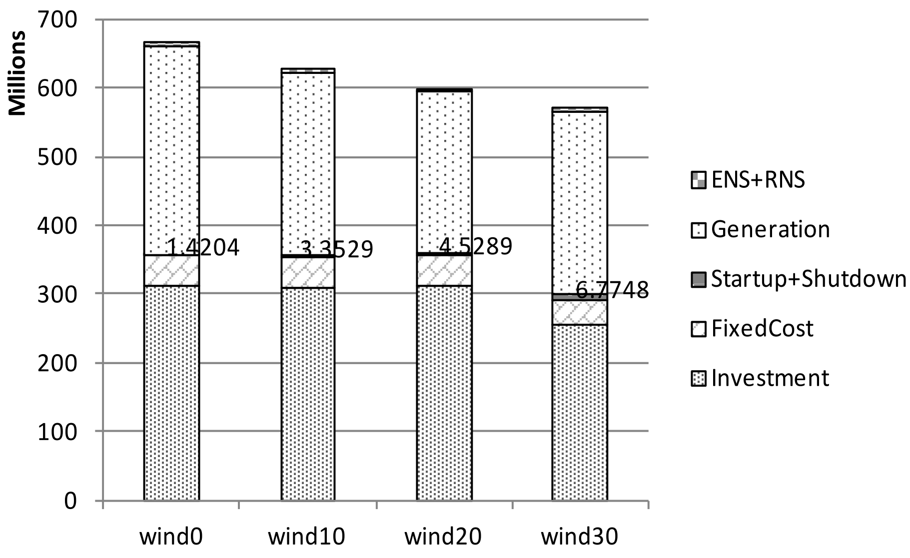
- Stochastic programming model for generation expansion with wind
  - Minimizes sum of investment cost, fixed O&M cost, and expected generation and load/reserve shortfall costs
  - Wind resource variability: scenarios for selected weeks
  - Wind forecast uncertainty: increased operating reserves
  - Unit commitment/dispatch constraints can be considered (start-up costs, max/min power output, ramp up/down, energy + reserve balance)
  - Demand response representation
- Model outputs
  - Optimal thermal generation mix
  - Dispatch results
  - Total system costs
  - Energy and reserve prices



- Review of current and proposed market solutions to ensure resource adequacy, flexibility, and revenue sufficiency (w/NREL)

- Generation expansion and system costs with increasing wind power:

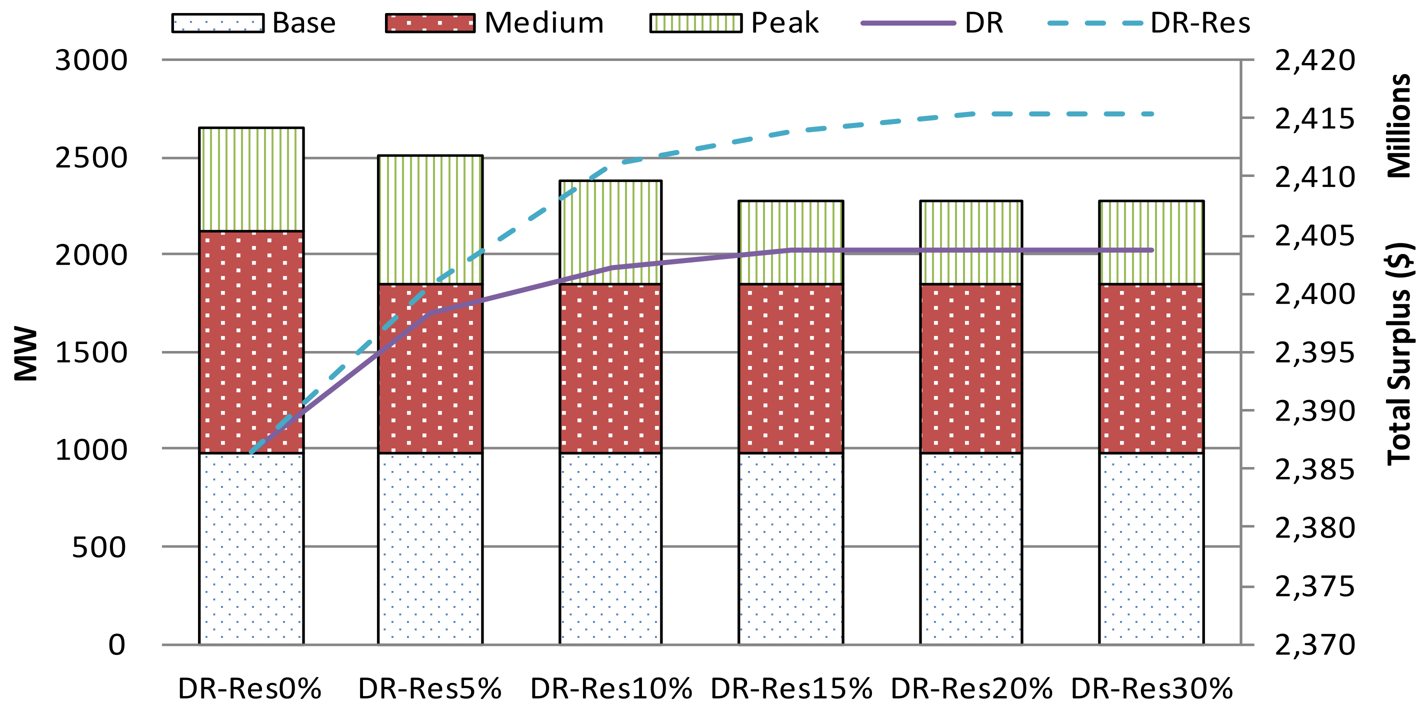




- Full unit commitment constraints have small impact on expansion results
  - Economic dispatch w/ramping constraints give similar results much faster
- A reduced scenario set is sufficient to capture wind power variability
  - Gives further reductions in model run-times

Jin, Botterud, Ryan (2014)

- Demand response (DR) helps integrate large shares of wind (30% case)



- Demand response has multiple advantages
  - Reduces the need for thermal generators and increases their capacity factors
  - Lowers wind curtailment
  - Lowers reserve shortfalls
  - Increases economic surplus

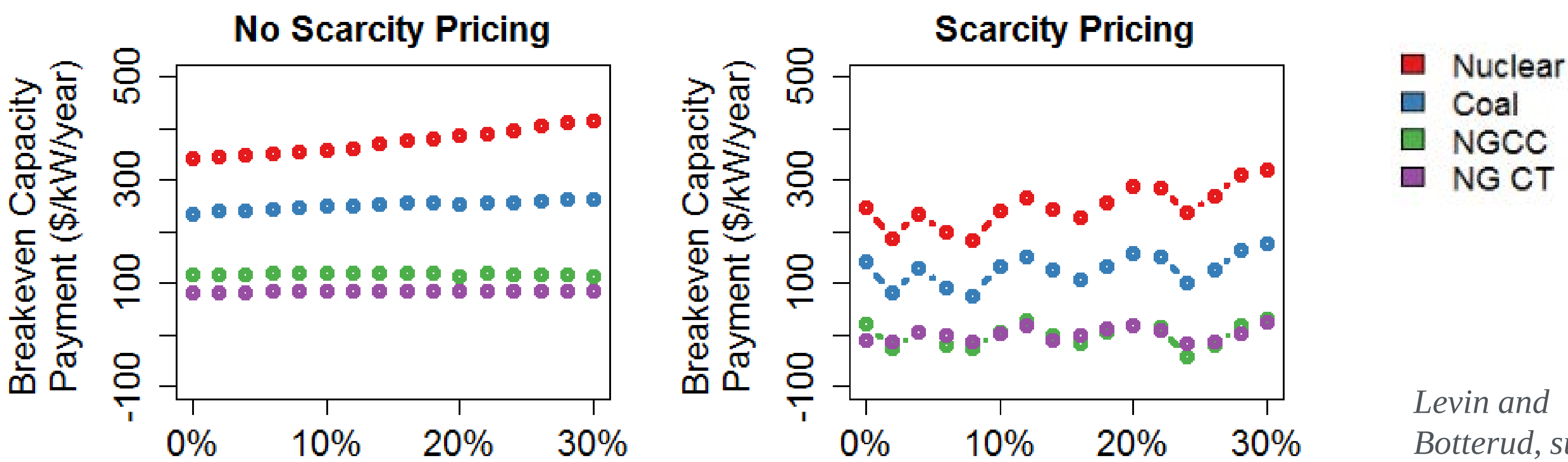
Jin, Botterud, Ryan (2013)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Impact of wind on energy/reserve prices and profitability of new generators
  - Impact of scarcity pricing (SP) rules is important

Energy	0% wind	10% wind	20% wind	30% wind
No Scarcity Pricing	29.4	27.5	24.4	21.0
Scarcity Pricing	40.3	41.0	34.5	31.8

Reserves	0% wind	10% wind	20% wind	30% wind
No Scarcity Pricing	0.0	0.6	5.5	7.5
Scarcity Pricing	10.8	14.1	16.7	18.4



Levin and Botterud, subm.

