Power Systems Engineering Research Center

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ABSTRACT

This paper provides an overview of the Power Systems Engineering Research Center (PSERC), a National Science Foundation Industry/University Cooperative Research Center. The PSERC mission is to produce innovative and effective solutions to challenges faced in the restructuring of the electric power business. There are eleven university members, with forty researchers and their students involved in multidisciplinary research projects. Projects are collaborative across universities and invite industry involvement from the thirty industrial sponsors. Research focuses on three stems: markets, transmission and distribution technologies, and systems. Completed and ongoing projects in each of these stems will be outlined.

INTRODUCTION

Current electric-power systems are vertically integrated and assume the responsibility for power supply from generation to load. They are configured to deliver electric energy produced by a mix of generation to the various loads by means of complex interconnected transmission and distribution systems. The individual systems are generally inflexible with respect to accommodating rapid changes in load, generation, and/or delivery conditions, or even rapidly changing economic, environmental, or regulatory policy changes. While present-day system operation may be designed for "least cost of electricity," based on the slowly changing environment of the past, it is not in a good position to enter the fast-paced competitive environment of the future. Therefore it is important for the industry to undertake a managed re-design of the Nation's power system. The alternative is to accept unmanaged change and to operate the system in ways that were not anticipated by the original designers.

Examples of the challenges facing industry include:

? Increasing reliability demands
? Aging infrastructure
? Increasing loading of components
? Increasing availability of operational data
? More dynamic power flows and increasing use of distributed generation
? Declining ability to remove components from service for maintenance.

The goal of the Power Systems Engineering Research Center (PSERC) is to create the necessary tools and models to aid in the technical design of a future high-performance electric-power system; a system that will be more efficient, more responsive, and more environmentally acceptable than the one that is operating today. This new design will enhance U.S. competitiveness by improving economic efficiency in electric energy supply, and by providing ideas for the engineering of the restructured power system.

Future power systems must have the ability to quickly reconfigure network flows in response to technical and economic pressures. This requirement means that the full capacity of every line in the system must be available at any and every instant in order to realize a substantial economic benefit. In order to achieve this high-performance level, innovative applications of emerging concepts in communications, computing, and power electronics will be required. The large-scale deployment of these high-speed technologies pose unique problems for power-system engineers. For example, little is known about control of power flow in this new fast-response regime. System complexity, however, indicates that substantial problems will be encountered when implementation of these novel techniques is attempted. Innovative solutions to such problems will require the expertise of non-traditional power-system engineers and scientists. Therefore, the vision for PSERC includes the education of a new breed of power engineer to ensure the training of the talented people needed to design and manage the new system. The PSERC multi-institutional research program will provide an opportunity to attract and support high-caliber engineering students to research and careers in the power industry. A single school could not hope to support a program of this breadth and scope. This paper provides an overview of this Center.

MISSION AND OBJECTIVES

PSERC is a National Science Foundation Industry/University Cooperative Research Center addressing challenges in the new electric power industry as it restructures to a competitive business environment. Finding innovative and efficient solutions to those challenges requires an unprecedented level of expertise, communication, and cooperation between university and industry. Through collaboration, PSERC:

- ? seeks innovative solutions to challenges facing its members and the industry as a whole as the industry evolves toward more decentralized, market-based decision-making
- ? partners with industry to develop research projects to resolve industry problems
- ? uses experienced and creative faculty who can provide objective perspectives on possible solutions to those challenges
- ? leverages industry support to resolve common problems
- ? uses multidisciplinary skills and expertise across eleven universities through collaborative research on projects
- ? provides opportunities for commercialization of research results
- ? prepares current and future professionals for the new power industry
- ? provides access to high quality students at the graduate and undergraduate levels
- ? encourages students to consider professions in the power industry
- ? sponsors short courses, workshops and other professional development education opportunities
- ? provides opportunities for direct interactions between industry and researchers
- ? stimulates productive interchange of ideas among university and industry professionals
- ? hosts industry-university meetings at which research needs and results are discussed
- ? conducts web-based forums involving industry and university students on current relevant topics
- ? facilitates communication with leading university researchers in the power industry

In summary, PSERC is a research and educational entity designed to produce a new breed of student and perform long-term research relevant to the electric power industry.

The National Science Foundation recently renewed PSERC's grant from the Industry/University Cooperative Research Center Program for five more years. PSERC first joined the program in 1996. Dr. Alex Schwarzkopf, Program Director of the I/UCRC program, states that "Industry–University collaboration is at the heart of the I/UCRC program. PSERC's commitment to collaboration using many universities as the research base is essential to meeting the wide-ranging challenges facing the electric power industry."

