Power Systems Engineering Research Center

Future Grid Initiative Workshop

December 7, 2011

Agenda

7:15 – 8:00	**Registration** (with Continental Breakfast)
8:00 – 8:30	**Central Decisions that will Shape the Future Grid and How it is Used** Vijay Vittal (Arizona State Univ.), Director, Power Systems Engineering Research Center
8:30 – 9:00	**Facilitated Discussion**
9:00 – 9:45	**Shaping the Future Grid: Context of the Research in Thrust Areas 1-3** • Design options, balancing, and wide area controls • Control and protection paradigms • Renewable energy integration Jerry Heydt (Arizona State Univ.), Anjan Bose (Washington State Univ.) and Shmuel Oren (Univ. of California, Berkeley)
9:45 – 10:45	**Gallery Walk for Thrust Areas 1 - 3**
10:45 – 11:15	**Discussion on Work in the Thrust Areas 1 - 3**
11:15 – 11:45	**Shaping the Future Grid: Context of the Broad Analysis White Papers** • Information Hierarchy of the Future Grid • Grid Enablers of Sustainable Energy Systems Peter Sauer (University of Illinois at Urbana-Champaign) Jim McCalley, Iowa State Univ.
11:45 - 12:15	**Gallery Walk for the Broad Analysis Areas**
12:15 – 1:15	**Lunch**
1:15 – 1:45	**Gallery Walk for the Broad Analysis Areas (continues)**
1:45 – 2:15	**Discussion on White Papers in the Broad Analysis Areas**
2:15 – 3:00	**Shaping the Future Grid: Context of the Research in Thrust Areas 4 - 6** • Computational challenges • Resiliency of cyber-physical systems • Workforce education Santiago Grijalva (Georgia Institute of Technology), Tom Overbye (Univ. of Illinois at Urbana-Champaign) and Chanan Singh (Texas A&M Univ.)
3:00 – 4:00	**Gallery Walk for Thrust Areas 4 - 6**
4:00 – 4:30	**Discussion on Work in the Thrust Areas 4 - 6**
4:30 – 5:30	**General Discussion on the Path to and Shape of the Future Grid**
5:30 – 5:45	**Closing Summary**
5:45 – 6:45	**Reception**

PSERC Mission:

Empowering minds to engineer the future electric energy system

2011 PSERC Industry Members

ABB	**American Electric Power**
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Arizona Public Service	**Bonneville Power Administration**
BC Hydro	**California ISO**
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San Diego Gas & Electric	**Salt River Project**
Southern Company	**Southern California Edison**
Tri-State Generation and Transmission	**Tennessee Valley Authority**
U.S. Department of Energy	**Western Area Power Administration**

Collaborating Universities and Site Directors

Arizona State (Jerry Heydt)	**Berkeley** (Shmuel Oren)	**Carnegie Mellon** (Marija Ilic)
Colorado School of Mines (P.K. Sen)	**Cornell** (Lang Tong)	**Georgia Tech** (Sakis Meliopoulos)
Howard University (James Momoh)	**Illinois** (Peter Sauer)	**Iowa State** (Venkataramana Ajjarapu)
Texas A&M (Mladen Kezunovic)	**Washington State** (Anjan Bose)	**Wisconsin** (Chris DeMarco)
	Wichita State University (Ward Jewell)	

Executive Overview of the Future Grid Initiative

In this initiative, PSERC will investigate requirements for a systematic transformation of today's electric grid to enable high penetrations of sustainable energy systems. A giant transformation in the electric grid is underway. The grid is evolving away from a network architecture with relatively few large, hierarchically-connected, tightly synchronized energy resources supplying large, medium, and very many small passive consumers. It is evolving toward a network driven by many highly variable distributed energy resources mixed with large central generation sources, energy storage, and responsive users equipped with embedded intelligence and automation to meet their unique energy needs while co-existing and interacting within a complex dynamic network system.

How the grid will evolve is an open question. In part, the future grid will be dependent on the resource technology decisions that can make a significant difference in the types of generation and demand resource technologies that are deployed. The working assumption of this proposal is that the future grid needs to support high penetrations of sustainable energy systems. The evolution will also be affected by decision-making objectives and flexibility across the grid. For example, tight synchronicity and balancing constraints may be relaxed through an architecture based on autonomous local energy clusters and microgrids that localize the quality standards. The future grid will also rely on an IT infrastructure with underlying communications networks that will enable the physical network, and will closely interact and support the performance objectives of sustainable energy systems. Finally, regional differences in energy resources will affect the requirements for the future grid.