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number 21118	
Agreement Number 22926	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Q2 Milestone: Complete OR demand curve design												
Q3 Milestone: Initial framework for long-term market implications												
Q4 Milestone: Interim report												
Q2 Milestone: Complete model for expansion and price analysis												
Q3 Milestone: Complete initial case study of long-term market impacts												
Q4 Milestone: Journal papers and interim report												
Current work and future research												
Complete review of market designs for adequacy and flexibility												
Complete analysis of capacity adequacy and revenue sufficiency												

Comments

- Project period: 10/2011-03/2014
- Scope of market design review task adjusted/expanded along the way

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:

Argonne team (Zhou, Levin)
NREL (Milligan, Ela, Bloom, Townsend)
Iowa State University (Jin, Prof. Ryan)
University of Illinois Urbana Champaign (Valentino, Vilim)

Communications and Technology Transfer:

- Results presented in main conferences, industry meetings, and workshops (IEEE, FERC, UVIG, AWEA)
- Numerous peer-reviewed publications (6 journal papers, 2 conference papers in FY12/13), 450+ citations since 2010
- Two prototype models: 1) probabilistic estimation of operating reserve demand curves 2) stochastic generation expansion and resource adequacy with wind power

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research:

Publish results from capacity adequacy and revenue sufficiency analysis

Finish report on current and proposed market designs (w/NREL)

Proposed future research:

Scale up models to larger and more realistic systems

Model a wider variety of potential market designs (short- and long-term incentives for flexibility and adequacy)

Consider out-of-equilibrium market assumptions outside least-cost system optimum

Wind Power Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Accommodating Wind and Solar Integration

BA Size	Sub-Hourly Energy Markets	Fast Access to Neighboring Markets	Geographically Dispersed Wind and Solar	Wind/Solar Forecasting Effectiveness	NonSpinning and 30 Minute Reserves for Wind/Solar Event Response	Effective Transmission Expansion	More Flexible Transmission Services	Flexibility in Generation	Responsive Load	Overall	Example Utility Structures
1	1		1	1	1	1	1	1	1	9	*Weightings Factors*
4	10	X	5	5	0	5	10	0	3	5	ISO-NE
9	10	X	8	10	6	5	10	6	3	7	PJM
8	10	X	8	10	6	10	10	7	4	8	MISO
5	10	X	5	5	8	2	10	0	3	5	CAISO
4	10	X	6	9	0	1	10	7	3	6	NYISO
6	10	X	9	9	3	10	10	0	9	7	ERCOT
5	10	X	5	6	0	6	10	7	2	6	SPP
5	10	√	4	5	0	2	5	0	3	4	PGE

Metrics/Balancing Area Analysis

Michael Milligan

NREL

Michael.Milligan@nrel.gov, 303 384-6927

March 27, 2014

Budget, Purpose, & Objectives

Total DOE Budget[1]: $0.280M

Total Cost-Share[1]:$0.000M

Problem Statement: Develop a methodology by which a balancing area (BA) can assess its ability to integrate wind and solar power and to inform DOE regarding integration status for selected utilities/BAs.

Impact of Project: Allows utilities and ISOs to identify operational procedures that will aid in their integration of variable and uncertain renewable energy sources. Provide metric to DOE to evaluate integration status.

This project aligns with the following DOE Program objectives and priorities:

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid.
- **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources.

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Defined 10 characteristics for BAs that impact their ability to integrate renewables, and developed quantitative methodologies for assessing their ability based on a score from 1 – 10.

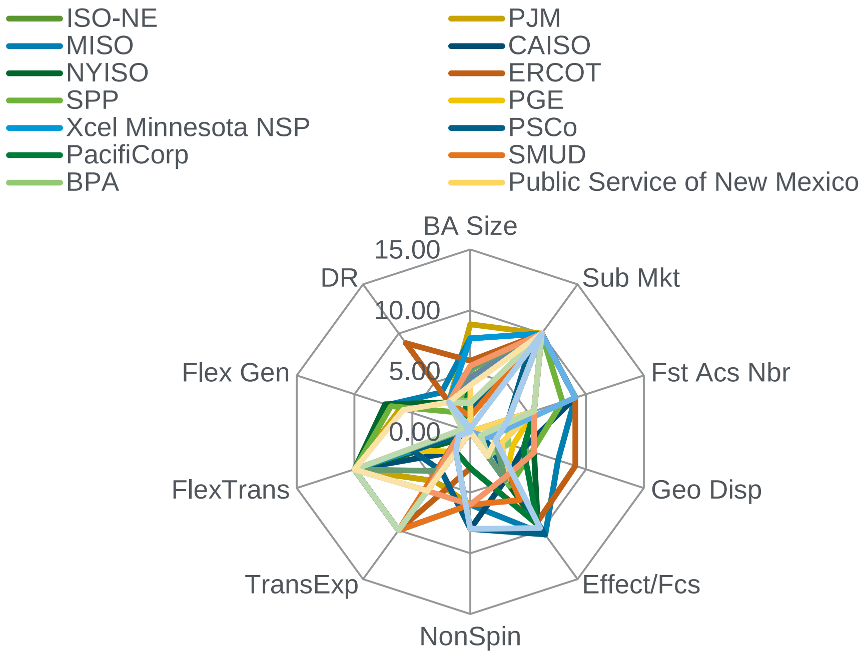
(1) Balancing area (BA) size
(2) Sub-hourly energy scheduling/markets
(3) Fast access to neighboring systems/resources/markets
(4) Geographic dispersal of wind and solar generation
(5) Wind/solar forecasting integrated into power system operations
(6) Non-spinning and 30-minute reserves for wind/solar event response
(7) Regional transmission planning for economics and reliability
(8) More flexible transmission services
(9) Flexibility in generation
(10) Responsive load

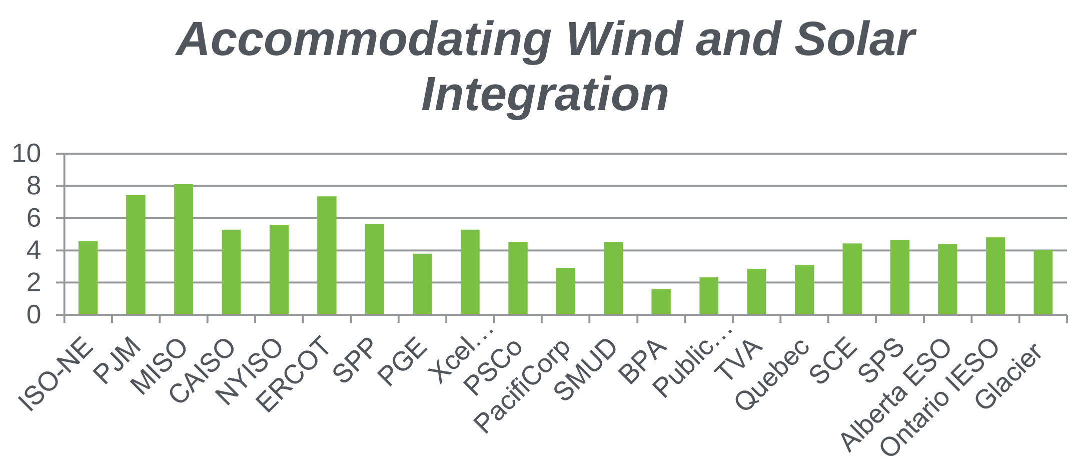
$$Region\ Score = \mathrm{Region\_Scaling\_Factor}\left(10\sqrt{\frac{Region\ MW}{150{,}000}} - 0.18 * Region\_Scheduling\_Minutes + 10.9\right)$$

Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Developed quantitative methodologies for calculating characteristic scores
- Analyzed 21 BA systems
- Developed visualization techniques (radar plots) for comparing regions strengths and weaknesses





Project Plan & Schedule need info

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
◆ (gray)	Milestones & Deliverables (Original Plan)
◆ (black)	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Metric/BA Analysis												
Q1 Milestone: Draft metrics recommendation delivered to DOE												
Q2 Milestone: Delivered draft updated scorecard/method to DOE												
Q3 Milestone: Results of scorecard application to multiple BAs delivered to DOE												
Q4 Milestone: Presentation material delivered to DOE												
Q1 Milestone: Letter report to DOE/alternative metrics												
Q2 Milestone: Deliver letter report to DOE on scenario selection												
Q3 Milestone: Delivered letter report documenting tool												
Q4 Milestone: Deliver final presentation materials to DOE												

Comments

- Project original initiation date FY 2013, Project planned completion date FY 2014

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators: The Western Interstate Energy Board has been a partner throughout the project and is adopting a modified methodology with stakeholder input, to communicate with member utilities about how they may more efficiently integrate renewable energy into their system.

Communications and Technology Transfer:

- Tool delivered to DOE to help inform research decisions
- Numerous presentations and meetings with the Western Interstate Energy Board
- Webinars to explain the methodology.

