
Power Systems Engineering Research Center

# Products to Date from the PSERC Future Grid Initiative

**An Initiative Funded by Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy**

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**May 21, 2013**

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**Power Systems Engineering Research Center**

The Power Systems Engineering Research Center (PSERC) is a multi-university center conducting research on challenges facing the electric power industry and educating the next generation of power engineers. More information about PSERC can be found at the center's website: http://www.pserc.org.

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# 1. Thrust Area 1: Electric Energy Challenges of the Future

**Thrust Area Leader**: Gerald Heydt, Arizona State University (heydt@asu.edu, 480-965-8307)

## 1.1 Integrating Transmission and Distribution Engineering Eventualities

**Task Leader:** Gerald Heydt, Arizona State University (heydt@asu.edu, 480-965-8307)

**Task Objective**: To bring together research and analysis of several energy transmission and distribution eventualities and examine 'what if' a given eventuality is implemented in the power system.

### *Published Papers*

1. Pierre, Brian.J. and Gerald T. Heydt. "Increased ratings of overhead transmission circuits using HTLS and compact designs." In *North American Power Symposium (NAPS), 2012*, pp.1-6, 9-11 Sept. 2012. doi: 10.1109/NAPS.2012.6336311.
2. Salloum, A., and Gerald T. Heydt. "Innovative HVDC connections in power transmission systems." In *Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES*, pp.1-8, 7-10 May 2012. doi: 10.1109/TDC.2012.6281423.
3. Heydt, Gerald T., and Vijay Vittal. "A Panel Session on: Curriculum development: Transmission expansion planning for systems with renewable energy resources." In *Power and Energy Society General Meeting, 2012 IEEE*, pp.1-2, 22-26 July 2012. doi: 10.1109/PESGM.2012.6343911.
4. Zhang, Hui, Gerald T. Heydt, Vijay Vittal, and H.D. Mittelmann. "Transmission expansion planning using an ac model: Formulations and possible relaxations." In *Power and Energy Society General Meeting, 2012 IEEE*, pp.1-8, 22-26 July 2012. doi: 10.1109/PESGM.2012.6345410.

### *Theses*

Pierre, B.J. "Innovative Concepts in High Power Transmission," PhD. diss., Arizona State University, 2014

### *Other Accomplishments*

It is anticipated that the concept of high phase order overhead transmission and high phase order underground cables shall be researched and studied to the point that concrete ideas and designs shall be available. That work is in partial completion as of January 2013.

### *Potential Patents*

It is possible that specialized designs for underground high phase order cables will be patentable, and the investigators will pursue this.

***Thrust Area 1 PSERC Meeting Presentations***

1. *Electric Energy Challenges of the Future: A PSERC Future Grid Initiative Progress Report***.** PSERC Webinar [Announcement | Slides [PDF 3.31MB] | Archived Webinar] (January 22, 2013)
2. *Research Results* [PDF 1.2MB]**:** PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. *Opening Presentation* [PDF 2.6MB], Power Delivery Infrastructure Session, Future Grid Forum. Washington DC. (June 27-28, 2012)

***PSERC White Paper***

*Electric* Energy *Challenges of the Future: Thrust Area 1 White Paper* [PDF 918KB] (May 2012)

***PSERC Poster***

*Integrating Transmission and Distribution Engineering Eventualities* (December 2011) [Workshop Poster, PDF 452KB]

## 1.2 A National Transmission Overlay

**Task Leader:** James McCalley, Iowa State University (jdm@iastate.edu, 515-294-4844)

**Collaborator:** Dionysios Aliprantis (dali@iastate.edu, 515-294-7387)

**Task Objective:** To design a US national transmission overlay and develop an associated design process to facilitate the growth of wind, solar, nuclear, geothermal, and clean-coal generation over the next 40 years.

***Theses***

1. Li, Y. "Design of high capacity interregional transmission systems." PhD diss., Iowa State University, in progress.
2. Villegas-Pico, Hugo. "Reachability methods for power system dynamic analysis." PhD diss., Iowa State University, in progress.

***Analysis Tools***

The following tools will be made available upon request:

1. Path selection: an iterative reweighting spanning tree algorithm to identify good candidates for transmission expansion paths based on right of way availability, economic benefit potential, land type, climate and population density, altitude, and isoceraunic conditions
2. Transmission optimizer: multi-period, multi-technology T-expansion planning model, implemented as a linear mixed-integer program;
3. NETPLAN: a generation-transmission expansion planning software modeling interdependencies between electric network, the fuel systems, and the transportation systems (passenger and freight);
4. Resilience planning: identifies designs that are resilient to large-scale disturbances (such as the Katrina/Rita hurricanes of 2005);
5. Flexibility planning: identifies designs capable of adapting at low cost to future uncertainties.

***Thrust Area 1 PSERC Meeting Presentations***

1. *Electric Energy Challenges of the Future: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Slides [PDF 3.31MB] | Archived Webinar] (January 22, 2013)
2. *Research Results* [PDF 1.2MB]**:** PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. *Opening Presentation* [PDF 1.4MB], Operations and Planning Session, Future Grid Forum. Washington DC. (June 27-28, 2012)

***PSERC White Paper***

*Electric* Energy *Challenges of the Future: Thrust Area 1 White* Paper [PDF 918KB] (May 2012)

***PSERC Poster***

*A National Transmission Overlay* (December 2011) [Workshop Poster, PDF 1.35MB]

## 1.3 Robust and Dynamic Reserve Requirements

**Task Leader:** Kory Hedman, Arizona State University (kory.hedman@asu.edu, 480-965-1276)

**Task Objective:** To investigate opportunities to greatly improve upon today's methods of determining reserve levels and reserve zones.

***Published Papers***

1. Wang, Fengyu and Kory W. Hedman. "Reserve zone determination based on statistical clustering methods." In *North American Power Symposium (NAPS), 2012*, pp.1-6, 9-11 Sept. 2012. doi: 10.1109/NAPS.2012.6336318.
2. Wang, Fengyu and Kory W. Hedman, "Dynamic reserve zones for day-ahead unit commitment with renewable resources," *IEEE Transactions on Power Systems*, submitted for publication, Feb. 2013.
3. Lyon, Joshua D., Kory W. Hedman, and Muhong Zhang, "Reserve requirements to efficiently manage intra-zonal congestion," *IEEE Transactions on Power Systems*, submitted for publication, Feb. 2013.

***Theses***

1. Lyon, J. D. "Reliability constraints in the transmission-constrained power grid," PhD. diss., Arizona State University, 2014.
2. Wang, F. "Improving reserve requirements and reserve zones," PhD. diss., Arizona State University, 2014.

***Thrust Area 1 PSERC Meeting Presentations***

1. *Electric Energy Challenges of the Future: A PSERC Future Grid Initiative Progress Report***.** PSERC Webinar [Announcement | Slides [PDF 3.31MB] | Archived Webinar] (January 22, 2013)
2. *Research Results* [PDF 1.2MB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Electric Energy Challenges of the Future: Thrust Area 1 White Paper* [PDF 918KB] (May 2012)

***PSERC Poster***

*Robust and Dynamic Reserve Requirements* (December 2011) [Workshop Poster, PDF 603KB]

## 1.4 Wide Area Control Systems

**Task Leader**: Mani Venkatasubramanian, Washington State Univ. (mani@eecs.wsu.edu, 509-335-6452)

**Task Objective:** To formulate, design, and investigate voltage controllers, oscillatory controls, and coordinated wide-area angle stability controls.

***Published Papers***

1. Venkatasubramanian, Mani V., J. Hong Chun, J. Guerrero, Frank Habibi-Ashrafi, and A. Salazar. "Hierarchical two-level voltage controller for Southern California Edison." In *Power and Energy Society General Meeting, 2012 IEEE*, pp.1-8, 22-26 July 2012. doi: 10.1109/PESGM.2012.6345413.
2. Zweigle, Greg, and Mani V. Venkatasubramanian. "Model prediction based transient stability control." In *Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES*, pp.1-8, 7-10 May 2012, doi: 10.1109/TDC.2012.6281646.

***Theses***

1. Chun, J. Hong. "Hierarchical two-level voltage controller large power systems (local substation level)." M.S. thesis, Washington State University, 2012.
2. Zweigle, Greg. "Wide area transient stability control." PhD diss., Washington State University, 2013.

***Presentations***

White, A., S. *Chisholm*, Z. Tashman, Hamed Khalilinia, and Mani V. Venkatasubramanian. "Analysis of Subsynchronous Oscillations at Oklahoma Gas and Electric." Paper presented at NASPI meeting, Champaign, IL, February 24, 2012. https://www.naspi.org/File.aspx?fileID=928

***Thrust Area 1 PSERC Presentations***

1. *Electric Energy Challenges of the Future: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Slides [PDF 3.31MB] | Archived Webinar] (January 22, 2013)
2. *Research Results* [PDF 1.2MB]**:** PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Electric Energy Challenges of the Future: Thrust Area 1 White Paper* [PDF 918KB] (May 2012)

***PSERC Poster***

*Wide Area Control Systems* (December 2011) [Workshop Poster, PDF 603KB]

# 2. Thrust Area 2: Control and Protection Paradigms of the Future

**Thrust Leader**: Chris DeMarco, University of Wisconsin-Madison (demarco@engr.wisc.edu, (608) 262-5546)

## 2.1 Requirements for Hierarchical Coordinated Control and Protection of the Smart Grid

**Task Leader:** Anjan Bose, Washington State University (bose@wsu.edu; 509-332-5114)

**Task Objective:** To define the overall concept for hierarchical coordinated control and protection of the smart grid assuming that a hierarchical and distributed structure will be used in the future grid.

***Published Papers***

1. Kansal, Prashant, and Anjan Bose. "Smart grid communication requirements for the high voltage power system." In *Power and Energy Society General Meeting, 2011 IEEE*, pp.1-6, 24-29 July 2011. doi: 10.1109/PES.2011.6038941.
2. Kansal, Prashant, and Anjan Bose. "Bandwidth and Latency Requirements for Smart Transmission Grid Applications." In *Smart Grid, IEEE Transactions on*, vol.3, no.3, pp.1344-1352, Sept. 2012. doi: 10.1109/TSG.2012.2197229.

***Theses***

Kansal, Prashant. "Communication Requirements for Smart Grid Applications in Power Transmission Systems." MS thesis, Washington State University, 2011.