The effective transformation of the grid will require identification and solution of major operating, planning, workforce, and economic challenges. To seamlessly integrate renewable resources in the grid, research and development must address challenges that high penetration levels of these energy resources will have in power system planning and operation, and in grid interconnection. Furthermore, new tools must be developed that explicitly account for the uncertainty and associated risks with such high levels of renewable resource penetration. The existing workforce and the students going into power and energy engineering careers need to be educated so that they can envision and develop the new approaches and technologies to maintain grid reliability and economy. There will need to be adaptation by the distributed resources and consumers, and by smart delivery technologies to avoid barriers detrimental to the energy system objectives. Many digital technologies are fairly mature and could be utilized to enable such adaptation. What is missing are basic problem formulations, modeling, analysis and decision support tools as enablers of such adaptation.

Engineering the envisioned sustainable energy systems is a problem of highly complex heterogeneous and dynamic network systems in an uncertain environment with diverse and distributed objectives. PSERC researchers will use their knowledge of today's operating and planning paradigms for electric power grids, as well as their knowledge of today's SCADA, EMS, DMS, and market systems, as the starting point for introducing new paradigms and transition strategies from today's legacy systems.

Organization

The Future Grid Initiative is structured into six thrust areas:

	Thrust Area	Leader
1	Electric energy challenges of the future	Gerald Heydt, heydt@asu.edu
2	Control and protection paradigms of the future	Anjan Bose, bose@wsu.edu
3	Renewable energy integration and the impact of carbon regulation on the electric grid	Shmuel Oren, oren@ieor.berkeley.edu
4	Workforce development	Chanan Singh, singh@ece.tamu.edu
5	Computational challenges and analysis under increasingly dynamic and uncertain electric power system conditions	Santiago Grijalva, sgrijalva@ece.gatech.edu
6	Engineering resilient cyber-physical systems	Tom Overbye, overbye@illinois.edu

The six thrust areas include specific tasks. The individual tasks in each thrust area include cross-cutting activities with tasks in other thrust areas. The cross-cutting research topics of the various tasks within the six thrust areas is depicted in Table 1 below where the shading indicates cross-cutting topics across thrust areas.

Table 1. Thrust Area (TA) Cross-Cutting Research Topics of Each Task

Task	Title	Cross-cutting research topics					
		TA 1	TA 2	TA 3	TA 4	TA 5	TA 6
	Thrust Area 1: Electric Energy Challenges of the Future						
1.1	Integrating Transmission and Distribution Engineering Eventualities			■			■
1.2	A National Transmission Overlay		■	■			■
1.3	Robust and Dynamic Reserve Requirements			■			
1.4	Wide Area Control Systems		■				■
	Thrust Area 2: Control and Protection Paradigms of the Future						
2.1	Requirements for Hierarchical Coordinated Control and Protection of the Smart Grid	■					■
2.2	Hierarchical Coordinated Control of Wind Energy Resources and Storage for Electromechanical Stability Enhancement of the Grid			■			■
2.3	Hierarchical Coordinated Protection of the Smart Grid with High Penetration of Renewable Resources			■			■
	Thrust Area 3: Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid						
3.1	Coupling Renewable Energy Supply with Deferrable Demand					■	
3.2	Mitigating Renewables Intermittency Through Non-Disruptive Distributed Load Control		■				
3.3	Planning and Market Design for Using Dispatchable Loads to Meet Renewable Portfolio Standards and Emissions Reduction Targets	■					
3.4	Probabilistic Simulation Methodology for Evaluating the Impacts of Renewable Intermittency on Operations and Planning					■	
	Thrust Area 4: Workforce Development						
4.1	Comprehensive Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid	■	■	■			■
4.2	PSERC Academy: A Virtual Library of Thousands of Short Videos	■	■	■		■	■
4.3	Synchrophasor Education for Students and Professionals	■				■	■
4.4	Energy Processing for Smart Grid Technology	■				■	■
4.5	A Course in Energy Economics						
4.6	Course Development - "Critical Infrastructure Security: The Emerging Smart Grid"						■
	Thrust Area 5: Computational Challenges and Analysis Under Increasingly Dynamic and Uncertain Electric Power System Conditions						
5.1	Decision-Making Framework for the Future Grid	■					■
5.2	Computational Issues of Optimization for Planning	■		■			■
5.3	Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances			■			
5.4	Real-Time PMU–Based Tools for Monitoring Operational Reliability	■		■			■
	Thrust Area 6: Engineering Resilient Cyber-Physical Systems						
6.1	Resiliency With Respect to Low Frequency, High Consequence Events	■	■	■			
6.2	Operational and Planning Considerations for Resiliency	■	■	■			
6.3	Improved Power Grid Resiliency through Interactive System Control	■	■	■			