NSF's I/UCRC program promotes "win-win" partnerships that strengthen the ability of universities to conduct high quality and relevant research, and the ability of industry members to meet their business objectives effectively. Some fifty other Centers in the I/UCRC program focus on a wide array of competitive industries. PSERC is the only Center in power systems. It is also the largest multi-university Center.

PSERC AS A MULTI-UNIVERSITY COLLABORATORY

PSERC is a multi-university center, involving the following eleven universities and site directors:

- ? Arizona State University (Prof. G.T. Heydt)
- ? University of California at Berkeley (Prof. Shmuel S. Oren)
- ? Carnegie Mellon University (Prof. Sarosh Talukdar)
- ? Colorado School of Mines (Prof. Rahmat Shoureshi)
- ? Cornell University (Prof. Robert J. Thomas)
- ? Georgia Institute of Technology (Prof. A.P. Sakis Meliopoulos)(
- ? University of Illinois at Urbana-Champaign (Prof. Peter W. Sauer)
- ? Iowa State University (Prof. Vijay Vittal)
- ? Texas A&M University (Prof. Mladen Kezunovic)
- ? Washington State University (Prof. Anjan Bose)
- ? University of Wisconsin-Madison (Prof. Robert H. Lasseter)

PSERC was organized as a multi-university center for several reasons. First, there is insufficient expertise at any one school to comprehensively address the challenges of the new electric power industry. PSERC academic researchers specialize in power systems, applied mathematics, non-linear systems, power electronics, control theory, computing, operations research, economics, industrial organization and public policy. Restructuring requires the marriage of economics and engineering, thus calling for greater multidisciplinary work than ever before in the industry. And no single school can afford the breadth of expertise because of limited resources. Another reason why multi-university appealing is that industry itself is geographically dispersed yet the interests are increasingly similar, such as in market designs that are regional in nature.

PSERC refers to itself as a "collaboratory" or an institution for which collaboration is an essential requirement. Collaboration is not easy and itis not a

usual part of the university culture. However, PSERC only supports projects in which there is inter-university collaboration – it's a rule. Industry members are a part of that collaboration as well, serving both on the stem committees and on the project teams.

There are a number of reasons why collaboration is essential. Collaboration:

- Captures intellectual synergies across universities, researchers, and industry
- Builds value from participation in PSERC, whether by universities or industry
- Facilitates efficient resource sharing.
- Collaboration is achieved through an organizational structure and policies that require collaboration, through electronic communications tools such as listserves and a website that support collaboration, through retreats that bring the diverse participants in PSERC together once a year, through Internet Seminars that provide communication of ideas and research activities across universities and industry participants, and through newsletters to bring PSERC news to all participants.

RESEARCH PROGRAM

Industry restructuring and technology change is creating new challenges for the operations, security and reliability of the power system, for the physical and institutional structures, and for delivery of economical and environmentally acceptable electricity services. PSERC's research program focus is on helping the next generation electric power system evolve into a competitive, high-performance component of the nation's infrastructure. Its research program is divided into three research stems.

Stem 1: Markets

The electric power industry is in transition toward a market-oriented structure with decentralized decision-making by a wide-ranging group of market participants. The research under this stem emphasizes the design and analysis of market mechanisms, computational tools and institutions that facilitate efficient coordination, investment, and operations while recognizing the economic and technical characteristics of power systems. Market design research includes verification in advance of the implementation and validation after implementation to provide feedback for market redesign when needed.

These general goals are pursued by means of the following methodological approaches that complement and support each other:

- *Analytical methods* that can be further classified into:
- *Theoretical analysis* focusing on conceptual abstract modeling and analysis, employing techniques of operations research, systems analysis, microeconomics, stochastic modeling, game theory and auction theory.
- *Empirical analysis* focusing on interpretation of empirical data and on estimation and validation of theoretical models using econometric methods, financial engineering approaches, statistical analysis and data mining.
- *Computational methods* employing numerical methods and agent-based models to simulate and forecast market outcomes under realistic modeling of the electric power system in conjunction with behavioral models of economic agents that control various aspects of the system and interact in the marketplace.
- *Experimental economic* approaches employing controlled laboratory experiments with live and artificial agents in order to explore decision patterns under alternative rules and system conditions, and to test behavioral assumptions upon which such rules are founded.