Next Steps and Future Research

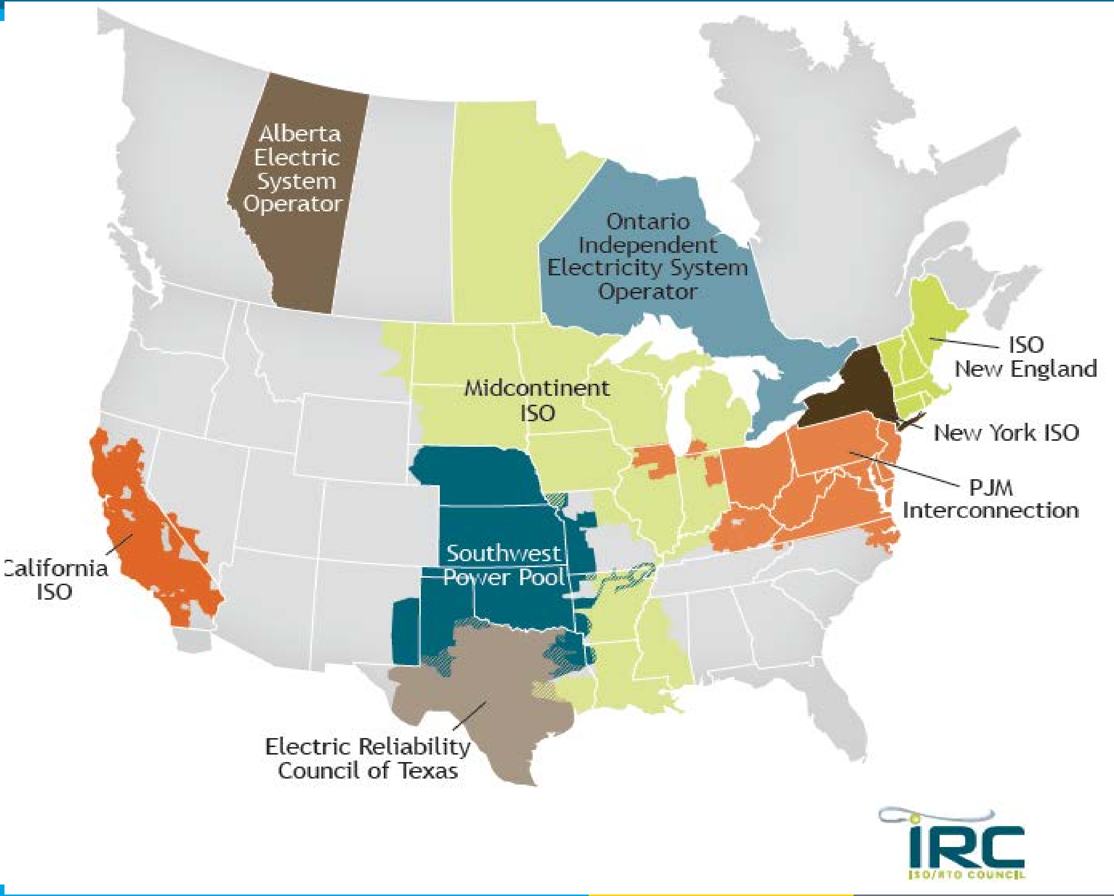
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research:

Continue collaboration/assistance to WIEB under OE budget.

Proposed future research:

It is envisioned that from this multi-year, multi-agency effort, more sophisticated approaches to solve this problem could be investigated.



Market Impacts

Erik Ela

NREL

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March 27,2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.400M

Total Cost-Share[1]:$0.000M

Problem Statement: Understand how wind power is influencing market outcomes and determine if changes to wholesale electricity market designs are needed.

Impact of Project: This work will help FERC and the ISOs understand the significance of increased wind power and what, if any, market design changes may be necessary as a result.

This project aligns with the following DOE Program objectives and priorities:

Advanced Grid Integration: Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

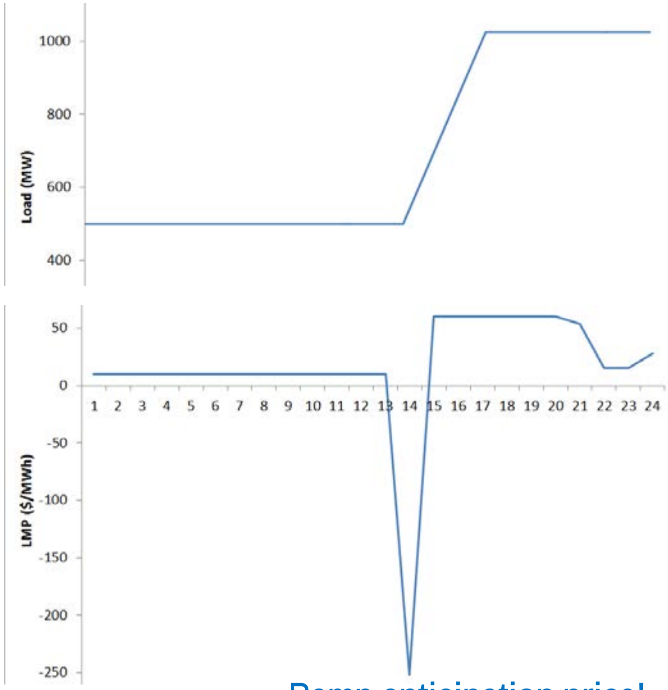
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Thorough review of how U.S. market operators are addressing two important questions related to increased penetrations of wind resources:
  - How markets are meeting long-term resource adequacy and how or if resources needed for resource adequacy are earning enough revenue to recover both variable and fixed capital costs
  - How markets are incentivizing the increased flexibility that is needed in short-term system operations
- Use production cost simulations to quantify the costs of integrating new generation resources and their related market characteristics into existing power systems.

Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Finished major report on wholesale electricity market designs with increasing levels of variable generation
- Traditional and new designs to answer the question of long-term revenue sufficiency and resource adequacy
  - Current forward capacity markets and scarcity pricing rules
  - Flexible capacity procurement (CAISO) and dynamic operating reserve demand curve (ERCOT)
- Traditional and new designs to answer the question of short-term flexibility incentives
  - 5-minute dispatch/settlement, make-whole payments, day-ahead margin assurance payments
  - Pay-for-performance regulation, flexible ramping markets, dispatchable intermittent resource programs



Ramp anticipation price!

Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

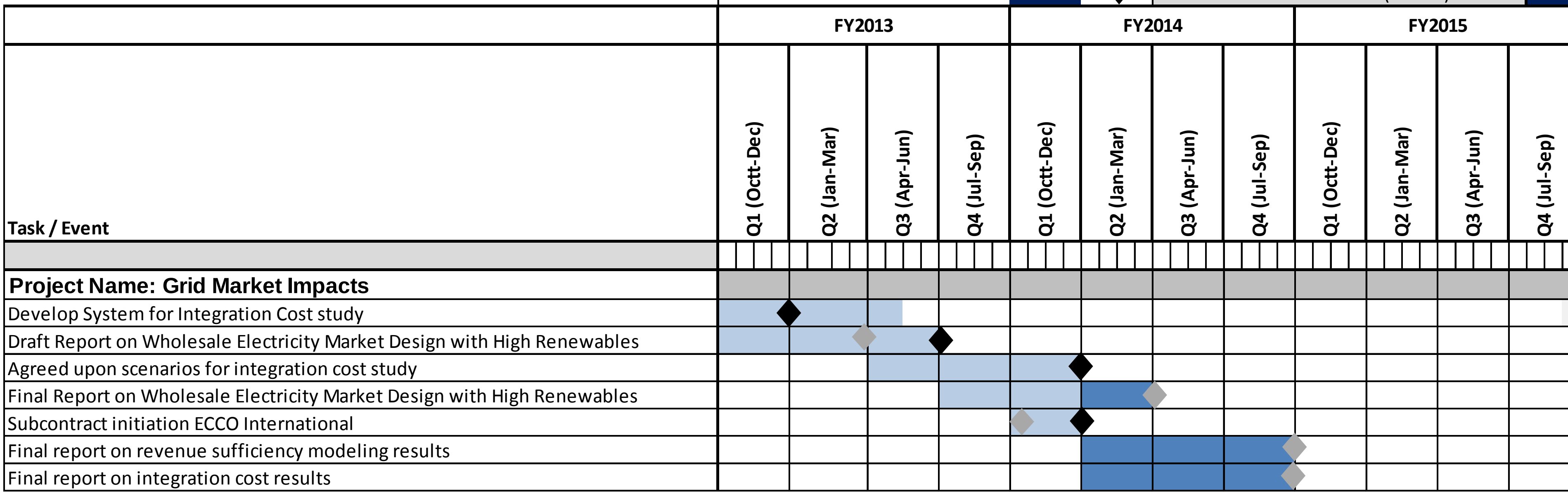
- Development of integration cost study test system complete
  - Modified IEEE 118 bus, ~70 generator system with NREL wind/load data
- Agreed-upon scenario priority with set of technical experts during technical review committee meeting
- Starting multi-stage production cost simulations for year 2020
  - Changes in production cost between scenarios will be evaluated to see ultimate drivers of integration costs

Scenario	Sensitivities
High penetration wind	Generation mix, gas prices, coal retirements, start and cycling costs
Large, inflexible coal plant	None – run against reference case only
Extended generator start times	None – run against reference case only
Self-scheduling	None – run against reference case only
Gas supply constraints	Generation mix (reference and high gas mix)

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary		Legend
WBS Number or Agreement Number		Work completed
Project Number		Active Task
Agreement Number		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)



Comments

- Project initiation: September 2013
- Delay in subcontract process led to delayed start in revenue sufficiency study

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators: Integration Cost Study Technical Review Committee, Argonne National Laboratory, and ECCO International. Other informal collaborators include ERCOT, CAISO, FERC, IEA, and MISO.