Broad Analysis White Papers

As a part of this initiative, PSERC will undertake actions that can be taken to help lead thought about solutions to what can be called “broad analysis” needs. A broad analysis need covers questions that are typically well beyond the scope of typical academic research projects in terms of size and definition. The questions are not strictly engineering, often involving issues of policy as well as stakeholder perspectives and impacts. Broad analysis may also include the exploration of major new ideas to facilitate discussion on their applicability such as on research needs, commercialization potential, etc. Importantly, they are questions that often need to be answered to reach public interest objectives for the supply, delivery and use of electric energy. The broad analysis work will include creation of white papers and discussions at workshops. The broad analysis area and white paper topics are:

TOPIC: The Information Hierarchy for the Future Grid (Leader: Pete Sauer, University of Illinois at Urbana/Champaign)

White Papers

- Cyber-Physical Systems Security for the Smart Grid
- AMI: Communication Needs and Integration Options
  Information and Computation Structures for the Smart Grid
- Networked Information Gathering and Fusion of PMU Measurements

TOPIC: Grid Enablers of Sustainable Energy Systems (Leader: Jim McCalley, Iowa State University)

White Papers

- Primary and Secondary Control for High Penetration Renewables
- Standards Associated with Power System Dynamics
- Future Grid: The Environment
- High Capacity Interregional Transmission Design: Benefits, Risks and Possible Paths Forward
- Distributed and Centralized Generation

Descriptions of Future Grid Initiative Thrust Area Tasks and Broad Analysis White Papers

Gallery Walk for Thrust Areas 1-3

1. **Thrust Area: Electric Energy Challenges of the Future**
   Lead: Gerald Heydt, Arizona State University

   - ***Robust and Dynamic Reserve Requirements***
     [Workshop Poster, PDF 603KB | Send Comments]
     Kory Hedman, Arizona State University

     This research aims to develop a systematic framework for the determination of operational reserve levels and reserve zones, as opposed to the use of ad-hoc, rule of thumb methods. Through the development of robust and dynamic reserve requirements, system reliability and operational efficiency will be improved. Furthermore, this research will also investigate the determination of reserve requirements for systems with high levels of variable renewable resources.

   - ***Integrating Transmission and Distribution Engineering Eventualities***
     [Workshop Poster, PDF 452KB | Send Comments]
     Gerald Heydt, Arizona State University

     This task relates to robust design and planning of the electric power grid. In design and planning, innovative methods of transmission and distribution engineering are reviewed in the context of 'what if ... ' scenarios which may stress the grid. Innovative technologies include new materials for transmission and distribution applications; HVDC designs; energy storage; wide area instrumentation; and applications of solid state technologies.

   - ***A National Transmission Overlay***
     [Workshop Poster, PDF 1.35MB | Send Comments]
     Jim McCalley, Iowa State University. Collaborator: Dionysios Aliprantis, Iowa State University.

     The objective of this work is to develop a design process for a robust national transmission overlay that facilitates the growth of wind, solar, nuclear, geothermal, clean-coal, natural gas, and other low-CO2 emitting generation technologies over the next 40 years. We will also provide a summary of recommended transmission overlay designs for several futures and robustness analysis showing performance of each design under various futures, including high inland wind/solar, high off-shore (wind/ocean), high geothermal, high nuclear, high clean-coal, high natural gas, and high distributed generation.

   - ***Wide Area Control Systems***
     [Workshop Poster, PDF 603KB | Send Comments]
     Mani Venkatasubramanian, Washington State University

     We need to rethink all of traditional controls AGC, voltage control, PSS to bring them up to speed with emerging technology such as near real-time wide-area dynamic state estimation and so they can handle unpredictable complex dynamic responses of large penetrations of renewable power sources in the future power system. We need new control paradigms on how next generation wide-area controls can be designed by utilizing wide-area real-time synchrophasor measurements that will be communicating with each other in a NASPInet like infrastructure. In the uncertain operating environments of the future with rapidly changing power-flows and with large numbers of diverse power electronic equipment, the complexity of operational reliability problems will force us to design wide-area controls that are designed and implemented in real-time for power system conditions at that time. This task addresses the formulation of such controls as well as specific controls strategies for mitigating voltage stability, oscillatory stability and angle stability issues in the new framework.

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

Lead: Anjan Bose, Washington State University

- ***Requirements for Hierarchical Coordinated Control and Protection of the Smart Grid***
  [Workshop Poster, PDF 158KB | Send Comments]
  Anjan Bose, Washington State University

  The main objective is to define the overall concept for hierarchical coordinated control and protection of the smart grid. Although individual control or protection schemes have been pro-posed and developed to aid in solving particular problems, there is yet no clear picture of the overall set of controls and protection that can aid the smart grid.

- ***Hierarchical Coordinated Control of Wind Energy Resources and Storage for Electromechanical Stability Enhancement of the Grid***
  [Workshop Poster, PDF 456KB | Send Comments]
  Chris DeMarco, University of Wisconsin-Madison. Collaborators: Bernard C. Lesieutre and Yehui Han, University of Wisconsin-Madison.