The Markets Stem is devoted to adapting, extending and applying the above methodological approaches for the purpose of advancing our understanding and developing solutions that address a variety of problem areas in current market designs such as:

- Market verification
  This area is concerned with verifying that market rules achieve their designed objectives including market efficiency and system reliability goals.

- Market-driven transmission adequacy
  This area focuses on mechanisms and organizational structure that will achieve operational goals, induce efficient planning, and incentivize investment and innovation in the transmission infrastructure.`

- Active load participation
  This area addresses the role of active load participation in achieving market efficiency, system reliability and risk management goals. It also explores market mechanisms and technological means that will facilitate such participation.

Stem 2: Transmission and Distribution Technologies

The power delivery infrastructure is critical to achieving efficiency, safety, security and reliability in electricity supply. Potential improvements in this infrastructure could be achieved through innovations in software, hardware, materials, sensors, communications

and operating strategies. Therefore, a central goal of this research stem is the improvement of transmission and distribution systems through the application of technological advances. Research areas include:

- ? Advanced computational methods
- ? Advanced control concepts and new network configurations
- ? Power quality control and customer interfaces
- ? Power electronic s technologies
- ? Distributed resources and micro-grids
- ? Sensory data collection, communication and storage
- ? System protection, security enhancement, system diagnosis, and maintenance strategies

There are a number of areas that are receiving particular focus.

Substation Data Integration and Enhanced Functions: A key element in the electric power infrastructure is the transmission or distribution substation. To ensure reliability and to gain additional value, the assets must be managed in new ways using available data as well as expanded data sets. Opportunities exist to capture and better utilize presently available data from relays, DFRs, and other IEDs, to better monitor assets, locate faults, and perform new functions. Additional opportunities exist to improve sensors, communications, capture new information and present information in new ways to enhance the performance. Examples include: transformer loading; fault location and outage management; automated analysis of data coming from DFRs and other IEDs; and power quality; and new communication techniques (e.g. wireless, etc.).

Managing an Aging Infrastructure: The transmission infrastructure is aging and being stressed as loads have increased. New methods need to be developed to better assess the condition of assets, especially methods that can be used without taking the asset out of service. Additional study is needed aimed at understanding the impact of increased loading and aging of assets such as transformers, breakers, conductors, underground cable, etc. Examples: Life assessment; life extension; upgrading and re-rating; risk management and related maintenance strategies; advanced diagnostics, monitoring and maintenance; better understanding of failure and stress mechanisms; and maximizing the utilization of the existing infrastructure.

Distribution and Transmission Automation: Technology improvements and increasing need to better manage assets have facilitated the implementation of substation automation. The use of automation increases the availability of information and the ability to improve control over the system. However, more work is required to better manage the information and develop methods and algorithms to automate systems to improve system performance and reliability. Some research topics in T&D automation include: EMS and DMS; improved monitoring and diagnostics; automated fault assessment and outage management; advanced communication infrastructures for feeder automation; new DMS functions; power quality assessment, quantification and mitigation; and load control.

New Devices and Related Control Concepts: Opportunities exist to study the increasing amounts of available data and identify new phenomena that can lead to the development of new devices and operating practices. Universities have played a major role in the development of foundation theories that have led the industry to new devices and systems in the past. Additionally, Universities are positioned to view more broad issues impacting the power delivery industry. Examples of this research include: new fault current management (devices, strategies, and systems); new power device concepts; advanced power electronics devices; new sensors and related measurement system; Novel devices and controls for distributed resources; and electric storage devices and related control issues to meet varied business and system objectives

New Monitoring, Control and Protection Paradigms: Existing monitoring, control, and protection systems are driven by established practices that have been proven in the utility market. However, opportunities to evaluate new control or protection systems exist that leverage the availability or more information and new devices. Universities are positions to have a broad and unbiased view and may identify improved control and protection system. Some examples of this research are dynamic rating concepts; system-wide relaying and related coordination with control strategies; Integration of substation and feeder automation into EMS and DMS; advanced tools for testing and evaluation; customer focused energy delivery (energy needs from a customer prospective); innovative data mining and visualization approaches; and interactive customer/supplier load control and protection.

Stem 3: Systems

Restructuring is leading to large and complex operational entities (such as Independent System Operators or Regional Transmission Organizations), while small-scale, dispersed generation technologies are increasing their penetration in power systems. The

challenge is to develop new operations frameworks and approaches that will effectively cope with the growing complexity of a restructured industry. Systems research concentrates on all aspects of operation of complex, dynamic systems.