Communications and Technology Transfer: This research was presented at a number of venues, including 2 FERC Technical Conferences, EUCI, PSERC, IEEE PES, UVIG, and the Flexible Power Symposium. Detailed presentations on wholesale markets were also presented to NYISO, ERCOT, FERC, and CAISO.

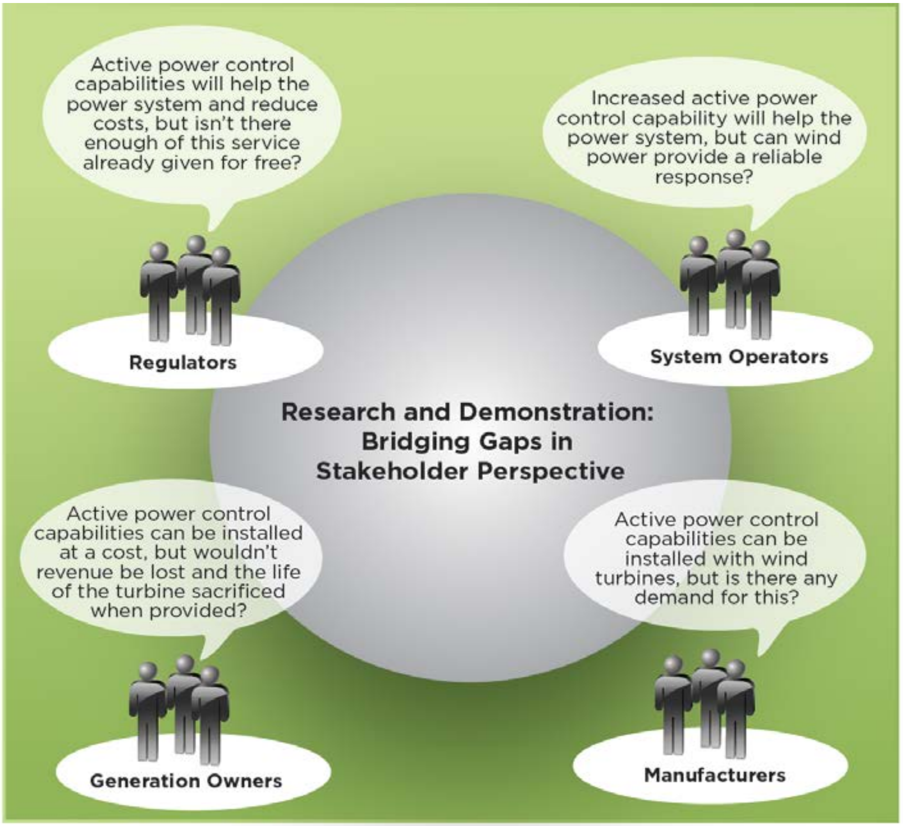
Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research: The focus of research in FY14 is to complete and analyze the simulation results for the integration cost study and complete the study on revenue sufficiency.

Proposed future research: Further research is needed on the short-term energy and ancillary services markets. New market design proposals are being introduced at the ISOs by stakeholders who often do not have the benefit of rigorous research before they are implemented (e.g., flexible ramping, pay for performance, pricing with stochastic market models, pricing with increasing non-convex costs).

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Active Power Control from Wind Power

Erik Ela

NREL

(303) 384-7089

March 27, 2014

Budget, Purpose, & Objectives

Total DOE Budget[1]: $0.625M

Total Cost-Share[1]:$0.000M

Problem Statement: Utilities, developers, owner/operators, OEMs, and regulators are trying to figure out what are the impacts of wind power plants providing grid support by various forms of active power control.

Impact of Project: The results of this project will help all of these entities understand the economic, system reliability, and structural impacts of allowing for wind to provide fast forms of active power control.

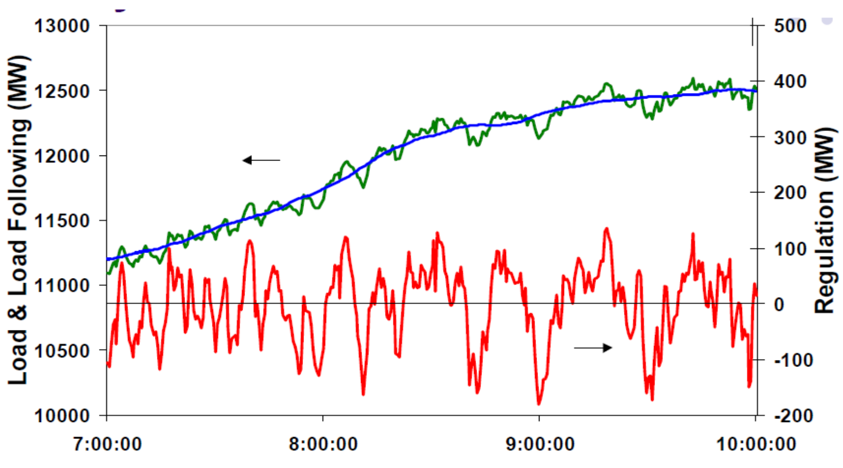
This project aligns with the following DOE Program objectives and priorities :

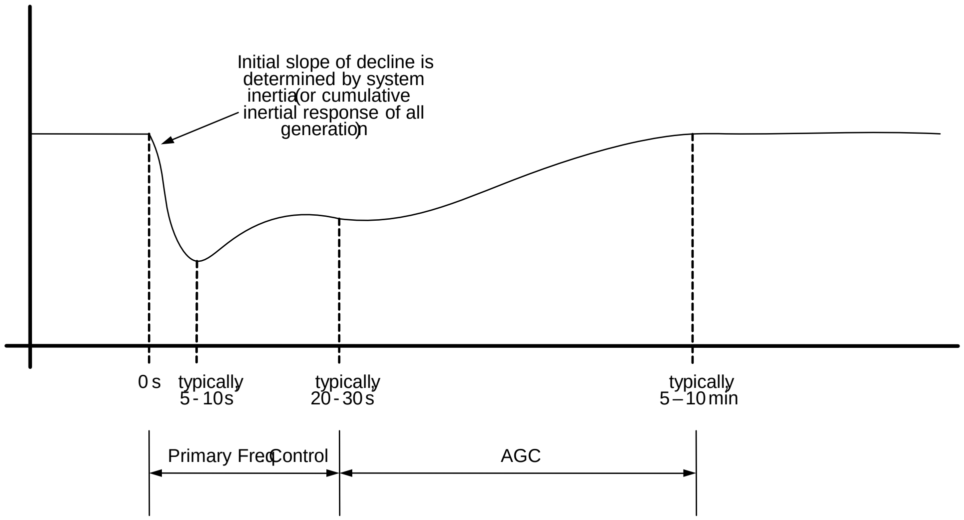
Advanced Grid Integration: Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

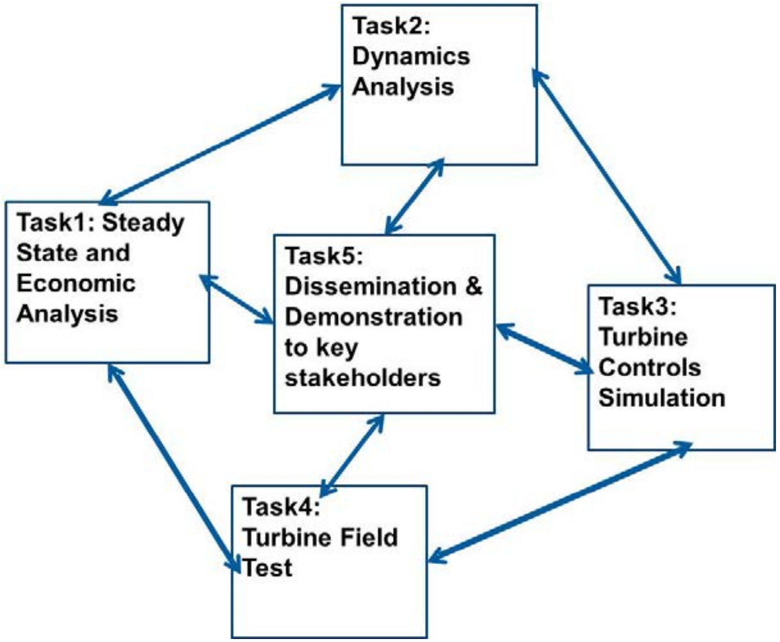
- Active Power Control: adjusting the active power injection during times when it is needed to support power system reliability
  – Inertial response: instantaneous power injection to reduce the rate of change of frequency decline
  – Primary frequency control: power injection used to stabilize the system frequency
  – Automatic generation control regulation: power injection to maintain the frequency at nominal level (60 Hz) and interchange errors at zero





Technical Approach

- The study analyzes:
  - Timeframes ranging from milliseconds to minutes to the lifetime of wind turbines
  - Spatial scope ranging from components of turbines to large wind plants to entire synchronous interconnections
  - Topics ranging from economics to power system engineering to control design
- Various simulation platforms (PLEXOS, PFRSCUC, PSLF, PSCAD, FAST, MAFRIT)
- Field testing on 3-bladed Controls Advanced Research Turbine
- Feedback from task to task
  - Example: Steady-state analysis uses input from dynamics analysis to ensure the right dynamic response was being modeled



Accomplishments and Progress

- Published major, 2-year report in December 2013. Received significant press.
- Held NREL/EPRI APCWP Workshop in May 2013.
- Developed primary frequency response market design in 2013. It is now being evaluated in the Electric Reliability Council of Texas.
- Western Interconnection frequency response study found little impact to frequency response without control but great improvement with control. (Prelude to WWSIS3)
- Designed and implemented torque tracking control on CART3. Performed loads analysis with new control.
- Published generic generator models with inertia and primary frequency response capabilities (Types 1, 2, 3, 4).