  This project will develop control methodologies and designs that optimally mix non-synchronous, variable generation sources such as wind and photovoltaic, with electrical energy storage resources, such as batteries, supercapacitors, and flywheels. It will 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.

- ***Hierarchical Coordinated Protection of the Smart Grid with High Penetration of Renewable Resources***
  [Workshop Poster, PDF 772KB | Send Comments]
  Mladen Kezunovic, Texas A&M University

  New protection paradigm for smart grids is proposed. It takes into account two seemingly unrelated concepts (decentralized component protection and centralized wide area protection) and creates a new integrated concept (hierarchically coordinated protection). The objective is to define the three hierarchical coordinated layers: predictive protection, inherently adaptive protection, and corrective protection.

3. Thrust Area: Renewable Energy Integration and the Impact of Carbon Regulation on the Electric Grid

Lead: Shmuel Oren, University of California at Berkeley

- ***Mitigating Renewables Intermittency Through Non-Disruptive Distributed Load Control***
  [Workshop Poster, PDF 1.69MB | Send Comments]
  Duncan Callaway, University of California at Berkeley

  The primary objectives of this task are: 1) To understand the potential for demand side flexibility to support variable and uncertain production from renewable sources.
  2) Develop modeling and control strategies that preserve end-use function while delivering systemic benefits. 3) Develop strategies to work within the current and future constraints of grid IT infrastructure.

- ***Probabilistic Simulation Methodology for Evaluating the Impacts of Renewable Intermittency on Operations and Planning***
  [Workshop Poster, PDF 495KB | Send Comments]
  George Gross, University of Illinois at Urbana/Champaign. Collaborator: Alejandro Dominguez-Garcia, University of Illinois at Urbana/Champaign.

  The objective of this task is the development of a computationally tractable approach that can quantify, over longer-term periods, the variable effects of economics, reliability, environmental impacts of power systems with integrated time-dependent resources. Such resources include demand response, renewable solar and wind and utility-scale storage resources. The proposed simulation approach captures the time-dependent resource utilization in the day-ahead transmission-constrained markets with the explicit representation of uncertainty and evaluates all the variable effect metrics of interest.

- ***Planning and Market Design for Using Dispatchable Loads to Meet Renewable Portfolio Standards and Emissions Reduction Targets***
  [Workshop Poster, PDF 495KB | Send Comments]
  Tim Mount, Cornell University. Collaborators: K. Max Zhang and Robert J. Thomas, Cornell University.

  The objectives of this task are to 1) develop a unifying framework to characterize different types of dispatchable loads, 2) determine the engineering and economic feasibility of aggregating dispatchable loads to provide systems services (including frequency response, frequency regulation, load/generation following), and 3) design a market that provides the correct incentives for managing the systems services provided by energy aggregators.

- ***Coupling Renewable Energy Supply with Deferrable Demand***
  [Workshop Poster, PDF 88KB | Send Comments]
  Shmuel Oren, University of California at Berkeley

  This task focuses on exploiting demand side flexibility as a hedge against wind power uncertainty. The project will explore the option of load control through direct physical or telemetric coupling of renewable generators with deferrable loads as a means of mitigating the adverse effect of intermittency in wind generation.

Gallery Walk for Broad Analysis Topics

Broad Analysis Topic: The Information Hierarchy for the Future Grid

Lead: Peter Sauer, University of Illinois at Urbana/Champaign

- ***Cyber-Physical Systems Security for the Smart Grid***
  [Workshop Poster, PDF 763KB | Send Comments]
  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.

  This white paper will focus on identifying a comprehensive set of cyber security challenges and the need for security at multiple levels of the cyber-physical power system, namely, information security, ICT infrastructure security, and application-level security. It will identify cyber security research issues beyond the tradition IT security issues. In particular, the white paper will clearly identify research issues such as: (i) cyber attack risk modeling and risk mitigation, (ii) attack-resilient monitoring, protection and control algorithms, (iii) defense against coordinated cyber attacks, (iv) AMI infrastructure security, (v) trust management and attack attributions, and (vi) simulation models, data sets, testbed evaluations. The white paper will articulate the need for going beyond (N-1) contingency criteria to deal with coordinated cyber attacks. Also, it will articulate the inadequacy of traditional models and algorithms (that are robust against random naturally occurring faults) to deal with malicious cyber attacks, and hence the need for development novel models and attack-resilient algorithms across generation, transmission, and distribution systems. Finally, the linkage between attack deterrence, prevention, detection, mitigation, and attribution will be identified.

- ***AMI: Communication Needs and Integration Options***
  [Workshop Poster, PDF 831KB | Send Comments]
  Vinod Namboodiri, Wichita State University. Collaborator: Visvakumar Aravinthan and Ward Jewell, Wichita State University. Reviewer: Eve Schooler, Intel.

