Power Systems Engineering Research Center

The Future Grid to Enable Sustainable Energy Systems: An Initiative of the Power Systems Engineering Research Center

Support Provided by the U.S. Department of Energy

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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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Executive Overview

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 as shown in Figure 1. 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.

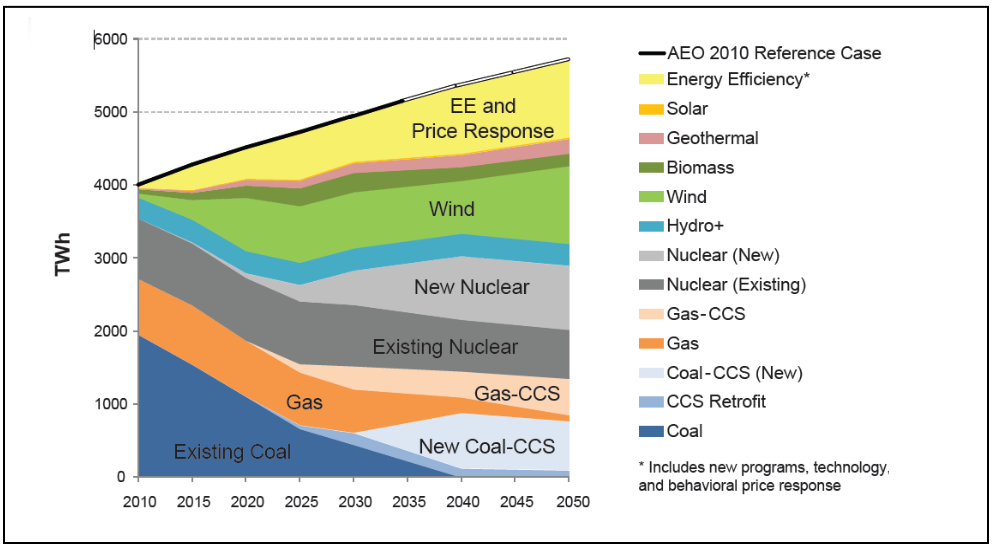

Figure 1: EPRI's PRISM 2.0 Modeling of Energy Resources for Rising Carbon Dioxide Emission Prices [1]

[1] Bryan Hannegan,"Prism 2.0: Preliminary Insights from EPRI's Regional Model." Presentation at the EPRI 2010 Summer Seminar. August 2, 2010.

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 green coloring 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	■	■	■			

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

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