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Active Power Control from Wind Power												
1st year project progress report												
Primary Frequency Response Market Design Paper												
2nd NREL/EPRI international workshop on Active Power Control												
Generic Wind Generator Dynamic Models with APC capabilities												
Comprehensive project report												
Loads suite analysis												
Development of MAFRIT												

Comments

- Significant editorial and approval needs caused slight delay in final project report

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators: Electric Power Research Institute, University of Colorado. Informal collaboration with APCWP Stakeholder Group, FERC, ERCOT, NERC, UVIG O&M user group, etc.

Communications and Technology Transfer: 2nd NREL/EPRI Active Power Control From Wind Power Workshop (May 2013). Presentations at UVIG, AWEA, ERCOT, FERC, IEEE PES, IEEE PEMWA, International Workshop on Wind Integration, ACC, and AIAA. Interviews, webinar, and numerous articles produced following large project report.

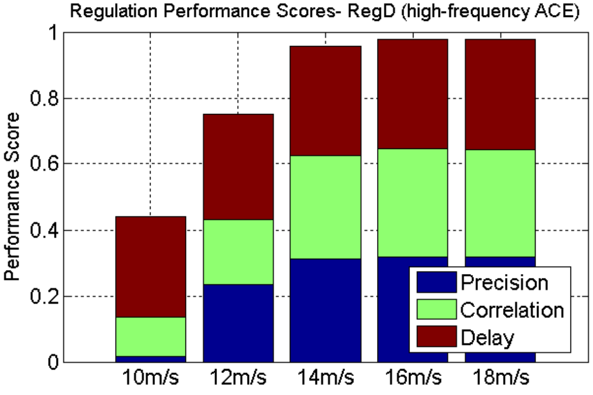
Next Steps and Future Research

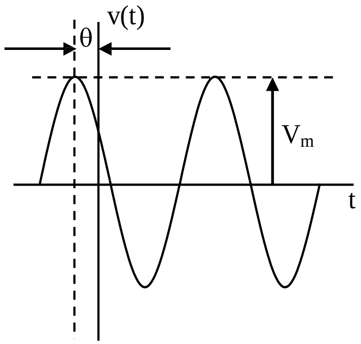
FY14/Current research

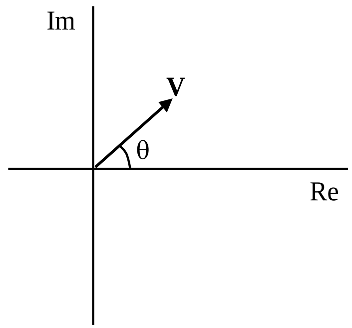
- Interaction of primary and secondary frequency control
- Advanced controls that focus on new ancillary service market requirements

Proposed future research

- Advanced control design field testing on wind plant level
- Better understanding of synthetic inertial response versus synchronous inertia
- How sensing technology can be used for APC (e.g., LIDAR)



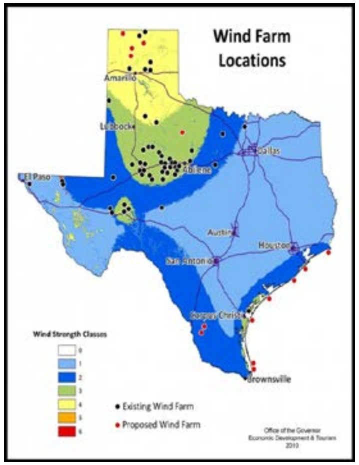


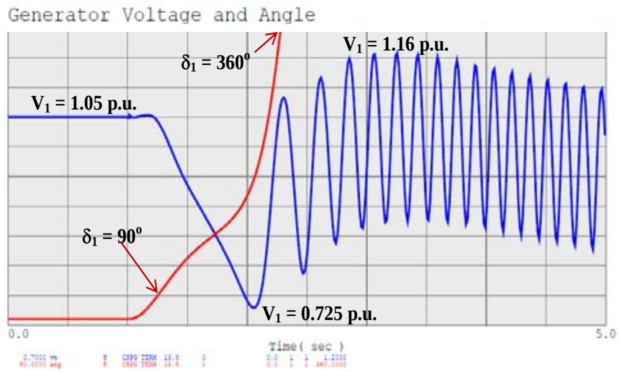


Principal Investigators:

Yih-huei Wan (FY12-FY13)

Eduard Muljadi (FY14)





Key Staff:

Alicia Allen (Post Doc)

Vahan Gevorgian

Mohit Singh

Y.C. Zhang

Reliability Analysis – Synchrophasor – Phasor Measurement Unit (PMU)

Eduard Muljadi

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March 27, 2014

Budget, Purpose, & Objectives

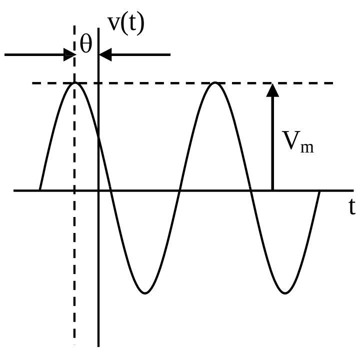
Total DOE Budget[1]: $0.435M

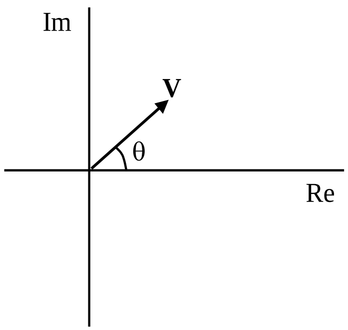
Total Cost-Share[1]:$0.000M

Problem Statement:

- The Phasor Measurement Unit (PMU) is an instrument that can provide precise measurements of voltage, current, and frequency of the grid synchronized to GPS. Thus, real-time measurements of voltage phasors and current phasors at multiple remote buses can be acquired and used to gauge the instantaneous power system stability.

- The objective of the project is to utilize available PMU data to better understand the dynamic interactions between wind power plants and the grid under normal and contingency conditions.





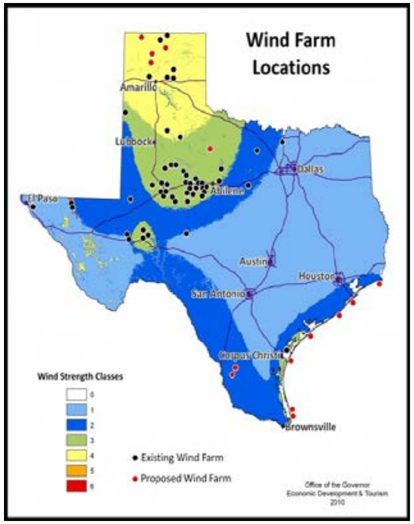
[1] *Budget/Cost-Share for Period of Performance FY2012 – FY2013*

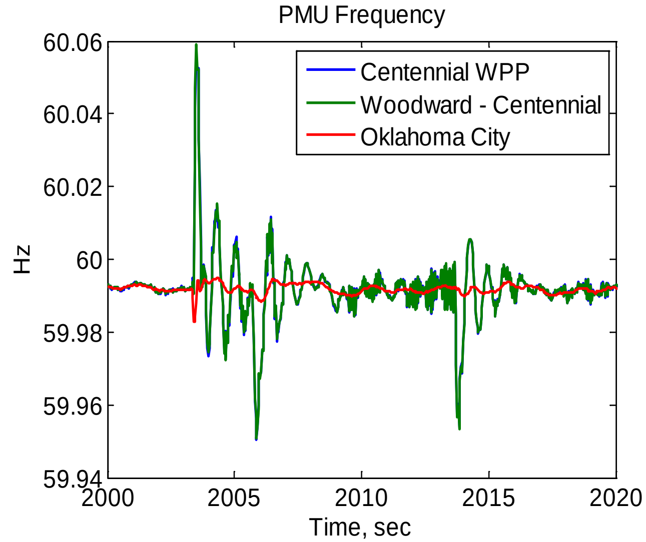
Budget, Purpose, & Objectives

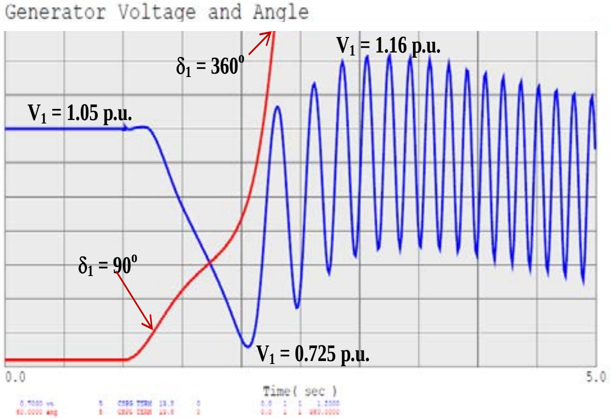
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Impact of Project:

- Help power system planners and operators to understand the interaction between wind power plants and the power system grid
- Support the system operator by providing an overview and awareness of the power system stability from the PMU measurements placed in strategic buses in the power system network







Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

This project aligns with the following DOE Program objectives and priorities

- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization

Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Collaborate with PMU data sources (e.g., utilities) to get access to synchrophasor data measured within their territories

- Develop tools and skills to automate the data retrieving and archiving process for synchrophasor data, analyze and screen the data for abnormal events, evaluate power system oscillations

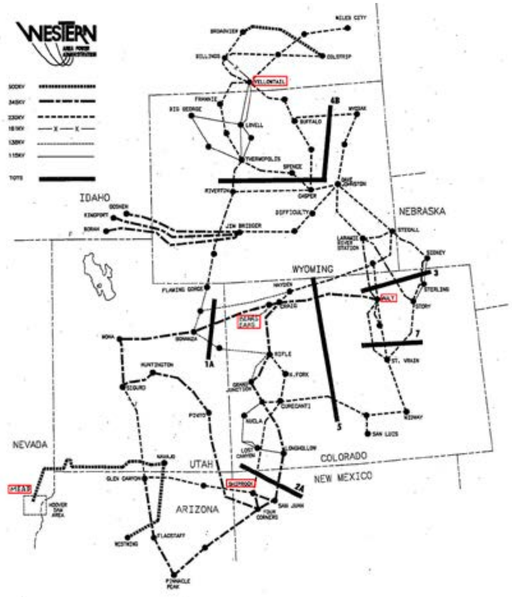
- Document the results through publications (NREL report, IEEE conferences, etc.) and reach out to stakeholders

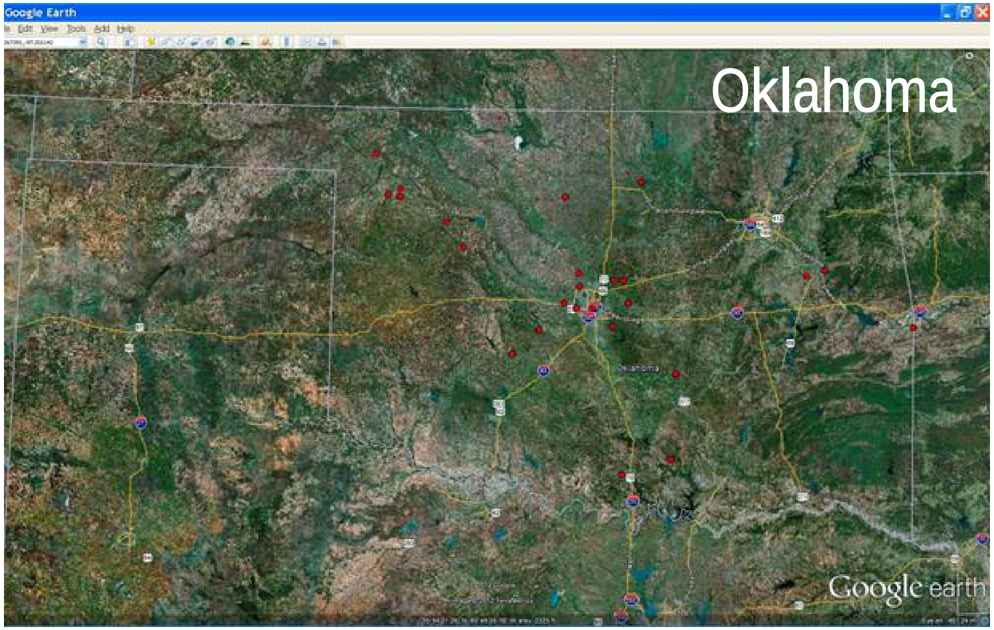
Technical accomplishments achieved in FY 2012-2013:

- Established partnerships to gain access to synchronized phasor data collected by Oklahoma Gas and Electric Company (OG&E) and Western Area Power Administration (WAPA)

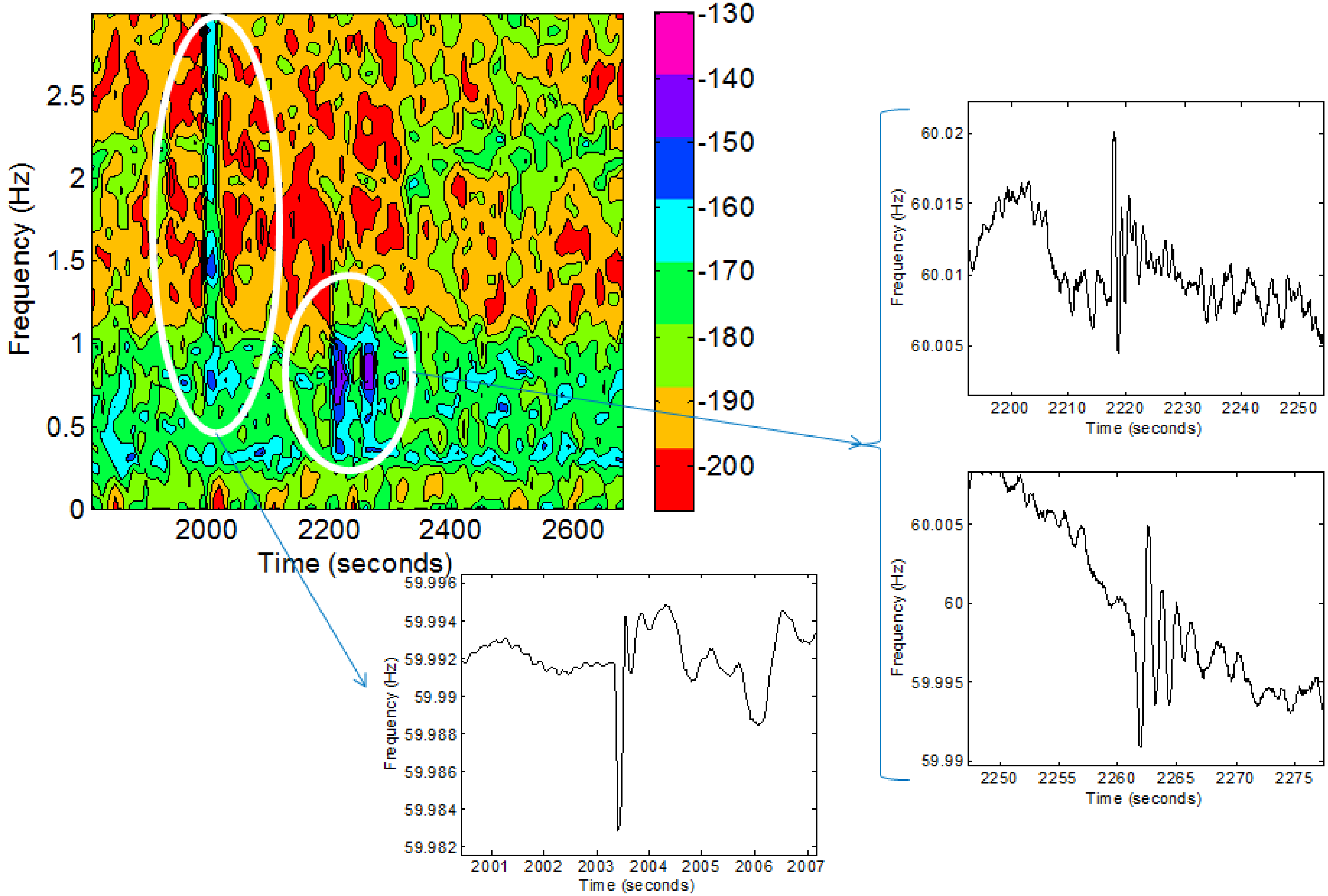
- Developed software tools to manage and process the synchronized phasor data streams and characterize the dynamic behaviors of wind power plants in grid contingencies.

WAPA





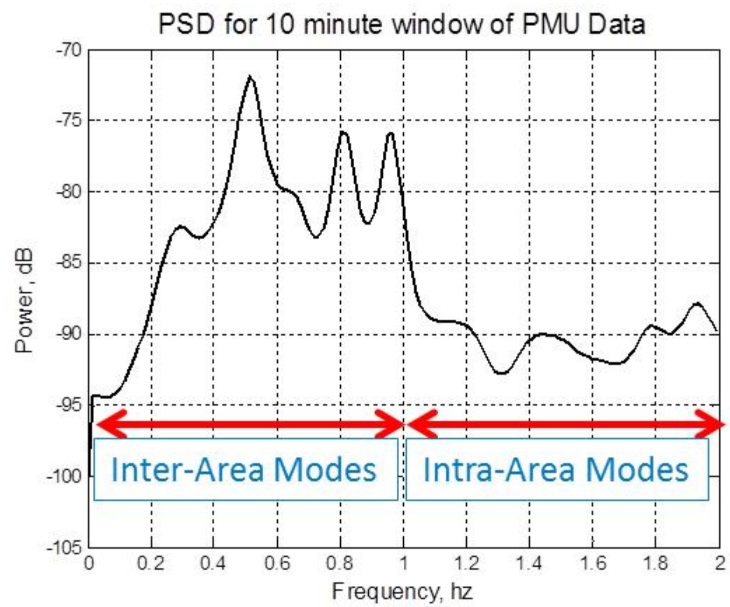
Technical accomplishments achieved in FY 2012-2013