***PSERC White Paper***

*Control and Protection Paradigms of the Future: Thrust Area 2 White Paper* [PDF 2.2MB] (May 2012)

***Thrust Area 2 PSERC Presentations***

1. *Control and Protection Paradigms of the Future: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 5, 2013)
2. *Research Results* [PDF 65.8KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC Poster***

*Requirements for Hierarchical Coordinated Control and Protection of the Smart Grid* (*December* 2011) [Workshop Poster, PDF 158KB]

## 2.2 Hierarchical Coordinated Control of Wind Energy Resources and Storage for Electromechanical Stability Enhancement of the Grid

**Task Leader:** Christopher L. DeMarco, Univ. of Wisconsin-Madison (demarco@engr.wisc.edu; 608-262-5546)

**Collaborators:**
Bernard C. Lesieutre, Univ. of Wisconsin-Madison (lesieutre@engr.wisc.edu; 608-890-1883)
Yehui Han, Univ. of Wisconsin-Madison (yehui@engr.wisc.edu; 608-262-2126)

**Task Objective:** To develop control methodologies and designs that address the problem of maintaining grid electromechanical stability as the percentage of power production from synchronous generators, the traditional grid stabilizing mechanism, decreases in the coming decade.

***Published Papers***

1. Baone, Chaitanya A., and Christopher L. DeMarco. "Observer-based distributed control design to coordinate wind generation and energy storage." In *Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES*, pp. 1-8. IEEE, 2010. doi: 10.1109/ISGTEUROPE.2010.5638922.
2. Baone, Chaitanya, and Christopher L. DeMarco. "Saturation-bandwidth tradeoffs in grid frequency regulation for wind generation with energy storage." In *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*, pp.1-7, 17-19 Jan. 2011. doi: 10.1109/ISGT.2011.5759127.
3. Baone, Chaitanya, and Christopher L. DeMarco. "Distributed control design to regulate grid frequency and reduce drivetrain stress in wind systems using battery storage." In *American Control Conference (ACC), 2012*, pp.1368-1375, 27-29 June 2012. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6315217&isnumber=6314593

***Theses***

Baone, Chaitanya. "Coordinated control of wind generation and energy storage for power system frequency regulation." PhD *diss*., University of Wisconsin, 2012.

***PSERC White Paper***

*Control and Protection Paradigms of the Future: Thrust Area 2 White Paper* [PDF 2.2MB] (May 2012)

***Thrust Area 2 PSERC Presentations***

1. *Control and Protection Paradigms of the Future: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 5, 2013)
2. *Research Results* [PDF 65.8KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

3. Control and Protection Session: Future Grid Forum. Washington DC. (June 27-28, 2012)
    - *Opening Presentation* [PDF 55.9KB] - Chris DeMarco, University of Wisconsin-Madison
    - *Panel Comments* [PDF 86.9KB]

***PSERC Poster***

*Hierarchical Coordinated Control of Wind Energy Resources and Storage for Electromechanical Stability Enhancement of the Grid* (December 2011)
[Workshop Poster, PDF 456KB]

## 2.3 Hierarchical Coordinated Protection of the Smart Grid with High Penetration of Renewable Resources

**Task Leader:** Mladen Kezunovic, Texas A&M University (kezunov@ece.tamu.edu, 979-845-7509)

**Task Objective:** To define the three hierarchical coordinated layers of predictive protection, inherently adaptive protection, and corrective protection in the future grid, using real-life systems scenarios with modeling and simulation to demonstrate findings.

***Published Papers***

1. Kezunovic, Mladen, and Yimai Dong. "Information exchange needs for new fault location applications in T&D systems." In *Electrotechnical Conference (MELECON), 2012 16th IEEE Mediterranean*, pp. 536-539. IEEE, 2012. doi: 10.1109/MELCON.2012.6196490.
2. Matic-Cuka, Biljana, and Mladen Kezunovic. "Improving Smart Grid Operation with New Hierarchically Coordinated Protection Approach." Paper presented at *The 8th Mediterranean Conference on Power Generation, Transmission and Energy Convention (MEDPOWER 2012)*, Cagliari, Italy, October 2012. http://eppe.tamu.edu/k/cnf/2012Medpower_biljana.pdf.

***Theses***

Matic-Cuka, Biljana. "Impacts of Distributed Generation on the Smart Grid." PhD diss., Texas A & M, 2013.

***PSERC White Paper***

*Control and Protection Paradigms of the Future: Thrust Area 2 White Paper* [PDF 2.2MB] (May 2012)

***Thrust Area 2 PSERC Presentations***

1. *Control and Protection Paradigms of the Future: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 5, 2013)
2. *Research Results* [PDF 65.8KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. Control and Protection Session: Future Grid Forum. Washington DC. (June 27-28, 2012)
   - *Opening Presentation* [PDF 55.9KB] - Chris DeMarco, University of Wisconsin-Madison
   - *Panel Comments (including Kezunovic)* [PDF 86.9KB]

***PSERC Poster***

*Hierarchical Coordinated Protection of the Smart Grid with High Penetration of Renewable Resources* (December 2011) [Workshop Poster, PDF 772KB]

# 3. Thrust Area 3: Renewable Energy Integration – Technological and Market Design Challenges

**Thrust Area Leader**: Shmuel Oren, University of California at Berkeley (oren@ieor.berkeley.edu, 510-642-1836)

## 3.1 Direct and Telemetric Coupling of Renewable Energy Resources with Flexible Loads

**Task Leader**: Shmuel Oren, UC Berkeley (oren@ieor.berkeley.edu, 510-642-1836)

**Task Objective:** To devise optimal strategies for the use of contracted renewable resources, supplemented by spot electricity purchased from the grid, to serve such flexible loads and to explore business models for serving such loads or for aggregating load flexibility to provide wholesale balancing energy and reserves.

***Published Papers***

1. Papavasiliou, Anthony, Shmuel Oren, and R.P. O'Neill. "Reserve Requirements for Wind Power Integration: A Scenario-Based Stochastic Programming Framework." In *Power Systems, IEEE Transactions on*, vol.26, no.4, pp.2197-2206, Nov. 2011. doi:10.1109/TPWRS.2011.2121095.
2. Papavasiliou, Anthony, and Shmuel Oren. "Integrating renewable energy contracts and wholesale dynamic pricing to serve aggregate flexible loads." In *Power and Energy Society General Meeting, 2011 IEEE*, pp.1-4. 24-29 July, 2011. doi: 10.1109/PES.2011.6039021.
3. Papavasiliou, Anthony, and Shmuel Oren. “Stochastic Modeling of Multiarea Wind Power Production.” Proceeding of 2012 PMAPS, Istanbul, Turkey, June 10-14, 2012. http://www.ieor.berkeley.edu/~oren/pubs/stochastic.pdf
4. Oren, Shmuel S. “Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid.” Proceeding of the IEEE PES General Meeting, San Diego CA, July 22-26, 2012. http://www.pserc.wisc.edu/documents/publications/papers/fgwhitepapers/Oren_PSERC_Future_Grid_TA3_May_2012.pdf.
5. Papavasiliou, Anthony, and Shmuel Oren. "A stochastic unit commitment model for integrating renewable supply and demand response." In *Power and Energy Society General Meeting, 2012 IEEE*, pp.1-6. 22-26 July 2012. doi: 10.1109/PESGM.2012.6344858.

***Presentations***

1. Papavasiliou, Anthony, and Shmuel Oren. "Integration of Contracted Renewable Energy and Spot Market Supply to Serve Flexible Loads." Paper presented at the 18th World Congress of the International Federation of Automatic Control, Milano, Italy, August 28-September 2, 2011.
2. Papavasiliou, Anthony, and Shmuel Oren. "Multi-area Stochastic Unit Commitment for Wind Penetration in Transmission Constrained Networks." Paper presented at INFORMS annual meeting, Charlotte, NC, November 12-14, 2011.
3. Oren, Shmuel, and Anthony Papavasiliou. "Coupling Deferrable Loads with Renewable Resources." Paper presented at Los Alamos National Laboratory Center for Nonlinear Studies Annual Conference: Optimization and Control for Smart Grids, Santa Fe, New Mexico, May 21-25, 2012.
4. Oren Shmuel, and Anthony Papavasiliou. "Coupling Deferrable Loads with Renewable Resources." Paper presented at Conference on Challenges to Electricity, Kellogg School of Business, Northwestern University, Chicago, Illinois, May 4-5, 2012.
5. Papavasiliou, Anthony, and Shmuel Oren. "Applying High Performance Computing to Multi Area Stochastic Unit Commitment for Wind Penetration." Paper presented at FERC Staff Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software, Washington, D.C., June 25-27, 2012.
6. Oren, Shmuel. "Variable Generation Integration." Paper presented at the PSERC Future Grid Forum, Washington, D.C., June 27-28, 2012.

***Thesis***

Papavasiliou, Anthony. "Coupling Renewable Energy Supply with Deferrable Demand." PhD diss., UC *Berkeley*, 2011.

***Thrust Area 3 PSERC Presentations***

1. *Renewable Energy Integration - Technological and Market Design Challenges: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 19, 2013)
2. *Research Results* [PDF 1.7MB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. *Variable Generation Integration Session. Future Grid Forum*. Washington DC. (June 27-28, 2012)
    - *Opening Presentation* [PDF 2.9MB] - Shmuel Oren, University of California, Berkeley
    - *Panel Comments* [PDF 72.5KB]

***PSERC White Paper***

*Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid: Thrust Area 3 White Paper* [PDF 812KB] (May 2012)

***PSERC Poster***

*Coupling Renewable Energy Supply with Deferrable Demand* (December 2011)
[Workshop Poster, PDF 603KB]

## 3.2 Mitigating Renewables Intermittency Through Non-disruptive Distributed Load Control

**Task Leader:** Duncan Callaway, UC Berkeley, (dcal@berkeley.edu, 510-423-3225)

**Task Objective:** For demand-side flexibility to support variable renewable electricity generation, (1) to develop and assess the potential of large-scale modeling strategies for aggregated load state estimation; (2) to develop novel control strategies that weigh the cost of control at the local level against benefits at the system level; and (3) to develop strategies to evaluate the end-use impact of the control actions, and use these impacts to understand the cost to recruit customers into this type of program.