  This white paper analyzes the current state of communications for the advanced metering infrastructure (AMI) and provides information future actions needed to enable consumer participation in the smart grid. It describes the motivation for AMI, surveys the current state of the art and deployment status, and points out technical, policy, and other challenges in moving forward. This white paper focuses on the technical aspects and capabilities of communication technologies being considered for AMI and what future research needs to be done to hasten the realization of benefits attributed to the AMI application scenario.

- ***Information and Computation Structures for the Smart Grid***
  [Workshop Poster, PDF 108KB | Send Comments]
  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.

  This white paper examines information and computation architectures for future smart grids. It focuses on three aspects of future smart grid: the computation, communication, and networking architecture, the space-time information hierarchy, and cyber-physical security and reliability. Challenges and open research directions are identified.

- ***Networked Information Gathering and Fusion of PMU Measurements***
  [Workshop Poster, PDF 300KB | Send Comments]
  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.

  The synchrophasor technology is emerging as an enabling technology to facilitate both information interaction as well as energy interaction between providers and customers, and help revolutionize the power system. In particular, it is critical to ensure reliable and secure communication systems for synchrophasor data. In this report, we identify a few important problems in this fundamental building block in the smart grid.

Broad Analysis Topic: Grid Enablers of Sustainable Energy Systems

Lead: Jim McCalley, Iowa State University

- ***Primary and Secondary Control for High Penetration Renewables***
  [Workshop Poster, PDF 88KB | Send Comments]
  Chris DeMarco, University of Wisconsin-Madison. Collaborators: Bernard Lesieutre and Yehui Han, University of Wisconsin-Madison. Reviewer: Jim Gronquist, BPA.

  The growing penetration of renewable generation technologies coupled to the grid through power electronic interfaces, and the potential for future growth of electrical storage similarly coupled through power electronics, raise new opportunities and challenges for primary and secondary control in the electric power system. In this context, the objective of this paper is to fundamentally re-examine the long-standing premises of primary and secondary control in the grid. We also consider both the capabilities of the new "control actuators" available to us (i.e., renewable generation, supplemented by power electronic coupled storage), as well as the wider system objectives to be achieved by the control. We believe that this approach will offer solutions far superior to simply trying to force new generation and storage technologies to behave like the old.

- ***Standards Associated with Power System Dynamics***
  [Workshop Poster, PDF 89KB | Send Comments]
  Marija Ilic, Carnegie Mellon University. Collaborators: Ian Dobson, University of Wisconsin-Madison; Gabriella Hug, Carnegie Mellon University. Reviewer: Mahendra Patel, PJM.

  In this white paper we will first review the standards currently used by the industry to ensure stable operations and acceptable quality of service. We will next pose the problem of designing specifications and protocols for enabling more flexible management of diverse energy resources without endangering system stability. The role of protection, control and communications in implementing stable operations in future electric energy systems operated in highly uncertain environment will be particularly assessed. Examples of open questions and possible future solutions will be provided in this document.

- ***Future Grid: The Environment***
  [Workshop Poster, PDF 1.54MB | Send Comments]
  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; Janos Toth, BC Hydro; Lisa Beard, Quanta

  The objective of this paper is to present the significant near- and long-term unresolved environmental issues relevant to the electric energy industry, and to summarize the technologies that will help resolve them. The issues are those that the industry will need to address in the coming years. The industry will face regulations on most of these issues and it is important that those regulations be effective, actually mitigating the environmental issues they were intended to address. Careful research and consideration of the environmental needs and the goals of regulations is needed before they are put into place.

- ***High Capacity Interregional Transmission Design: Benefits, Risks and Possible Paths Forward***
  [Workshop Poster, PDF 582KB | Send Comments]
  Jim McCalley, Iowa State University. Collaborator: Jim Bushnell, University of California, Davis. Reviewers: Dale Osborn, MISO; Doug McClaughlin, Southern Co.

  For renewables, the levelized cost of energy production can double or even triple as one moves from one part of the country to another. Furthermore, unlike coal, natural gas, and uranium which may be moved electrically or in other ways (rail and truck, or for natural gas, by pipeline), the only way to move renewable energy is by electric transmission. These two attributes of renewables, the heavy influence of location on their economic viability, and their complete dependence on electric transmission for energy transfer, increases the need for interregional transmission in future scenarios where renewables comprise an increased percentage in the national generation portfolio. We define a national transmission overlay as a high capacity, multiregional transmission grid that spans all three interconnections, designed as a single integrated system to provide economic and environmental benefits to the nation. The objective of this paper is to identify benefits to building a national transmission overlay, to lay out essential elements to facilitate continued dialogue on this topic, and to frame possible paths by which it could be realized. A preliminary study illustrated that a national transmission overlay, under high renewable penetration and low CO_2 emissions, could result in a significant cost-reduction over a 40-year period, while increasing infrastructure resilience and flexibility.