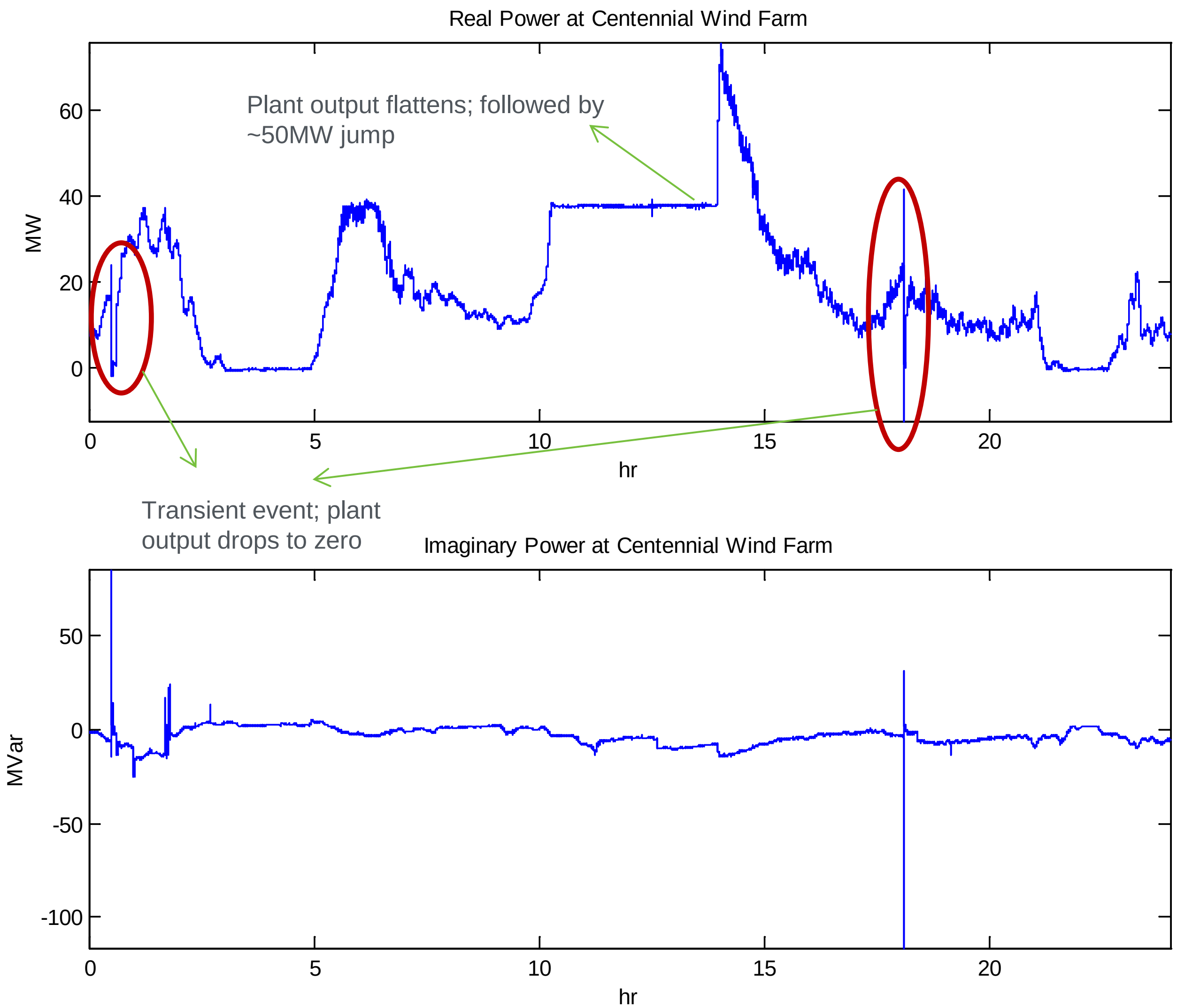
Technical accomplishments achieved in FY 2012-2013

- NREL hired Dr. Alicia Allen as a post-doc after finishing her Ph.D. from the University of Texas in Austin on PMU-based stability analysis

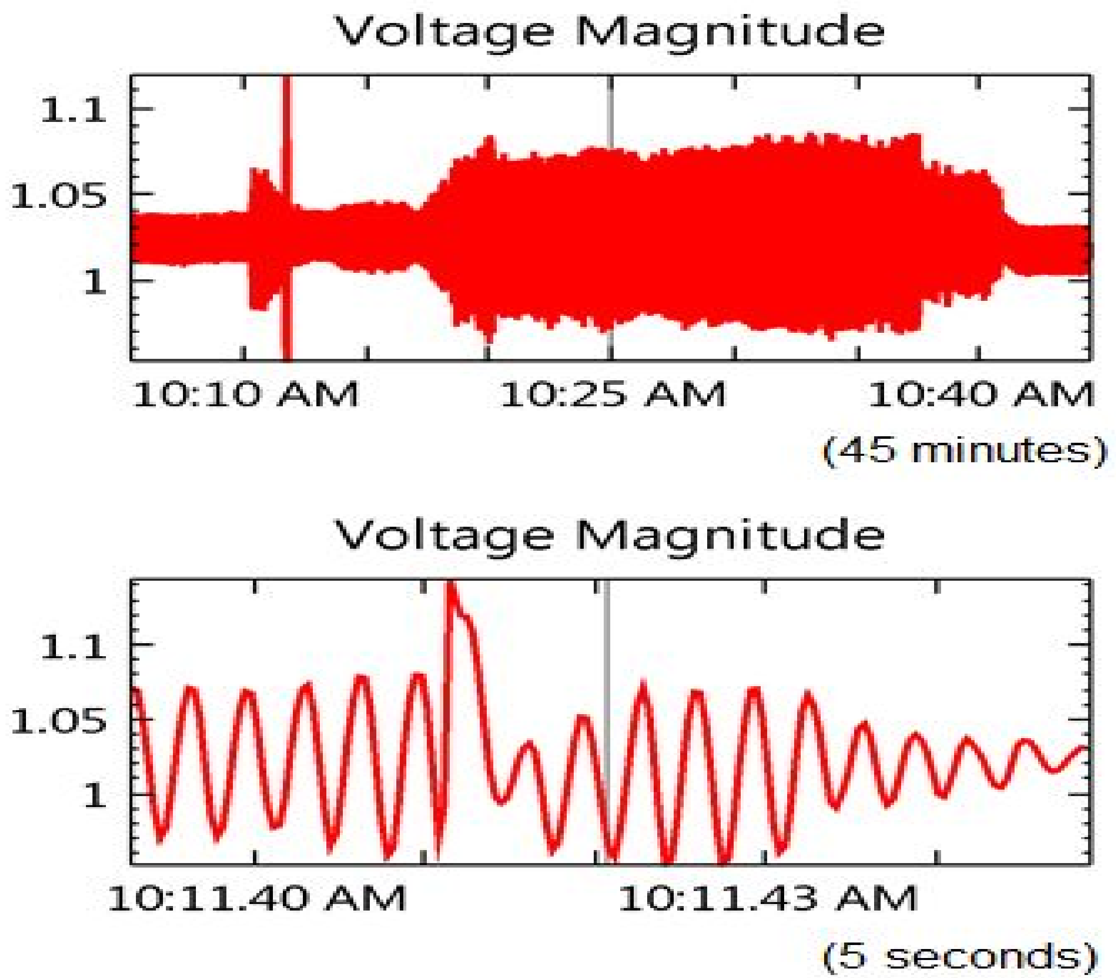
- Six NREL and IEEE technical papers have been published on different topics (wind plant prediction using artificial neural net - ANN, wind power variability, wind plant inertia estimation, PMU data screening and analysis, PMU-based stability analysis)



Technical accomplishments achieved in FY 2012-2013



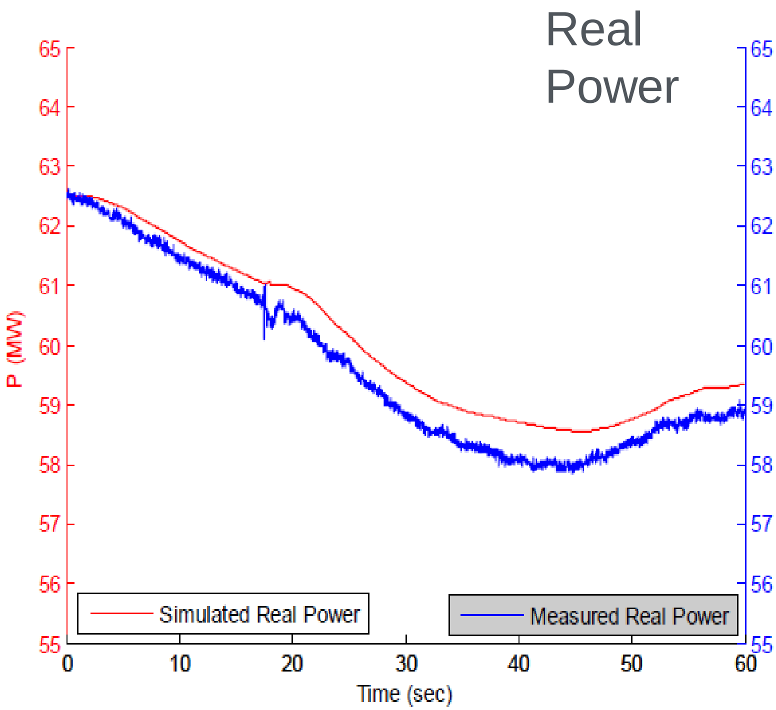
Technical accomplishments achieved in FY 2012-2013