***Published Papers***

1. Mathieu, Johanna L., Mark E. Dyson and Duncan S. Callaway. "Using Residential Electric Loads for Fast Demand Response: The Potential Resource, the Costs, and Policy Recommendations." Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, August 12-17, 2012. http://www.aceee.org/files/proceedings/2012/data/papers/0193-000009.pdf
2. Mathieu, Johanna L., S. Koch and Duncan S. Callaway. "State Estimation and Control of Electric Loads to Manage Real-Time Energy Imbalance." In *Power Systems, IEEE Transactions on*, vol.28, no.1, pp.430-440, Feb. 2013. doi: 10.1109/TPWRS.2012.2204074.
3. Mathieu, Johanna L., and Duncan S. Callaway. "State Estimation and Control of Heterogeneous Thermostatically Controlled Loads for Load Following." In *System Science (HICSS), 2012 45th Hawaii International Conference on*, pp.2002-2011, 4-7 Jan. 2012. doi: 10.1109/HICSS.2012.545

***Presentations***

1. Mathieu, Johanna L., M. Kamgarpour, J. Lygeros, and Duncan S. Callaway. "Energy Arbitrage with Thermostatically Controlled Loads." Paper submitted to the European Control Conference, Zurich, 2013.
2. Callaway, Duncan.S. "Quantifying and lowering the cost of fast demand response resources for renewables integration." Paper presented at Carnegie Mellon University Electrical and Computer Engineering, Pittsburg, PA, October 4, 2012.
3. Callaway, Duncan S. "Fast demand response with residential and light commercial loads." Paper presented at CERTS Internal Program Review, Lawrence Berkeley National Lab, Berkeley, CA, September 20, 2012.
4. Callaway, Duncan S. "Quantifying and lowering the cost of fast demand response resources for renewables integration." Paper presented at Arizona State University Electrical, Computer and Energy Engineering Department, Tempe, AZ, August 24, 2012.

5. Mathieu, Johanna, and Mark E. Dyson. “Using Residential Electric Loads for Fast Demand Response: The Potential Resource, the Costs, and Policy Recommendations.” Paper presented at ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, August 13, 2012.
6. Mathieu, Johanna L. “Moving from Open-loop to Closed-loop Control of Demand Response Resources.” Paper presented at Pacific Northwest National Laboratory Smart Grid Controls, Optimization, and Economics Meeting Seminar, Richland, Washington, June 15, 2012.
7. Mathieu, Johanna L. “Using Residential Loads like Grid-Scale Batteries: The Resource, Potential Revenues, and Costs.” Paper presented at Los Alamos National Laboratory Center for Nonlinear Studies Annual Conference: Optimization and Control for Smart Grids, Santa Fe, New Mexico, May 25, 2012.
8. Callaway, Duncan S. “Distributed Coordination for Demand Response.” Paper presented at Los Alamos National Laboratory Center for Nonlinear Studies Annual Conference: Optimization and Control for Smart Grids, Santa Fe, New Mexico, May 24, 2012.
9. Mathieu, Johanna L. “Modeling, Analysis, and Control of Demand Response Resources.” Paper presented at LBNL Environmental Energy Technologies Division Seminar, Berkeley, California, April 27, 2012.
10. Mathieu, Johanna L. “Modeling, Analysis, and Control of Demand Response Resources.” Paper presented at University of California, Berkeley Department of Mechanical Engineering, Ph.D. Candidate Seminar, Berkeley, California, April 19, 2012.
11. Callaway, Duncan S. “Distributed computation in complex energy networks.” Paper presented at Massachusetts Institute of Technology, Laboratory for Information and Decision Systems Special Seminar, Cambridge, Massachusetts, April 12, 2012.
12. Mathieu, Johanna L. “How your refrigerator can help the smart grid: understanding the size of the resource in California, potential revenues, and costs.” Paper presented at University of California, Berkeley Expert System Technologies Lab Seminar, Berkeley, California, April 4, 2012.
13. Mathieu, Johanna L. “The Value of Real-Time Data in Controlling Electric Loads for Demand Response.” Paper presented at Carnegie Mellon Conference on the Electricity Industry: Data Driven Sustainable Energy Systems, Pittsburgh, Pennsylvania, March 13, 2012.
14. Callaway, Duncan S. “Mining for demand response resources: lowering extraction costs and examining the resource potential for non-disruptive load control.” Paper presented at University of Illinois, Electrical and Computing Engineering Colloquium , Urbana-Champaign, Illinois, February 23, 2012.
15. Mathieu, Johanna L. “State Estimation and Control of Heterogeneous Thermostatically Controlled Loads for Load Following.” Paper presented at Hawaii International Conference on Systems Science, Wailea, Hawaii, January 6, 2012.

16. Callaway, Duncan S. “Aggregation models and feedback control for demand side flexibility in power systems.” Paper presented at ETH Zürich, EEH Colloquium, Zürich, Switzerland, November 29, 2011.
17. Mathieu, Johanna L. “Using Residential Electric Loads in Energy and Ancillary Services Markets.” Paper presented at Trans-Atlantic INFRADAY Conference on Applied Infrastructure Modeling and Policy Analysis, Preconference Event at FERC, Washington, D.C., November 10, 2011.
18. Mathieu, Johanna L. “Modeling, State Estimation, and Control of Aggregated Heterogeneous Appliances for Load Following.” Paper presented at University of California Berkeley and LBNL Discussion Group on Demand Response, Renewables, and ISO Issues Seminar, Berkeley, California, October 17, 2011.
19. Mathieu, Johanna L. “Modeling, State Estimation, and Control of Aggregated Heterogeneous Appliances for Power Systems Services.” Paper presented at University of California Berkeley, Variaya Energy Group Seminar, Berkeley, California, July 21, 2011.
20. Callaway, Duncan S. “Responsive Load and Distributed Storage.” Paper presented at American Control Conference Workshop on Control, Modeling and Optimization Challenges in the Smart Grid, San Francisco, California, June 28, 2011.
21. Callaway, Duncan S. “Modeling and Control of Aggregated Heterogeneous Thermostatically Controlled Loads for Ancillary Services.” Paper presented at University of California Berkeley and LBNL Discussion Group on Demand Response, Renewables, and ISO Issues Seminar, Berkeley, California, April 7, 2011.

***Posters***

1. Mathieu, Johanna L., and Duncan S. Callaway. “Mitigating Renewables Intermittency through Nondisruptive Load Control.” Power Systems Engineering Research Center (PSERC) Future Grid Initiative Workshop, Berkeley, CA, December 2011.
2. Mathieu, Johanna L., S. Koch, and Duncan S. Callaway. “Modeling, State Estimation, and Control of Thermostatically Controlled Loads for Load Following and Regulation.” University of California, Berkeley Energy Symposium, Berkeley, CA, October 2011.
3. Mathieu, Johanna L., S. Koch, and Duncan S. Callaway. “Modeling, State Estimation, and Control of Thermostatically Controlled Loads for Load Following and Regulation.” Lawrence Livermore National Laboratory Current Challenges in Computing Conference: Energy Resources Modeling, Napa, CA, August 2011.

***Theses***

Mathieu, Johanna. “Modeling, Analysis, and Control of Demand Response Resources.” PhD diss., University of California at Berkeley, 2012.

***Thrust Area 3 PSERC Presentations***

1. *Renewable Energy Integration - Technological and Market Design Challenges: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 19, 2013)
2. *Research Results* [PDF 1.7MB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. *Variable Generation Integration Session. Future Grid Forum***.** Washington DC. (June 27-28, 2012)
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    - *Panel Comments (including Callaway)* [PDF 72.5KB]

***PSERC White Paper***

*Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid: Thrust Area 3 White Paper* [PDF 812KB] (May 2012)

***PSERC Poster***

*Mitigating Renewables Intermittency Through Non-Disruptive Distributed Load Control* (December 2011)
[Workshop Poster, PDF 603KB]

## 3.3 Planning and Market Design for Using Dispatchable Loads to Meet Renewable Portfolio Standards and Emissions Reduction Targets

**Task Leader**: Timothy D Mount, Cornell University (tdm2@cornell.edu, 607-255-4512)

**Collaborators**: K. Max Zhang, Cornell University (zhang@cornell.edu, 607-254-5402)
Robert J. Thomas Cornell University (rjt1@cornell.edu, 607-255-5083)

**Task Objectives:** 1) To develop a unifying framework to characterize different types of dispatchable loads (e.g., electric vehicles and HVAC systems with thermal storage or on-demand temperature management; 2) to determine the engineering and economic feasibility of aggregating dispatchable loads to provide systems services (including frequency response, frequency regulation, load/generation following); and 3) to design a market that provides the correct incentives for managing the systems services provided by energy aggregators.

***Published Papers***

1. Lamadrid, Alberto; Wooyoung Jeon, and Tim Mount. "The Effect of Stochastic Wind Generation on Ramping Costs and the System Benefits of Storage." 46th IEEE HICSS Conference, Maui, HI, January 2013.
2. Mount, Tim, Judy Cardell, Lindsay Anderson and Ray Zimmerman. "Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF." Final Project Report for *Project M-22, PSERC Publication*, 12-29, Nov. 2012. http://eaei.lbl.gov/coupling-wind-generation-controllable-load-and-storage-time-series-application-superopf.
3. Valentine, K.; W. Temple, Robert Thomas, Timothy Mount, J. Mercurio, and K. Max Zhang. "The relationship between wind power and electric vehicles in the wholesale electric energy market." Energy Policy, October 2012.
4. Jeon, Wooyoung; Jung Youn Mo, and Timothy Mount. "Developing a Smart Grid that Customers can Afford: The Impact of Deferrable Demand." *Journal of Energy Policy*, August 2012.
5. Valentine, K., W. Temple, and K. Max Zhang. "Electric Vehicle Charging and Wind Power Integration: Coupled or Decoupled Electricity Market Resources?." In *Power and Energy Society General Meeting*. 2012.
6. Lamadrid, Alberto J.; Timothy Mount, Ray Zimmerman, C.E. Murillo-Sanchez, L. Anderson. "Alternate mechanisms for integrating renewable sources of energy into electricity markets." In *Power and Energy Society General Meeting, 2012 IEEE*, pp.1-8, 22-26 July 2012. doi: 10.1109/PESGM.2012.6345107.
7. Lamadrid, Alberto J., and Timothy Mount. "Ancillary services in systems with high penetrations of renewable energy sources, the case of ramping." *Energy Economics* (2012).