- ***Distributed and Centralized Generation***
  [Workshop Poster, PDF 443KB | Send Comments]
  James Momoh, Howard University. Collaborator: Sakis Meliopoulos, Georgia Institute of Technology. Reviewer: Bob Saint, National Rural Electric Cooperative Association.

  The objective of this white paper is to evaluate the relative benefits and weaknesses of centralized generation and distributed generation in the future electric grid interface.

Gallery Walk for Thrust Areas 4-6

4. Thrust Area: Workforce Development

Lead: Chanan Singh, Texas A&M University

- ***PSERC Academy: A Virtual Library of Thousands of Short Videos***
  [Workshop Poster, PDF 261KB | Send Comments]
  Raja Ayyanar, Arizona State University

  The objective is to create an online library of approximately 20-minute videos on various topics in sustainable energy systems, smart grid and power engineering with the vision of eventually developing several hundreds or even thousands of such videos that will serve as a major online reference source. The videos will have power-point lectures with audio narration, interactive simulations, animations, movie clips, and the library will also feature online exercises and feedback. Videos will be made available through a dedicated website and also through YouTube. Modules on power electronics and wind energy are under development presently. The library is planned to go live around March 2012.

- ***A Course in Energy Economics***
  [Workshop Poster, PDF 142KB | Send Comments]
  James Bushnell, University of California, Berkeley

  This task is developing curricula in energy economics focused at three levels, masters level for energy professionals, doctoral level for future energy researchers, and short-courses for practitioners currently working in the energy industries. Emerging technologies imply that the electricity sector will become increasingly integrated with other energy sectors, both directly through substitution such as with electric vehicles, and indirectly through environmental and climate policy. Thus these courses will present the economics of the electricity industry in the context of its role within the broader energy sector.

- ***Synchrophasor Education for Students and Professionals***
  [Workshop Poster, PDF 106KB | Send Comments]
  Mladen Kezunovic, Texas A&M University. Collaborators: Sakis Meliopoulos, Georgia Institute of Technology; Vijay Vittal, Arizona State University; Mani Venkatasubramanian, Washington State University; Alex Sprintson, Texas A&M University

  The effort is focused on educational efforts related to synchrophasors and their applications. The goals is to reach academic, as well as industrial audiences. The objective is to illustrate the benefits through some recent application developments. The experiences will be summarized in a book to be widely available for academia and industry to use.

- ***Energy Processing for Smart Grid Technology***
  [Workshop Poster, PDF 117KB | Send Comments]
  James Momoh, Howard University. Collaborator: Peter Bofah, Howard University.

  This thrust is aimed at enhancing power modules in the university in two major broad topics critical to the Nation's objective of attaining energy independence. These two areas include: smart grid fundamentals and applications; and integration of renewable energy resources into the bulk power system.

- ***Comprehensive Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid***
  [Workshop Poster, PDF 296KB | Send Comments]
  Chanan Singh, Texas A&M University

  Because of uncertainty and complexity of the future grid, reliability will be an important issue. This task will develop presentations for two courses for education of power system reliability, one semester long and the other a short course. The semester long course will be focused more on university students and the short course will be more for practicing professionals.

- ***Course Development - Critical Infrastructure Security: The Emerging Smart Grid***
  [Workshop Poster, PDF 424KB | Send Comments]
  Anurag Srivastava, Washington State University. Collaborators: Carl Hauser, David Bakken and M.S. Kim, Washington State University.

  The course will provide the necessary background for engineering students to work on problems, issues and cyber-security challenges associated with the smart grid. The target audience will be senior undergraduate students and graduate students with electrical engineering and computer science backgrounds in addition to an online offering to industry.

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

Lead: Santiago Grijalva, Georgia Institute of Technology

- ***Real-Time PMU-Based Tools for Monitoring Operational Reliability***
  [Workshop Poster, PDF 1.24MB | Send Comments]
  Alejandro D. Dominguez-Garcia, University of Illinois at Urbana-Champaign. Collaborator: Peter Sauer, University of Illinois at Urbana-Champaign.

  The objective of this project is to develop real-time PMU-based tools for helping operators with operational reliability issues. In particular, this project will address the following problems: i) system loadability condition monitoring, ii) transient stability analysis, and iii) Real-time line model and equivalent parameter updating.

- ***Decision-Making Framework for the Future Grid***
  [Workshop Poster, PDF 686KB | Send Comments]
  Santiago Grijalva, Georgia Institute of Technology

  This project develops and demonstrates a decision-making framework for the future grid that: a) Ensures that the goals of the future grid can be met, b) Covers all relevant spatial and temporal scales, c) Addresses decision complexity through layered abstractions, and d) Uncovers the gaps and technological needs for the industry transformation.