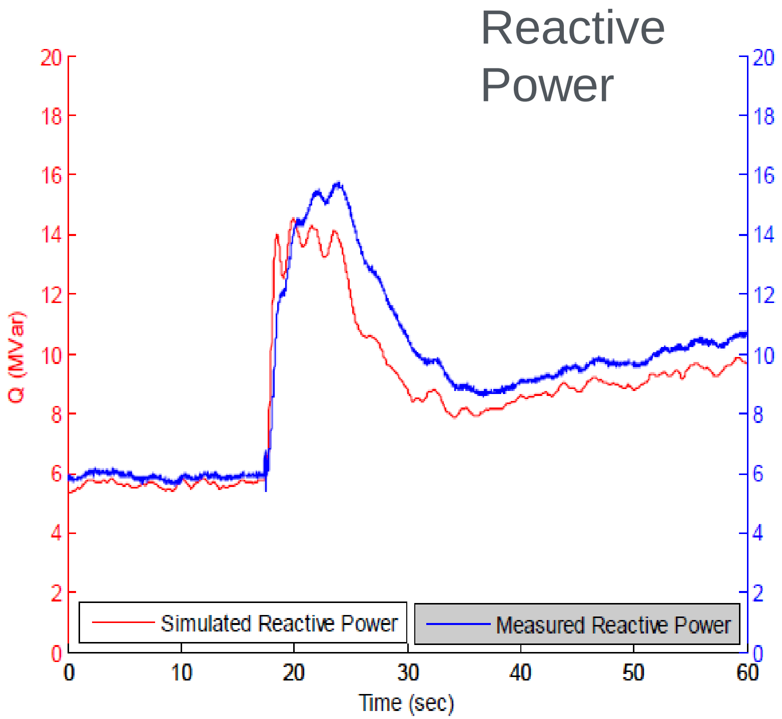


Subsynchronous Resonance at a Wind Power Plant

Credit: Austin White – OG&E

Technical accomplishments achieved in FY 2012-2013





An example of dynamic model validation (**measured** data vs. **simulated** data)

Project Plan & Schedule

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Q2: Develop tools and skills to analyze synchrophasor data for investigating the interactions and operating impact of wind power plant and grid.												
Q4: Produce final report on wind plant synchrophasor data to show frequency response of large wind plant and its behavior under system disturbance												
Q1: Complete a draft report of wind power plant dynamic performance under system contingencies using synchronized phasor data from OG&E												
Q2 Complete a draft report on using synchronized phasor data for wind power plant model benchmarking and validation												
Q3 Complete a technical report of PMU data screening and PMU data analysis												
Q4 Complete a technical report of system stability analysis with synchronized phasor data												
Current work and future research												
Complete the user guide for software programming to screen PMU data												

Comments

FY2012 Q1 and Q3 milestones are related to installation of a synchrophasor PMU node at an Xcel substation and were cancelled due to a lack of funding.

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:

- University of Texas – Austin: Dr. S. Santoso, Dr. Alicia Allen (currently an NREL postdoc)
- University of Denver: Dr. David Gao, graduate student Z. Liu
- Oklahoma Gas and Electric
- North American Synchrophasor Program Initiative (NASPI)
- Bonneville Power Authority
- EPRI
- Sandia National Laboratories

Communications and Technology Transfer:

- ***Wind Power Plant Prediction by Using Neural Networks.*** 2012 IEEE Energy Conversion Congress and Exposition (ECCE)
- ***Long-Term Wind Power Variability*.** NREL Report No. TP-5500-53637.
- ***Synchronized Phasor Data for Analyzing Wind Power Plant Dynamic Behavior and Model Validation*.** NREL Report No. TP-5500-57342.
- ***Synchrophasor Measurement-Based Wind Plant Inertia Estimation.*** NREL Report No. CP-5500-57471.
- ***Algorithm for Screening Phasor Measurement Unit Data for Power System Events and Categories and Common Characteristics for Events Seen in Phasor Measurement Unit Relative Phase-Angle Differences and Frequency Signals*.** NREL Report No. TP-5500-58611.
- ***Synchrophasor Applications for Wind Power Generation*.** NREL report NREL/TP-5D00-60772

Next Steps and Future Research

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FY14/Current research:

- Develop a user guide for the suites of software tools developed to manage and process the synchrophasor data streams
- Investigate methods to use the PMU data to gauge the operating stability of power system in real time
- Screen, select, and use PMU data to validate wind plant models
- Continue collaboration with WECC, EPRI, BPA, Sandia, and OG&E in the area of PMU data collection and data sharing

Next Steps and Future Research

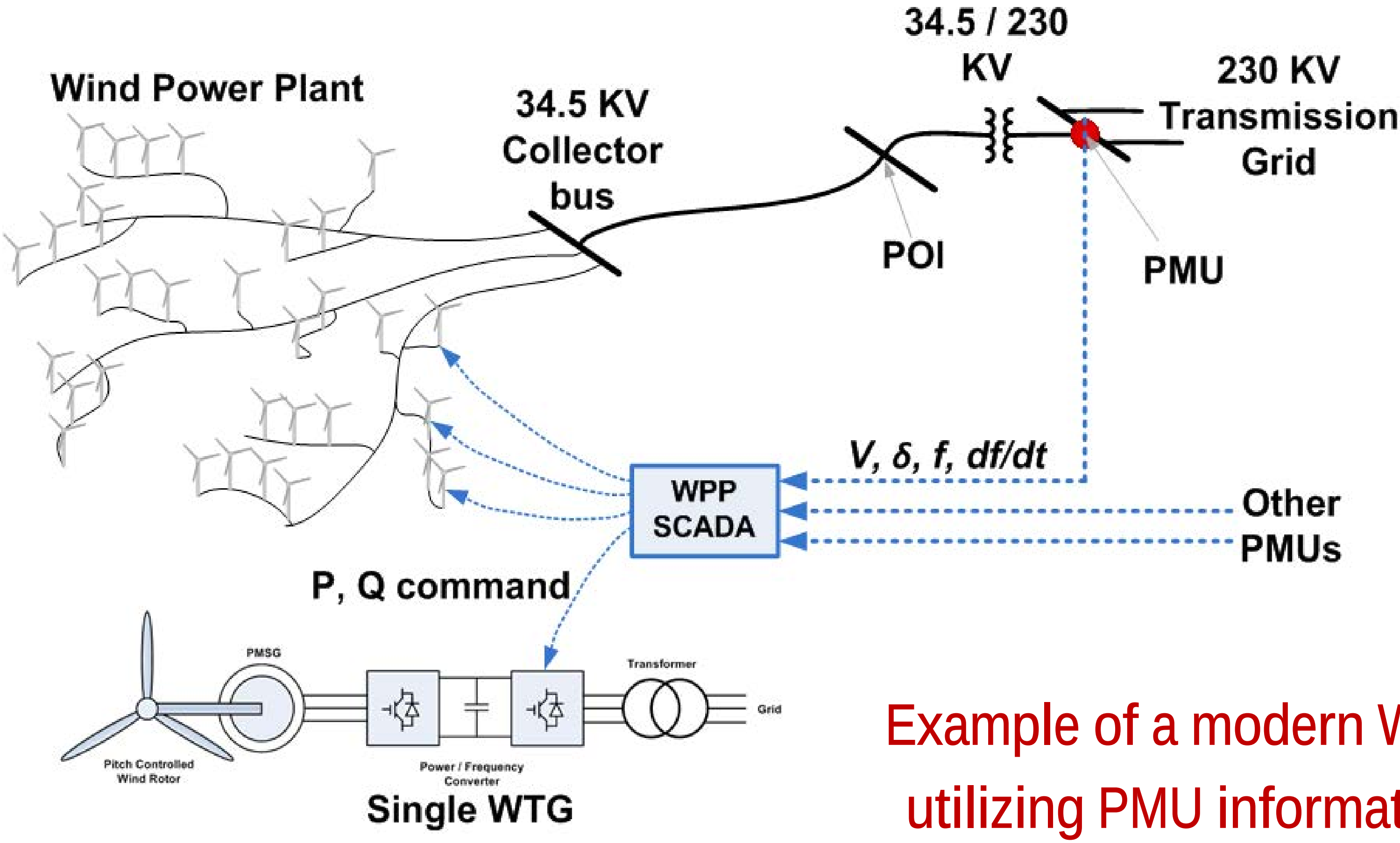
Proposed future research:

- Identify generators participating in oscillations and assign participation factor for each generator involved
- Early detection of system faults or oscillations, and develop method to map the stability trajectory online
- Prepare remedial action as power systems get closer to the stability margin
- Define boundary, spread, and direction of the instability region
- Identify and activate control of the wind plants that can contribute to actively dampening the system oscillations
- Formulate regional load shedding schemes as we map area of instability
- Develop methods to split power systems into intentional islanding within manageable regional autonomies based on load-generation balance
- Deploy multi-agent control authorities as instability spreads to different areas before and after separations
- PMU-based substation automation
- PMU-based FACTs control strategies

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Proposed future research:



Example of a modern WPP utilizing PMU information