8. Mount, Timothy, and Alberto Lamadrid. “Using Deferrable Demand to Increase Revenue Streams for Wind Generators.” In *Proceedings of the 25th Annual CRRI Western Conference*, Monterey CA, June 27-29, 2012.
9. Mount, Tim, Alberto Lamadrid, Wooyoung Jeon, and Hao Lu. “Is Deferrable Demand an Effective Alternative to Upgrading Transmission Capacity?.” In *Proceedings of the 31st Annual CRRI Eastern Conference,* Shawnee, PA, May 16-18, 2012.
10. Palacio, Santiago Naranjo, Keenan Valentine, Myra Wong, and K. Max Zhang. "System-level Price Responsive Ice Storage Systems.” In *World Renewable Energy Forum*, Denver CO, 2012.
11. Valentine, K., W. Temple, and K. Max Zhang. “Intelligent electric vehicle charging: Rethinking the valley fill.” In *Journal of Power Sources*, 196 (24): 10717-10726, 2011. http://energy.mae.cornell.edu/PDF/Intelligent%20electric%20vehicle%20charging-%20Rethinking%20the%20valley-fill.pdf.
12. Mount, Tim, Alberto Lamadrid, Surin Maneevitjit, Bob Thomas, and Ray Zimmerman. "The hidden system costs of wind generation in a deregulated electricity market." In *System Sciences (HICSS), 2010 43rd Hawaii International Conference on*, pp. 1-10. IEEE, 2010.
13. Mount, Timothy D.,Wooyoung Jeon, and Jung-Youn Mo. “Utopia Electric: Developing a Smart Grid that Customers can Afford.” Presented at the *Workshop on ‘Advances in Electricity Planning & Policy Modeling’*, FERC, Washington. D.C., November 10, 2011.
14. Mount, Timothy D., Alberto J. Lamadrid, Wooyoung Jeon, and K. Max Zhang. “The Potential Benefits for Electricity Customers from Controllable Loads.” Presented at the *24th Annual CRRI Western Conference in Regulated Industries*, Monterey, CA, June 2011.

***Theses***

1. Mo, Jung Youn. “Economic Analyses of PHEVs, Carbon Markets and Temperature-Sensitive Loads.” PhD diss., Cornell University, 2012.
2. Maneevitjit, Surin. “The Economic Value of Reliability in Deregulated Electricity Markets.” PhD diss., Cornell University, 2012.
3. Lamadrid, Alberto. “The Welfare Effects of Renewables Integration into Electricity Markets.” PhD diss., Cornell University, 2013.
4. Maneevitjit, Surin. “The Evolution of Capacity Markets in the USA.” Masters diss., Cornell University, May 2013.
5. Jeon, Wooyoung, “Integrating Renewable Energy into Electricity Markets and the Economic Value of Deferrable Demand and Storage.” PhD diss., Cornell University, 2014..

***Thrust Area 3 PSERC Presentations***

1. *Renewable Energy Integration - Technological and Market Design Challenges: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 19, 2013)
2. *Research Results* [PDF 1.7MB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid: Thrust Area 3 White Paper* [PDF 812KB] (May 2012)

***PSERC Poster***

*Planning and Market Design* for *Using Dispatchable Loads to Meet Renewable Portfolio Standards and Emissions Reduction Targets* (December 2011)
[Workshop Poster, PDF 495KB]

## 3.4 Probabilistic Simulation Methodology for Evaluating the Impact of Renewables Intermittency on Operation and Planning

**Task Leader:** George Gross, University of Illinois at Urbana/Champaign (gross@illinois.edu, 217-244-6346)

**Collaborators:** Alejandro Dominguez-Garcia, University of Illinois at Urbana/Champaign (aledan@illinois.edu, 217-333-3953)

**Task Objective:** To develop a comprehensive simulation methodology to quantify the economic and reliability impacts on overall grid performance and operation of storage applications in systems with high penetrations of variable wind and solar power generation resources.

***Published Papers***

1. Degeilh, Y., F. Cadoux, N. Navid, and George Gross. "Impacts of ramp capability constraints in electricity markets with the participation of renewable resources." In *Proceeding of IEEE PES General Meeting*, San Diego, CA, July 21-25, 2012.
2. Smater, S.S., Alejandro Dominguez-Garcia. "A Framework for Reliability and Performance Assessment of Wind Energy Conversion Systems," In *Power Systems, IEEE Transactions on*, vol.26, no.4, pp.2235-2245, Nov. 2011. doi: 10.1109/TPWRS.2011.2111466.
3. Dominguez-Garcia, A. D. "Reliability Engineering for Electrical Energy Systems 2020: Smart Grid Applications and Beyond." Presented at University of Castilla–La Mancha, Toledo, Spain, December 2011.
4. Gross, George. "Renewable Energy Integration: The Grand Challenges And Opportunities Towards A Sustainable Energy Future." Keynote address at the Premio REN 2011- 2012 ceremonies, Lisbon, Portugal, July 6, 2012.
5. Dageilh, Y., George Gross, and Alejandro Dominguez-Garcia. "Simulation of Power Systems with Time-Dependent Resources." Poster presentation in *Future Grid Initiative Workshop*, PSERC, University of California at Berkeley, Berkeley, CA, December 7, 2011.

***Theses***

1. Degeilh, Y. "Stochastic Simulation of Power Systems with Variable Energy Resources." PhD diss., University of Illinois, Urbana, IL, 2013.
2. Hughes, Justin T. "Type-C Wind Turbine Model Order Reduction and Parameter Identification." MS thesis, University of Illinois, Urbana, IL, 2012.
3. Zheng, Z. "Impacts of Energy Storage Siting on Power System." Senior thesis, University of Illinois, Urbana, IL, 2012.

***Presentations***

1. Gross, George. “Simulation of Power Systems with Integrated Renewable, Demand Response and Storage Resources.” Paper presented at the Graduate School of Information Engineering, University, of Salerno, Salerno, Italy, June 22, 2011.
2. Gross, George. “Simulation of Power Systems with Integrated Renewable, Demand Response and Storage Resources.” Paper presented at the Department of Electrical Engineering, Politecnico di Torino, Turin, Italy, July 1, 2011.
3. Gross, George. “Simulation of Power Systems with Integrated Renewable, Demand Response and Storage Resources,” Paper presented at the Department of Energy Engineering, Politecnico di Milano, Milan, Italy, July 5, 2011.
4. Gross, George. “Renewable Energy Integration: The Grand Challenges And Opportunities Towards A Sustainable Energy Future.” Keynote address at the IV Simpósio Brasileiro de Sistemas Elétricos Goiânia, Goiás, Brazil, May 15 – 18, 2011.
5. Gross, George. “Renewable Energy Integration: The Grand Challenges And Opportunities Towards A Sustainable Energy Future.” Paper presented at the Facultad de Ingeniería, Universidad Nacional de Río Cuarto, Rio Cuarto, Argentina, June 8, 2012.
6. Gross, George. "Renewable Energy Integration: The Grand Challenges And Opportunities Towards A Sustainable Energy Future.” Keynote at the IEEE Transmission and Distribution Conference - Latin America, Montevideo, Uruguay, September 3, 2012.

***Thrust Area 3 PSERC Presentations***

1. *Renewable Energy Integration - Technological and Market Design Challenges: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar [Announcement | Archived Webinar] (February 19, 2013)
2. *Research Results* [PDF 1.7MB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid: Thrust Area 3 White Paper* [PDF 812KB] (May 2012)

***PSERC Poster***

*Probabilistic Simulation Methodology for Evaluating the Impacts of Renewable Intermittency on Operations and Planning* (December 2011)
[Workshop Poster, PDF 495KB]

# 4. Thrust Area 4: Workforce Development

**Thrust Area Leader**: Chanan Singh, Texas A&M University (singh@ece.tamu.edu, 979-845-7589)

## 4.1 Comprehensive Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid

**Task Leader**: Chanan Singh, Texas A&M University (singh@ece.tamu.edu, 979-845-7589)

**Task Objective:** To develop educational material for teaching reliability modeling and evaluation of the emerging power grid with heavy penetration of renewables and massive deployment of computer and communication technologies.

***Course Materials and Accessibility***

Course materials are being finalized for a graduate level course "Electric Power System Reliability Evaluation" (ECEN 643) that has around 30 graduate students with varied academic concentrations (power systems, power electronics, etc.). There are nine main modules for this course with some modules having further sub-modules. The materials are continuing to be enhanced as the course is taught every Fall Semester. This course will be made available on internet starting end of summer 2013.

The materials for the short course on power system reliability are being organized into seven modules that can be used either in academic courses, in short professional courses, or by individuals via downloading the on-line materials. The materials should be accessible on-line by late summer 2013.

***Presentation***

Singh, Chanan. "Workforce Development for the Future Grid to Enable Sustainable Energy Systems." Paper presented at the IEEE PES General Meeting, San Diego, July 2012.

***Thrust Area 4 PSERC Presentations***

1. Education in Workforce Development. PSERC Webinar (March 5, 2013)
2. Progress Report [PDF 789KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. Workforce Session: Building the Future Grid Workforce. Future Grid Forum. Washington DC. (June 27-28, 2012)
    - *Workforce Development Challenges* [PDF 1.7MB] - Wanda Reder, S&C Electric
    - *Meeting the Educational Challenge of the Smart Sustainable Grid* [PDF 194KB] - Chanan Singh, Texas A&M University

***PSERC White Paper***

*Workforce Development:  Thrust Area 4 White Paper* [PDF 452KB] (May 2012)

***PSERC Poster***

*Comprehensive Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid* (December 2011)
[Workshop Poster, PDF 296KB]

## 4.2 PSERC Academy: A Virtual Library of Thousands of Short Videos

**Task Leader**: Raja Ayyanar, Arizona State University (rayyanar@asu.edu, 480-727-7307)

**Collaborators**: PSERC community in an advisory role

**Task Objective:** To create an online library of short (i.e., 15-20 minute) videos on various topics of sustainable energy systems, smart grid and power engineering, and on important background topics required to understand these concepts.

***Access to Developed Materials***

The material for PSERC Academy will be primarily put on the website 'PsercAcademy.asu.edu'. I have obtained approval for this domain name. Most of the videos will be on YouTube and the PsercAcademy.asu.edu website will provide links to these under different topic areas. The simulation files and animations will be hosted directly on the PsercAcademy.asu.edu website. I expect to make it available by the end of Q2 2013 and it will be available to the general public.