- ***Hierarchical Probabilistic Coordination and Optimization of DERs and Smart Appliances***
  [Workshop Poster, PDF 302KB | Send Comments]
  Sakis Meliopoulos, Georgia Institute of Technology

  This project addresses the computational challenges in coordinating and optimizing the operation of utility assets and distributed and renewable assets at all levels of the electric power grid, i.e., distribution, substation and bulk system. It develops and demonstrates an infrastructure and a hierarchical optimization framework that coordinates the instant by instant utilization of assets as well as planning the operation of assets. Business case analysis illustrates substantial benefits that clearly justify the investment requirements for this system.

- ***Computational Issues of Optimization for Planning***
  [Workshop Poster, PDF 479KB | Send Comments]
  Sarah Ryan, Iowa State University

  The aim is to develop improved computational methods for long-term resource planning under uncertainty. In the first year, efforts are focused on further developing, implementing, and testing a method to reduce the number of scenarios considered in stochastic programming when implemented with a rolling time horizon. Compared to a common scenario reduction heuristic, the new method finds a very similar solution in a fraction of the computation time.

6. Thrust Area: Engineering Resilient Cyber-Physical Systems

Lead: Tom Overbye, University of Illinois at Urbana/Champaign

- ***Operational and Planning Considerations for Resiliency***
  [Workshop Poster, PDF 1.83MB | Send Comments]
  Ian Dobson, Iowa State University

  The objective is to engineer power transmission system resilience to cascading failure blackouts. To do this, we need to quantify the propagation of outages in cascading blackouts and then show approaches to monitoring and mitigation of cascading risk.

- ***Resiliency with Respect to Low Frequency, High Consequence Events***
  [Workshop Poster, PDF 408KB | Send Comments]
  Tom Overbye, University of Illinois at Urbana/Champaign

  The overall objective is to develop techniques to improve the resiliency of the electric grid with respect to low frequency, high consequence events. The current focus is on the development of algorithms to assess the impact of geomagnetically induced currents (GICs) on the power grid. The developed algorithms are in the process of being commercialized.

- ***Improved Power Grid Resiliency through Interactive System Control***
  [Workshop Poster, PDF 105KB | Send Comments]
  Vijay Vittal, Arizona State University

  The objective is to identify wide area signals and appropriately design control systems such that the system as a whole continues to work reliably in the event that any wide area signal is lost.

Discussion Questions

After keynote address by Vijay Vittal:

- What will be the key new capabilities of the future grid?
- What are the technical challenges in providing those capabilities?

For the Thrust Area panels:

- What are the thrust areas that you are leading? Why are they important for shaping the future grid that enables renewable generation technologies?
- What are the fundamental building blocks of the future grid in the thrust areas that you are leading?
- Are the building blocks themselves dependent on the type, location and size of generation, energy storage, demand-side resources and overall demand for electricity in the future? If so, how?
- What are the challenges in developing those building blocks?

For the Broad Analysis panel:

- The Future Grid Initiative has six Thrust Areas in which a range of research tasks are being conducted to work on building blocks of the future grid. What distinguishes the Broad Analysis efforts from those tasks? What are the objectives of the Broad Analysis efforts?
- What is the plan for the use and dissemination of the white papers from the Broad Analysis effort? What is the schedule?
- A Future Grid Initiative Forum is scheduled for June 27-28. What is the objective of the Forum and who is invited to attend?
- Tell us more about the two areas in the Broad Analysis efforts: “Grid Enablers of Sustainable Energy Systems” and “The Information Hierarchy for the Future Grid”. Why are they important in designing the future grid?
- What are the specific topics for the white papers within each area? How do they relate to shaping the future grid that enables sustainable energy systems?

For the final discussion:

- What desired but not yet conceived “game-changing” technologies would significantly affect the design of the future grid to enable sustainable energy systems?
- What “game-changing” technologies are already on the radar screen?
- What are the current directions for scientific discovery that could make a significant difference in the building blocks of the future grid?
- What new ideas have come to mind over the course of the day regarding the shaping of the future grid to enable sustainable energy systems?
- Transmission siting and cost recovery issues aside, what do you think are the major challenges in designing the future grid?