***Thrust Area 4 PSERC Presentations***

1. Education in Workforce Development. PSERC Webinar (March 5, 2013)
2. Progress Report [PDF 789KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Workforce Development: Thrust Area 4* White *Paper* [PDF 452KB] (May 2012)

***PSERC Poster***

*PSERC Academy: A Virtual Library of Thousands of Short Videos* (December 2011) [Workshop Poster, PDF 261KB]

## 4.3 Smart Grid Education for Students and Professionals

**Task Leader**: Mladen Kezunovic, Texas A&M University (kezunov@ece.tamu.edu, 979-845-7509)

**Collaborators**: Sakis Meliopoulos, Georgia Institute of Technology (sakis.meliopoulos@ece.gatech.edu, 404-894-2926),
Vijay Vittal, Arizona State University (vijay.vittal@asu.edu, 480-965-1879),
Mani Venkatasubramanian, Washington State University (mani@eecs.wsu.edu, 509-335-6452),
Alex Sprintson, Texas A&M University (spalex@tamu.edu, 979-458-0092)

**Task Objective:** (1) To build a comprehensive educational package that will reach out to educators, students, practicing engineers, managers, legislators, public officials, etc. (2) To write a text book and prepare a set of supplemental PowerPoint presentations that may be used.

### *Access to Developed Materials*

This will be a book for students and industry professionals. It is anticipated that there will be a camera-ready manuscript ready for publishing by December 31, 2013.

### *Thrust Area 4 PSERC Presentations*

1. Education in Workforce Development. PSERC Webinar (March 5, 2013)
2. Progress Report [PDF 789KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

### *PSERC White Paper*

*Workforce Development: Thrust Area 4* White *Paper* [PDF 452KB] (May 2012)

### *PSERC Poster*

*Synchrophasor Education for Students and* Professionals (December 2011) [Workshop Poster, PDF 106KB]

## 4.4 Energy Processing for Smart Grid

**Task Leader:** James A. Momoh, PhD, Howard University (jmomoh@howard.edu, 202-806-5350)

**Collaborator:** Peter A. Bofah, PhD, Howard University (pbofah@howard.edu, 202-806-4819)

**Task Objective:** To develop a university course, with materials, on smart grid technology for undergraduates and first year graduate students.

***Presentations***

1. Tutorial presented at the 9th International Conference on Power System Operation and Planning (ICPSOP) held between the 14th and 19th January 2012 in Kenya.
2. Presentation at the 1st Solar Africa Conferences in Usmanu Danfodio Universit Sokoto , Nigeria held between December 14 -19, 2012.
3. Presentation at the IEEE PES summer meeting 2012
4. Presentation made at the World Energy conference in Washington DC- summer 2012.

***Thrust Area 4 PSERC Presentations***

1. Education in Workforce Development. PSERC Webinar (March 5, 2013)
2. Progress Report [PDF 789KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Workforce Development: Thrust Area 4 White Paper* [PDF 452KB] (May 2012)

***PSERC Poster***

*Energy Processing for Smart* Grid *Technology* (December 2011)
[Workshop Poster, PDF 117KB | Send Comments]

## 4.5 Energy Economics and Policy: Courses and Training

**Task Leader**: James Bushnell, UC Davis (jbbushnell@ucdavis.edu, 530-752-3129)

**Task Objective:** To develop a masters-level graduate course on the Policy and Economics of Energy Markets designed for both non-economists with backgrounds in energy technology and engineering, and economists interested in applications to energy.

***Courses and Access to Materials.***

1. Masters Course delivered at UC Berkeley in Spring of 2012. Course Materials (Syllabus, Presentations, Exams) for Masters course in Energy Markets and Policy are available upon request to instructors at accredited universities from project team upon request.
2. Ph.D Course delivered at UC Davis in Fall of 2012. Course Materials (Syllabus and Presentations, Exams) are available for Ph.D level class in energy economics will be available to instructors at accredited universities from project team upon request.

   Note: A specific website will be set-up where the course materials would be available subject to a password provided upon request.
3. Professional Short Courses were delivered in 2011 and 2012. Enrollment at each offering reached capacity of around 60 students drawn from ISO's, electric utilities, and regulatory bodies.
4. The Electricity Strategy Game has been implemented at https://esg.haas.berkeley.edu. Games have been run at UC Berkeley, Dartmouth, MIT, Stanford, Yale, and other Universities. Access to this site is available upon request.

***Thrust Area 4 PSERC Presentations***

1. Education in Workforce Development. PSERC Webinar (March 5, 2013)
2. Progress Report [PDF 789KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Workforce Development: Thrust Area 4 White* Paper [PDF 452KB] (May 2012)

***PSERC Poster***

*A Course in Energy* Economics (December 2011)
[Workshop Poster, PDF 142KB]

## 4.6 Course Development, "Critical Infrastructure Security: The Emerging Smart Grid"

**Task Leader:** Anurag Srivastava, Washington State University (asrivast@eecs.wsu.edu, 509-335-2348)

**Collaborators:** Carl Hauser, Washington State University (hauser@eecs.wsu.edu, 509-335-6470);
David Bakken, Washington State University (bakken@eecs.wsu.edu, 509-335-2399),
M.S. Kim, Washington State University (msk@eecs.wsu.edu, 509-335-1846)

**Task Objective:** To develop a university course that with multi-disciplinary content from areas of data communication, computing, control, and cyber-security that provides the necessary background for engineering students to work on problems, issues and cyber-security challenges associated with the smart grid.

### *Course and Access to Developed Materials*

This course titled, "Critical Infrastructure Security: The Emerging Smart Grid "has been offered in Spring 2012 for the first time. It was team taught by Dr. Srivastava, Dr. Hauser, Dr. Bakken and Dr. Kim and was offered in class, for distance WSU campus and as online course through distance education.

Course is being offered again in Spring 2013 with the same title and team taught by Dr. Srivastava, Dr. Hauser and Dr. Bakken. Course is being offered to in class student, WSU distance campus as well as online offering. Anyone with engineering or computer science BS degree through WSU enrollment service can take course by paying 3 credit tuition fees.

Both the offering was based on temporary special topic course as EE and CS course with the school of electrical engineering and computer science. and has not been approved by WSU graduate committee as regular course. We plan to do that after 3 offerings and making it more rigorous course.

In future, we plan to have two separate course offerings:

1) In class and WSU distance campus for 3 credits towards graduate and undergraduate degree
2) Online for certificate (this may change to online degree program in long term). This will be marketed through WSU global campus.

### *Access to Course Materials*

Developed course can be adopted for smart grid cyber security education by other faculty members. All the developed materials will be available in the summer of 2013 based on individual requests and, in 2014, from a password protected website for faculty members.

***Published Papers and Articles***

1. Srivastava, Anurag K.; Carl Hauser, David Bakken, and Min Sik Kim. *Design and Development of a New Smart Grid Course at Washington State University*. IEEE PES General Meeting, San Diego, CA, July 2012.
2. Srivastava, Anurag K.; Carl Hauser, and David Bakken. *IEEE PES* "*Study Buddies*", IEEE Power and Energy Society Magazine, vol. 11, issue 1, pp. 39-43, Jan. 2013.

***Thrust Area 4 PSERC Presentations***

1. Education in Workforce Development. PSERC Webinar (March 5, 2013)
2. Progress Report [PDF 789KB]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Workforce Development: Thrust Area 4 White Paper* [PDF 452KB] (May 2012)

***PSERC Poster***

*Course Development - Critical* Infrastructure *Security: The Emerging Smart Grid* (December 2011) [Workshop Poster, PDF 424KB]

# 5. Thrust Area 5: Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power System Conditions

**Thrust Area Leader**: Santiago Grijalva, Georgia Institute of Technology (sgrijalva@ece.gatech.edu, 404-894-2974)

## 5.1 Decision-Making Framework for the Future Grid

**Task Leader**: Santiago Grijalva, Georgia Institute of Technology (sgrijalva@ece.gatech.edu, 404-894-2974)

**Task Objective:** To develop and demonstrate a decision-making framework for the future grid that:

1. ensures that all the goals of the future grid can be met
2. covers all relevant spatial and temporal scales
3. addresses decision complexity through layered abstractions
4. uncovers the gaps and technological needs as the industry evolves into the future grid.

***Published Papers***

1. Hubert, Tanguy, and Santiago Grijalva. "Modeling for Residential Electricity Optimization in Dynamic Pricing Environments." In *Smart Grid, IEEE Transactions on*, vol.3, no.4, pp. 2224-2231, Dec. 2012. doi: 10.1109/TSG.2012.2220385.
2. Costley, M., and Santiago Grijalva. "Efficient distributed OPF for decentralized power system operations and electricity markets." In *Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES*, pp.1-6, 16-20 Jan. 2012. doi: 10.1109/ISGT.2012.6175797.
3. Hubert, Tanguy, and Santiago Grijalva. "Realizing smart grid benefits requires energy optimization algorithms at residential level." In *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*, pp.1-8, 17-19 Jan. 2011. doi: 10.1109/ISGT.2011.5759175.
4. Grijalva, Santiago, and M. U. Tariq. "Prosumer-based smart grid architecture enables a flat, sustainable electricity industry." In *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*, pp.1-6, 17-19 Jan. 2011. doi: 10.1109/ISGT.2011.5759167.

***Thrust Area 5 PSERC Presentations***

1. Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power Systems: A PSERC Future Grid Initiative Progress Report. PSERC Webinar (March 26, 2013)
2. Research Results [PDF 2.6M]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

3. Computational Challenges Session: Future Grid Forum. Washington DC. (June 27-28, 2012)
4. Opening Presentation [PDF 635KB] - Santiago Grijalva, Georgia Tech University
5. Panel Comments [PDF 88.8KB]

***PSERC White Paper***

*Computational Challenges and Analysis* Under *Increasingly Dynamic and Uncertain Electric Power System Conditions: Thrust Area 5 White Paper* [PDF 734KB] (May 2012)

***PSERC Poster***

*Decision-Making Framework for the Future Grid* (December 2011)
[Workshop Poster, PDF 686KB]

***Leveraged Research (Future Grid Initiative Funding Provided Seed Support)***

ARPA-E project. *Autonomous, Decentralized Grid Architecture*.

## 5.2 Computational Issues of Optimization for Planning

**Task Leader:** Sarah M. Ryan, Iowa State University (smryan@iastate.edu, 515-294-4347)

**Task Objective:** To develop improved computational methods for long-term resource planning under uncertainty in a model familiar to grid planners while seeking solutions to tractable enhancements in planning models to enable analysis of changing goals in coordinated markets.

***Published Papers***

1. Yonghan Feng, Sarah M. Ryan. "Scenario construction and reduction applied to stochastic power generation expansion planning." In *Computers & Operations Research*, Volume 40, Issue 1, January 2013, Pages 9-23, ISSN 0305-0548, 10.1016/j.cor.2012.05.005. (http://www.sciencedirect.com/science/article/pii/S0305054812001074)
2. Yonghan Feng, and Sarah M. Ryan. "Application of scenario reduction to LDC and risk based generation expansion planning." *Power and Energy Society General Meeting, 2012 IEEE*, pp.1-8, 22-26 July 2012. doi: 10.1109/PESGM.2012.6345655.

***Theses***

Jin, S. "Electricity System Expansion Studies to Consider Uncertainties and Interactions in Restructured Markets." PhD diss., Iowa State University, 2012.

***Presentations***

Jin, S. and Sarah M. Ryan. "Impact of carbon emission policies on capacity expansion in the integrated supply network for an electricity market." Presented in *Industrial Engineering Research Conference*, Reno, NV, May, 2012.

***Thrust Area 5 PSERC Presentations***

1. Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power Systems*: A PSERC Future Grid Initiative Progress Report*. PSERC Webinar (March 26, 2013)
2. *Research Results* [PDF 2.6M]: PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. Computational Challenges Session: Future Grid Forum. Washington DC. (June 27-28, 2012)

    - *Opening Presentation* [PDF 635KB] - Santiago Grijalva, Georgia Tech University
    - *Panel Comments(including Ryan)* [PDF 88.8KB]

***PSERC White Paper***

*Computational Challenges and Analysis Under* Increasingly *Dynamic and Uncertain Electric Power System Conditions: Thrust Area 5 White Paper* [PDF 734KB] (May 2012)

***PSERC Poster***

*Computational Issues of Optimization for Planning* (December 2011)
[Workshop Poster, PDF 479KB | Send Comments]

## 5.3 Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances

**Task Leader**: A.P. Sakis Meliopoulos, Georgia Institute of Technology (sakis.m@gatech.edu, 404-894-2926)

**Task Objective:** To develop an hierarchical stochastic optimization method and a supporting infrastructure to capture the potential benefits from levelizing total load, reducing losses substantially, providing ancillary services, and maximizing system reliability in distribution.

### *Published Papers*

1. Meliopoulos, A.P. Sakis, G. J. Cokkinides, R. Huang, and E. Farantatos. "Integrated Smart Grid Hierarchical Control." In *System Science (HICSS), 2012 45th Hawaii International Conference on*, pp.1967-1976, 4-7 Jan. 2012. doi: 10.1109/HICSS.2012.331.
2. Meliopoulos, Sakis, G. Cokkinides, R. Huang, E. Farantatos, Sungyun Choi, Yonghee Lee, Xuebei Yu. "Smart Grid Infrastructure for Distribution Systems and Applications." In *System Sciences (HICSS), 2011 44th Hawaii International Conference on*, pp.1-11, 4-7 Jan. 2011.
doi: 10.1109/HICSS.2011.377.
3. Farantatos, E., Renke Huang, G. J. Cokkinides, A. P. Meliopoulos. "Implementation of a 3-phase state estimation tool suitable for advanced distribution management system." In *Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES*, pp.1-8, 20-23 March 2011.
doi: 10.1109/PSCE.2011.5772554.
4. Meliopoulos, A.P.Sakis, G. Cokkinides, Renke Huang; E, Farantatos, Sungyun Choi, Yonghee Lee, Xuebei Yu. "Smart Grid Technologies for Autonomous Operation and Control." In *Smart Grid, IEEE Transactions on*, vol.2, no.1, pp.1-10, March 2011.
doi: 10.1109/TSG.2010.2091656.
5. Sungyun Choi, Beungjin Kim, G. J. Cokkinides, A. P. Sakis Meliopoulos. "Feasibility Study: Autonomous State Estimation in Distribution Systems." In *Power Systems, IEEE Transactions on*, vol.26, no.4, pp.2109-2117, Nov. 2011. doi: 10.1109/TPWRS.2011.2151260.

### *Theses*

Huang, Renke. “Hierarchical Optimization for Smart Grids.” PhD diss., Georgia Institute of Technology, December 2013.

### *Analysis Tools*

Object-oriented, multi-phase optimization tool based on interior point method. This computational tool optimizes the operation of an integrated feeder with utility as well as customer owned resources.

***Thrust Area 5 PSERC Presentations***

1. Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power Systems: A PSERC Future Grid Initiative Progress Report. PSERC Webinar (March 26, 2013)
2. Research Results [PDF 2.6M]: PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Computational Challenges and Analysis* Under *Increasingly Dynamic and Uncertain Electric Power System Conditions: Thrust Area 5 White Paper* [PDF 734KB] (May 2012)

***PSERC Poster***

*Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances* (December 2011) [Workshop Poster, PDF 302KB]

## 5.4 Real-Time PMU-Based Tools for Monitoring Operational Reliability

**Task Leader**: Alejandro D. Dominguez-Garcia, University of Illinois at Urbana-Champaign, (aledan@illinois.edu, 217-333-3953)

**Collaborators**: Peter W. Sauer, University of Illinois at Urbana-Champaign (psauer@illinois.edu, 217-333-0394)

**Task Objective:** To develop real-time PMU-based tools for helping operators with operational reliability assessment, including system loadability condition monitoring, transient stability analysis, and real-time line model and equivalent parameter updating.

***Published Papers***

Reinhard, Karl E., Peter W. Sauer, and Alejandro D. Dominguez-Garcia. "On Computing Power System Steady-State Stability Using Synchrophasor Data." In *Proceedings, 46th Hawaiian International Conference on System Science (HICSS)*, January 7-10, 2013, Maui, Hawaii.

***Theses***

Hughes, Justin T. "Type-C Wind Turbine Model Order Reduction and Parameter Identification." MS thesis, University of Illinois at Urbana-Champaign, 2012.

***Thrust Area 5 PSERC Presentations***

1. Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power Systems: A PSERC Future Grid Initiative Progress Report. PSERC Webinar (March 26, 2013)
2. Research Results [PDF 2.6M]: PSERC Industry-University Meeting. Golden, CO. (December 2012)
3. Computational Challenges Session: Future Grid Forum. Washington DC. (June 27-28, 2012)
   - *Opening Presentation* [PDF 635KB] - Santiago Grijalva, Georgia Tech University
   - *Panel Comments(including Dominguez-Garcia)* [PDF 88.8KB]

***PSERC White Paper***

*Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power System Conditions: Thrust Area 5 White Paper* [PDF 734KB] (May 2012)

***PSERC Poster***

*Real-Time PMU-Based Tools for Monitoring Operational Reliability* (December 2011) [Workshop Poster, PDF 1.24MB | Send Comments]

# 6. Thrust Area 6: Engineering Resilient Cyber-Physical Systems

**Thrust Area Leader:** Thomas Overbye, University of Illinois at Urbana-Champaign (overbye@illinois.edu, 217-333-4463)

## 6.1 Resiliency With Respect To Low Frequency, High Consequence Events

**Task Leader**: Thomas J. Overbye, University of Illinois at Urbana-Champaign (overbye@illinois.edu, 217-333-4463)

**Task Objective:** To research grid resiliency to geomagnetic storms, including the development of power system analysis techniques and tools for assessing grid resiliency and adverse impact mitigation options.

### *Published Papers*

1. Horton, R,, D. H, Boteler, Thomas Overbye, R. J. Pirjola, R. Dugan. "A Test Case for the Calculation of Geomagnetically Induced Currents." In *Power Delivery, IEEE Transactions on*, vol.27, no.4, pp.2368-2373, Oct. 2012. doi: 10.1109/TPWRD.2012.2206407.
2. Overbye, Thomas J., T. R. Hutchins, K. Shetye, J. Weber, S. Dahman. "Integration of geomagnetic disturbance modeling into the power flow: A methodology for large-scale system studies." In *North American Power Symposium (NAPS), 2012*, pp.1-7, 9-11 Sept. 2012. doi: 10.1109/NAPS.2012.6336365.

### *Theses*

Hutchins, Trevor. “Geomagnetically Induced Currents and their Effect on Power Systems.” MS thesis, Universit of Illinois at Urbana, 2012. Available online at: https://www.ideals.illinois.edu/bitstream/handle/2142/30963/Hutchins_Trevor.pdf?sequence=1

### *Analysis Tools*

The project developed Matlab code to consider the sensitivities of the geomagnetic induced currents (GICs) on particular transformers to the geomagnetically induced electric fields on individual transmission lines. The code uses superposition to analyze all the line induced GICs separately. The contributed GIC from each line can then be tracked throughout the system, allowing for the determination of which transformers and substations are sensitive to which lines. The code will be made available upon request to Overbye@illinois.edu.

### *Thrust Area 6 PSERC Presentations*

1. Engineering Resilient Cyber-Physical Systems: A PSERC Future Grid Initiative Progress Report. PSERC Webinar (April 2, 2013)
2. Research Results [PDF 337KB]**:** PSERC Industry-University Meeting. Golden, CO. (December 2012)

3. Integration of Geomagnetic Disturbances (GMDs) Modeling into the Power Flow (March 13, 2012) [Announcement | Slides PPT 3.33MB | Archived Webinar]

***PSERC White Paper***

*Engineering Resilient Cyber-Physical Systems: Thrust Area 6 White Paper* [*PDF* 620KB] (May 2012)

***PSERC Poster***

*Resiliency with Respect to Low Frequency, High Consequence Events* (December 2011) [Workshop Poster, PDF 408KB | Send Comments]

## 6.2 Operational and Planning Considerations for Resiliency

**Task Leader**: Ian Dobson, Iowa State University (dobson@iastate.edu, (515) 294 0922)

**Task Objective:** To engineer power transmission system resilience to cascading failure blackouts by developing metrics, cascading failure models, methods of statistical processing, and risk communication methods, incorporating the results of case studies using observed and simulated power system data.

***Published Papers***

1. Sehwail, H., and Ian Dobson. "Locating line outages in a specific area of a power system with synchrophasors." In *North American Power Symposium (NAPS), 2012*, pp.1-6, 9-11 Sept. 2012. doi: 10.1109/NAPS.2012.6336315.
2. Dobson, Ian. "Estimating the Propagation and Extent of Cascading Line Outages From Utility Data With a Branching Process." *Power Systems, IEEE Transactions on* , vol.27, no.4, pp.2146-2155, Nov. 2012. doi: 10.1109/TPWRS.2012.2190112.
3. Dobson, Ian. "Voltages across an area of a network." IEEE Transactions on Power Systems, vol. 27, no. 2, May 2012, pp. 993-1002. doi: 10.1109/TPWRS.2011.2168985. Also presented at IEEE *Power and Energy Society General Meeting, July 2012*.
4. Carreras, B. A., D.E. Newman, Ian Dobson, N.S. Degala. "Validating OPA with WECC Data." *46th Hawaii International Conference on System Sciences*, Maui, Hawaii, January 2013. http://iandobson.ece.iastate.edu/PAPERS/carrerasHICSS13.pdf.