Future Grid Initiative

Enabling renewable energy resources

Vijay Vittal
Director, Power Systems Engineering Research Center
Professor, Arizona State University

Workshop objectives

- PSERC has embarked on an exciting and challenging research initiative to address national energy challenges associated with the evolution of the electric energy grid. The initiative is funded by **DOE's Office of Electricity Delivery and Energy Reliability**
- A critical component of this initiative is an attempt to encapsulate the engineering building blocks required for the future grid architecture to support an increased penetration of renewable resources – **wind and solar**

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Workshop objectives

- The PSERC collaboratory has formulated an approach to tackle this problem taking into account (1) research priorities identified through an extensive interactive process and (2) the technical expertise available to PSERC
- The primary objective of this workshop is to present the proposed approach and to listen to your feedback and comments

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Workshop objectives

1. Stimulate discussion on the proposed solution approach related to the building blocks identified by the thrust areas in the initiative
2. Critique the specific technical aspects of the tasks associated with each thrust area
3. Provide feedback and comments on the thrust area tasks and on the broad analysis topics and white papers

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National energy challenges

- Energy independence, affordability
- Energy reliability, security, efficiency
- Economic development and job security
- Environmental concerns and impact of climate change
- Aging infrastructure, technology change, workforce needs

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Range of energy solution options

Renewable resource technologies
Energy efficiency
Demand resources
Market solutions
Nuclear energy technologies
Develop domestic resources
Improved asset utilization
Electric transportation
Carbon capture and storage
Energy storage

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Overarching issues

- Given this set of national energy solutions, how does the electric grid infrastructure **evolve** to **accommodate** these solutions?
- What elements constitute the **building blocks** of this **evolution**?
- Given the **large capital investment** in the **legacy grid**, what steps are required to **seamlessly transition** from the legacy grid to accommodate the elements of the proposed building blocks?

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Critical elements of the evolution

Changing Generation Supply Mix

- T&D additions and changes
- Energy storage
- Enhanced control/communications
- Handling increased uncertainty

Needed evolution/ changes to support this element

Drivers of the evolution/ changes

- Renewable resources
- Retirement of aging conventional plants
- Questions regarding nuclear addition
- Carbon regulation

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Critical elements of the evolution

PSERC

Demand Transformation

- Expanding digital economy
- Power quality and reliability needs
- Demand flexibility
- Electric vehicles

Needed evolution/ changes to support this element

Drivers of the evolution/ changes

- Economic constraints
- Changing customer needs
- Green awareness and demand
- Need for higher reliability and efficiency

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Critical elements of the evolution

PSERC

Complexity of Grid

- Expanding footprint
- Impact of markets
- Tighter operating limits
- Greater reliance on communication and control
- Need for advanced analytical tools

Needed evolution/ changes to support this element

Drivers of the evolution/ changes

- Spatio-temporal constraints
- Computational complexity
- Stochastic nature of variables
- Need to contain cost

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Critical elements of the evolution

PSERC

Infrastructure Vulnerability

- Reduce footprint of disruptions
- Reliability of communication and control
- Reduced duration of disruptions
- Guard against malicious attacks

Needed evolution/ changes to support this element

Drivers of the evolution/ changes

- Shortage of skilled personnel
- Inadequate analytical tools
- Interdependence of cyber-physical systems

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Key requirements based on NERC operating and planning criteria

PSERC

1. **Balance power generation and demand continuously**
2. **Balance reactive power supply and demand to maintain scheduled voltages**
3. **Monitor flows over transmission lines and other facilities to ensure that thermal (heating) limits are not exceeded**
4. **Keep the system in a stable condition**

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Key requirements based on NERC operating and planning criteria

5. **Operate the system so that it remains in a reliable condition even if a contingency occurs, such as the loss of a key generator or transmission facility (the "*N*-1 criterion")**
6. **Plan, design, and maintain the system to operate reliably**
7. **Prepare for emergencies**

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Synthesis of the building blocks in this initiative

- **Plan** and **operate** grid with increased penetration of **renewable resources** while meeting any **carbon regulation requirements**
- **Design grid architecture** to support **renewable penetration** and **transformation of demand as a resource**
- Manage increased dependence on **control, communication** and **cyber-physical systems** to handle **grid complexity**

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Synthesis of the building blocks in this initiative

- **Create analytical tools** to account for increased **variability** and **stochastic** nature of elements
- **Prepare needed workforce** training

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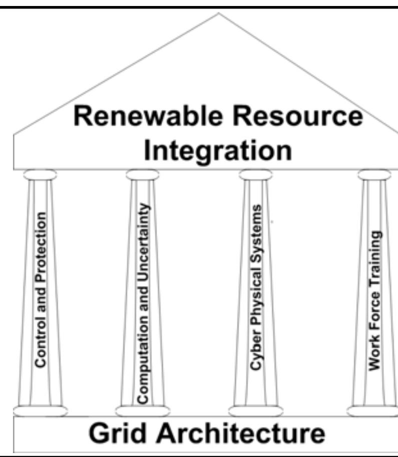

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Questions for Discussion

- What will be the key new capabilities of the future grid?
- What are the technical challenges in providing those capabilities?

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