***Theses***

1. Kim, Jang Hoon. "Quantifying failure propagation in electric power transmission systems." PhD diss., University of Wisconsin-Madison, 2011.
2. Darvishi, Atena. "Applications of stress angles across areas of power systems." PhD diss., in progress, Iowa State University, 2016.
3. Ding, Lingyun. "How cascading failures propagate in power grids." MS thesis, in progress, Iowa State University, 2014.

***Presentations***

Dobson, Ian. "Alarming with Area Phase Angles?." presentation to industry at WECC JSIS (Western Electricity Coordinating Council Joint Synchronized Information Subcommittee) meeting Tempe AZ, January 2013.

***Analysis Tools***

Prototype software to estimate annual cascading risk in terms of number of lines outages from standard utility data. The intention is to share the software with industry so that they can process their own data.

***Thrust Area 6 PSERC Presentations***

1. Engineering Resilient Cyber-Physical Systems: A PSERC Future Grid Initiative Progress Report. PSERC Webinar (April 2, 2013)
2. Research Results [PDF 337KB]**:** PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Engineering Resilient Cyber-Physical Systems: Thrust Area 6 White Paper* [PDF 620KB] (May 2012)

***PSERC Poster***

*Resiliency with Respect to Low Frequency, High Consequence Events* (December 2011) [Workshop Poster, PDF 408KB | Send Comments]

## 6.3 Improved Power Grid Resiliency through Interactive System Control

**Task Leader**: Vijay Vittal, Arizona State University (vijay.vittal@asu.edu, 480-965-1879)

**Task Objective:** To design and test corrective controls that incorporate appropriate synchronized wide area measurements to enhance grid resiliency and robustness with respect to increased penetration of renewable resources and the resulting uncertainty arising from those resources.

***Published Papers***

1. Zhang, S., V. Vittal. "Design of Wide-Area Power System Damping Controllers Resilient to Communication Failures." To appear in the *IEEE Transactions on Power Systems*.

2. Zhang, S., V. Vittal. "Improving Grid Resiliency Using Hierarchical Wide Area Measurements." IEEE GM13. Vancouver, CA. Jul. 2013.

***Theses***

Zhang, Song. "Improved Power Grid Resiliency through Interactive System Control." PhD diss., Arizona State University, December 2013.

***Thrust Area 6 PSERC Presentations***

1. Engineering Resilient Cyber-Physical Systems: A PSERC Future Grid Initiative Progress Report. PSERC Webinar (April 2, 2013)
2. Research Results [PDF 337KB]**:** PSERC Industry-University Meeting. Golden, CO. (December 2012)

***PSERC White Paper***

*Engineering Resilient Cyber-Physical Systems: Thrust Area 6 White Paper* [PDF 620KB] (May 2012)

***PSERC Poster***

*Resiliency with Respect to Low Frequency, High Consequence Events* (December 2011) [Workshop Poster, PDF 408KB | Send Comments]

# 7. Broad Analysis

## 7.1 The Information Hierarchy for the Future Grid

**Leader**: Peter Sauer, University of Illinois at Urbana-Champaign (psauer@illinois.edu, 217-333-4463)

**Collaborators:**
Manimaran Govindarasu, Iowa State University (gmani@iastate.edu, 515-294-9175)
Vinod Namboodiri, Wichita State University (vinod.namboodiri@wichita.edu, 316-978-3922)
Lang Tong, Cornell University (ltong@ece.cornell.edu, 607-255-3900)
Junshan Zhang, Arizona State University (junshan.zhang@asu.edu, 480-727-7389)

***Broad Analysis Webinar, November 2012:***

*The Information Hierarchy for the Future Grid: Conclusions and Research Directions*
[Announcement | Slides [PDF 1.77MB] | Archived Webinar] November 6, 2012
Speaker: Peter Sauer, University of Illinois at Urbana-Champaign

**White Paper Topics**

1. ***Cyber-Physical Systems Security for the Smart Grid***
   Lead: Manimaran Govindarasu, Iowa State University. Collaborators: Peter Sauer and Rakesh Bobba, University of Illinois at Urbana/Champaign. Reviewers: Jianhui Wang, Argonne National Laboratory; Chen-Ching Liu, Washington State University; and Scott Backhaus, Los Alamos National Laboratory.

   - White Paper, PDF 878 KB (May 2012)
   - Workshop Poster, PDF 763KB (December 2011)
   - Presentation Slides, PDF 1.6MB (February 7, 2012)
   - Archived Webinar (February 7, 2012)

2. ***Communication Needs and Integration Options for AMI in the Smart Grid***
   Lead: Vinod Namboodiri, Wichita State University. Collaborator: Visvakumar Aravinthan and Ward Jewell, Wichita State University. Reviewer: Eve Schooler, Intel.

   - White Paper, PDF 520KB (May 2012)
   - Workshop Poster, PDF 831KB (December 2011)
   - Presentation Slides, PDF 2.85MB (March 13, 2012)
   - Archived Webinar (March 13, 2012)

3. ***Information and Computation Structures for the Smart Grid***
   Lead: Lang Tong, Cornell University. Collaborators: Salman Avestmehr, Elyan Bitar, Kevin Tang, and Aaron Wagner, Cornell University; Peter Sauer, University of Illinois at Urbana/Champaign. Reviewers: Paul DeMartini, Jeff Taft, and Barbara Fraser, Cisco Systems Inc.; and Annabelle Pratt, Intel Energy Research Lab.

   - Workshop Poster, PDF 108KB (December 2011)
   - Presentation Slides, PDF 4.31MB (June 5, 2012)
   - Archived Webinar (June 5, 2012)

4. ***Networked Information Gathering and Fusion of PMU Measurements***
   Lead: Junshan Zhang, Arizona State University. Collaborators: Peter Sauer, University of Illinois at Urbana/Champaign and Vijay Vittal, Arizona State University. Reviewers: Floyd Galvan, Entergy; Naim Logic, SRP; and Shimo Wang, SCE.

   - Workshop Poster, PDF 300KB (December 2011)
   - White Paper, PDF 744KB (May 2012)
   - Presentation Slides, PDF 875KB (April 3, 2012)
   - Archived Webinar (April 3, 2012)

## 7.2 Grid Enablers of Sustainable Energy Systems

**Leader**: Jim McCalley, Iowa State University (jdm@iastate.edu, 515-294-4844)

**Collaborators:**
Chris DeMarco, University of Wisconsin-Madison (demarco@engr.wisc.edu, 608-262-5546)
Marija Ilic, Carnegie Mellon University (milic@ece.cmu.edu, 412-268-9520)
Ward Jewell, Wichita State University (ward.jewell@wichita.edu, 316-978-6340)
James Momoh, Howard University (jmomoh@howard.edu, 202-806-5350)

***Broad Analysis Webinar, November 2012***

*Grid Enablers of Sustainable Energy Systems: Conclusions and Research Directions*
[Announcement | Slides [PDF 1.01MB] | Archived Webinar] (#12-17, November 27, 2012)
Speaker: James McCalley, Iowa State University

**White Paper Topics**

1. ***Primary and Secondary Control for High Penetration Renewables***
   Lead: Chris DeMarco, University of Wisconsin-Madison. Collaborators: Bernard Lesieutre and Yehui Han, University of Wisconsin-Madison. Reviewer: Jim Gronquist, BPA.

   - White Paper, PDF 1.6MB (May 2012)
   - Workshop Poster, PDF 88KB (December 2011)
   - Presentation Slides, PDF 4MB (March 20, 2012)
   - Archived Webinar (March 20, 2012)

2. ***Toward Standards for Dynamics in Electric Energy Systems***
   Lead: Marija Ilic, Carnegie Mellon University

   - White Paper, PDF 1.3MB (June 2012)
   - Workshop Poster, PDF 89KB (December 2011)
   - Presentation Slides, PDF 2MB (May 2012)
   - Archived Webinar (May 22, 2012)

3. ***Future Grid: The Environment***
   Lead: Ward Jewell, Wichita State University. Collaborators: Lindsey Anderson, Cornell University; Judy Cardell, Smith College; Marija Ilic, Carnegie Mellon. Reviewers: Floyd Galvan, Entergy; Jim Price, CAISO; Lisa Beard, Quanta

   - White Paper, PDF 913KB (May 2012)
   - Workshop Poster, PDF 1.54MB (December 2011)
   - Presentation Slides, 4.6MB (February 21, 2012)
   - Archived Webinar (February 21, 2012)

4. ***Transmission Design at the National Level: Benefits, Risks and Possible Paths Forward***
   Lead: Jim McCalley, Iowa State University. Collaborator: Jim Bushnell, University of California, Davis. Reviewers: Dale Osborn, MISO; Doug McClaughlin, Southern Co.

   - White Paper, PDF 1.6MB (May 2012)
   - Workshop Poster, PDF 582KB (December 2011)
   - Presentation Slides, PDF 1.7MB (January 24, 2012)
   - Archived Webinar (January 24, 2012)

5. ***Distributed and Centralized Generated Power Systems - A Comparison Approach***
   Lead: James Momoh, Howard University. Collaborator: Sakis Meliopoulos, Georgia Institute of Technology. Reviewer: Bob Saint, National Rural Electric Cooperative Association.

   - White Paper, PDF 314KB (June 2012)
   - Workshop Poster, PDF 443KB (December 2011)
   - Presentation Slides, PDF 550KB (April 2012)
   - Archived Webinar (April 17, 2012)

# 8. Events

## 8.1 Future Grid Workshop, December 7, 2011

***Announcement, Handouts and Overview Presentation***

- Future Grid Initiative Workshop Announcement
- Workshop Handout: Provides the agenda, an Initiative summary, summaries of the projects, and Vijay Vittal's opening presentation.
- Future Grid Initiative Overview Presentation: Presented by Vijay Vittal, Director, PSERC

***Panel and Discussion Notes***

- Workshop Panel Notes: These are notes of the comments by the faculty panelists.
- Participant Discussion Notes: These notes are from flipcharts and from written notes by faculty volunteers.

## 8.2 Future Grid Forum, June 27-28, 2012

***Agenda, Presentations and Panel Comments***

Handout Materials for Future Grid Forum

***Presentations***

- Forum Opening Presentation - Vijay Vittal, PSERC Director
- Session 1: Power Delivery Infrastructure Opening Presentation - Jerry Heydt, Arizona State Univ.
- Session 2: Operations and Planning Opening Presentation - Jim McCalley, Iowa State University
- Session 3: Control and Protection Opening Presentation - Chris DeMarco, University of Wisconsin-Madison
- Session 4: Communications and Information Infrastructure Opening Presentation - Lang Tong, Cornell University
- Session 5: Variable Generation Integration Opening Presentation - Shmuel Oren, University of California, Berkeley
- Session 6: Computational Challenges Opening Presentation - Santiago Grijalva, Georgia Tech
- Workforce Development Challenges - Wanda Reder, S&C Electric
- Meeting the Educational Challenge of the Smart Sustainable Grid - Chanan Singh, Texas A&M University

***Discussion Panel Comments***

- Session 1: Power Delivery Infrastructure
- Session 2: Operations and Planning
- Session 3: Control and Protection
- Session 4: Communications and Information Infrastructure
- Session 5: Variable Generation Integration
- Session 6: Computational Challenges

## 8.3 The Future Grid to Enable Sustainable Energy Systems (panel), IEEE PES General Meeting, July 23, 2012

- **Renewable Energy Integration and the Control and Protection Paradigms of the Future**
  A. BOSE, Washington State University, 2012GM1562
- **Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power System Conditions**
  S. GRIJALVA, Georgia Institute of Technology, 2012GM0498
- **Electric Energy Challenges of the Future**
  G. HEYDT, ASU, 2012GM0456
- **Future Grid Enablers of Sustainable Energy Systems: A Broad Analysis of Five Issues**
  J. MCCALLEY, Iowa State University, 2012GM1711
- **Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid**
  S. OREN, University of California, Berkeley, 2012GM0544
- **Engineering Resilient Cyber-Physical Systems**
  T. OVERBYE, University of Illinois at Urbana-Champaign, 2012GM0762
- **The Information Hierarchy for the Future Grid**
  P. SAUER, University of Illinois at Urbana-Champaign, 2012GM1700
- **Workforce Development for the Future Grid to Enable Sustainable Energy Systems**
  C. SINGH, Texas A&M University, 2012GM0629
- **The Future Grid to Enable Sustainable Energy Systems**
  V. VITTAL, Arizona State University, 2012GM0543

## 8.4 Webinars in 2013

- **Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power System Conditions: A PSERC Future Grid Initiative Progress Report** [Announcement] (#13-06, April 16, 2013)
  Research Team: Santiago Grijalva, Georgia Institute of Technology; Alejandro D. Dominguez-Garcia, University of Illinois at Urbana-Champaign; A.P. Sakis Meliopoulos, Georgia Institute of Technology; Sarah M. Ryan, Iowa State Univ.
- **Engineering Resilient Cyber-Physical Systems: A PSERC Future Grid Initiative Progress Report**[Announcement] (#13-05, April 2, 2013)
  Research Team: Tom Overbye, University of Illinois at Urbana-Champaign; Ian Dobson, Iowa State Univ.; Vijay Vittal, Arizona State University (vijay.vittal@asu.edu)
- **Education for Workforce Development: A PSERC Future Grid Initiative Progress Report** [Announcement] (#13-04, March 5, 2013)
  Research Team: Chanan Singh, and Mladen Kezunovic, Texas A&M Univ.; Raja Ayyanar, Arizona State Univ.; James Bushnell, Univ. of California, Davis; James Momoh, Howard Univ.; Anurag Srivastava, Washington State Univ.
- **Renewable Energy Integration - Technological and Market Design Challenges: A PSERC Future Grid Initiative Progress Report** [Announcement | Slides [PDF 3.06MB] | Archived Webinar] (#13-03, February 19, 2013)
  Research Team: Shmuel Oren, Univ. of California-Berkeley, Duncan Callaway, Univ. of California-Berkeley, George Gross, Univ. of Illinois-Urbana, Tim Mount, Cornell Univ.
- **Control and Protection Paradigms of the Future: A PSERC Future Grid Initiative Progress Report** [Announcement | Slides [PDF 655KB] | Archived Webinar] (#13-02, February 5, 2013)
  Research Team: Chris DeMarco, University of Wisconsin-Madison, Anjan Bose, Washington State University, Mladen Kezunovic, Texas A&M University
- **Electric Energy Challenges of the Future: A PSERC Future Grid Initiative Progress Report** [Announcement | Slides [PDF 3.31MB] | Archived Webinar] (#13-01, January 22, 2013)
  Research Team: Gerald Heydt, and Kory Hedman, Arizona State University; Jim McCalley, and Dionysios Aliprantis, Iowa State University; and Mani Venkatasubramanian, Washington State University

## 8.5 Webinars in 2012

- **Grid Enablers of Sustainable Energy Systems: Conclusions and Research Directions** [Announcement | Slides [PDF 1.01MB] | Archived Webinar] (#12-17, November 27, 2012)
  Speaker: James McCalley, Iowa State University

- **The Information Hierarchy for the Future Grid: Conclusions and Research Directions** [Announcement | Slides [PDF 1.77MB] | Archived Webinar] (#12-15, November 6, 2012)
  Speaker: Peter Sauer, University of Illinois at Urbana-Champaign
- **Information Hierarchy for Heterogeneous Smart Grid** [Announcement | Slides [PDF 4.31MB] | Archived Webinar] (#12-10, June 5, 2012)
  Speaker: Lang Tong, Cornell University
- **Toward Standards for Dynamics in Electric Energy Systems** [Announcement | White Paper | Slides [PDF 2.01MB] | Archived Webinar] (#12-09, May 22, 2012)
  Speaker: Marija Ilic, Carnegie Mellon University
- **Distributed and Centralized Generation - A Comparison Approach** [Announcement | White Paper | Slides [PDF 653KB] | Archived Webinar] (#12-08, April 17, 2012)
  Speaker: James Momoh, Howard University
- **Networked Information Gathering and Fusion of PMU Data** [Announcement | White Paper | Slides [PDF 875KB] | Archived Webinar] (#12-07, April 3, 2012)
  Speaker: Junshan Zhang, Arizona State University
- **Primary and Secondary Control for High Penetration Renewables** [Announcement | White Paper | Slides [PDF 4.05MB] | Archived Webinar] (#12-06, March 20, 2012)
  Speaker: Chris DeMarco, University of Wisconsin-Madison
- **Integration of Geomagnetic Disturbances (GMDs) Modeling into the Power Flow** [Announcement | Slides [PPT 3.33MB] | Archived Webinar] (#12-05, March 13, 2012)
  Speaker: Tom Overbye, University of Illinois at Urbana-Champaign
- **Communication Needs and Integration Options for AMI in the Smart Grid** [Announcement | White Paper | Slides [PDF 1MB] | Archived Webinar] (#12-04, March 6, 2012)
  Speaker: Vinod Namboodiri, Wichita State University
- **Future Grid: The Environment** [Announcement | White Paper | Color Slides [PDF 5MB] | Black & White Slides [PDF 25MB] | Archived Webinar] (#12-03, February 21, 2012)
  Speaker: Ward Jewell, Wichita State University
- **Cyber-Physical Systems Security for the Smart Grid** [Announcement | White Paper | Slides [PDF 1.61MB] | Archived Webinar] (#12-02, February 7, 2012)
  Speaker: Manimaran Govindarasu, Iowa State University
- **Transmission Design at the National Level: Benefits, Risks and Possible Paths Forward** [Announcement | White Paper | Slides [PDF 1.67MB] | Archived Webinar ] (#12-01, January 24, 2012)
  Speaker: James McCalley, Iowa State University

# 9. White Papers

## 9.1 Thrust Area White Papers

- Thrust Area 1: Electric Energy Challenges of the Future (May 2012)
  Lead: Jerry Heydt, Arizona State Univ.
- Thrust Area 2: Control and Protection Paradigms of the Future (May 2012)
  Lead: Chris DeMarco, University of Wisconsin-Madison
- Thrust Area 3: Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid (May 2012)
  Lead: Shmuel Oren, University of California, Berkeley
- Thrust Area 4: Workforce Development - Meeting the Educational Challenge of the Smart Sustainable Grid (May 2012)
  Lead: Chanan Singh, Texas A&M
- Thrust Area 5: Computational Challenges and Analysis under Increasingly Dynamic and Uncertain Electric Power System Conditions (May 2012)
  Lead: Santiago Grijalva, Georgia Tech
- Thrust Area 6: Engineering Resilient Cyber-Physical Systems (May 2012)
  Lead: Tom Overbye, University of Illinois at Urbana-Champaign
- Synthesis: Technology Challenges in Designing the Future Grid to Enable Sustainable Energy Systems (June 2012)
  Vijay Vittal, Arizona State Univ.

## 9.2 Broad Analysis White Papers

***Topic 1: The Information Hierarchy for the Future Grid***
*Lead: Peter Sauer, University of Illinois at Urbana-Champaign*

- Cyber-Physical Systems Security for the Smart Grid (May 2012)
  Lead: Manimaran Govindarasu, Iowa State University
- Communication Needs and Integration Options for AMI in the Smart Grid (May 2012)
  Lead: Vinod Namboodiri, Wichita State University
- Networked Information Gathering and Fusion of PMU Measurements (May 2012)
  Lead: Junshan Zhang, Arizona State University

***Topic 2: Grid Enablers of Sustainable Energy Systems***
*Lead: Jim McCalley, Iowa State University*

- Primary and Secondary Control for High Penetration Renewables (May 2012)
  Lead: Chris DeMarco, University of Wisconsin-Madison

- Toward Standards for Dynamics in Electric Energy Systems White Paper, PDF 1.3MB (June 2012)
  Lead: Marija Ilic, Carnegie Mellon University
- Future Grid: The Environment (May 2012)
  Lead: Ward Jewell, Wichita State University
- Transmission Design at the National Level: Benefits, Risks and Possible Paths Forward White Paper, PDF 1.6MB (May 2012)
  Lead: Jim McCalley, Iowa State University
- Distributed and Centralized Generated Power Systems - A Comparison Approach White Paper, PDF 314KB (June 2012)
  Lead: James Momoh, Howard University