The goal of the Systems Stem research is to increase the utilization and reliability of the system via a balanced approach between basic and applied research. Topics for the research include:

? Very Large Scale Computational Methods including stability computations in large scale systems; state estimation for very large systems, single phase/three phase, and remote calibration; advanced computational tools for FTR/FGR/TLR/ATC/OPF; computational tools for power markets; large scale energy systems and their information flows
? Reliability/Economics/Risk/Maintenance including probabilistic security assessment; decision tools (n-k, risk based, benefits); reliability assessment/economics and uncertainty management; reliability/risk based decision processes; distribution system reliability
? Visualization/Animation including wide area operation visualization; system condition visualization; equipment status visualization; human factors testing
? Complex Systems including complex system interactions; response based wide area controls; hybrid system models

Leveraged Research Projects: Industrial members and NSF support is leveraged into other research initiatives, such as:

? Consortium for Electric Reliability Technology Solutions (CERTS), formed in 1998 to research, develop and commercialize new methods, tools and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structure. CERTS is conducting research for the U.S. Department of Energy's Transmission Reliability Program and for the California Energy Commission's Public Interest Energy Research program. PSERC faculty are working with researchers at Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories and Southern California Edison. In a current CERTS effort, several PSERC researchers are on the technical team advising the US DOE in its study of elements of the Administration's National Energy Policy related to transmission.
? By working with industry under the NSF Research Centers - Small Firms Collaborative R&D initiative, and with funding and advice from industrial members of PSERC, PSERC researchers been on a research team that has developed more accurate ways to compute the maximum power that can be transferred in power systems and to quickly estimating how this maximum power can be increased by adjusting power system controls. The researchers have also addressed the need for participants in power markets to understand limits to power transfers in power systems. They are transferring the technological developments about the new methods using an interactive calculator and tutorial that are available on the web at http://www.pserc.cornell.edu/tcc/.

Rationale for the Multi-Institutional Makeup of the Center

There are many dimensions to the PSERC vision including analytical, technical, regulatory, economic and educational. Some of the issues associated with certain dimensions are currently being attacked vigorously and others are being ignored. Some can be resolved quickly and others will take a substantial amount of time. However, one thing is clear: the quantity, composition and breadth of expertise needed to synchronously address all dimensions of the vision will not be found in any single university in the US. And, coordination between the Center, the current industry, and its new players is vital to achieving the vision. Therefore, a special collection of talent that can be mixed and matched to form unique teams is what is needed.

Both industry and university members of PSERC are eager to find a way to include other than full-member universities in our Center. As a result PSERC created the Research Partners Program. proposals for RP membership are peer reviewed by NSF in the same fashion that they are now peer reviewed for full membership in PSERC.

Industrial Members

As a National Science Foundation Industry/University Cooperative Research Center, PSERC partners with industry to identify research needs and directions arising from the restructuring electric power industry, and to collaborate in implementing research projects. Through PSERC, industrial members can contribute to advancing the knowledge needed to address the challenges facing the industry and to educating the students that will become the next generation of industry professionals.

PSERC provides its industrial members:

? Results of innovative research and early access to the research publications

- ? Opportunities for collaboration with researchers
- ? Means for attracting students to the industry and for recruiting students
- ? Business opportunities for commercialization of intellectual property
- ? Education and professional development opportunities such as through workshops, short courses and on-line seminars

Members join PSERC by signing a membership agreement with the Cornell University, the lead PSERC university. Annual fees are $40,000 for full members.

PSERC members include energy companies, government agencies, companies providing consulting and other technical support services, and associations. Recent new members include new organizations to the industry: ISOs (ISO New England and the New York ISO) and transmission companies (American Transmission Company). Current membership is given in Table I.

Table I: Current Industrial Members of PSERC

ABB	Alcatel
AEP	Allegheny Power
Alliant Energy	Alstom ESCA
American Transmission Company	Arizona Public Service
Bonneville Power Administration	Constellation Power Source
Electric Power Research Institute	Duke Energy
Exelon	Entergy
GE Power Systems	Florida Power & Light
Institute de Recherche d'Hydro-Quebec (IREQ)	Iberdrola
MidAmerican Energy	ISO - New England
New York ISO	Mitsubishi Electric
Omaha Public Power District	PowerWorld Corp.
NY State Electric & Gas	Salt River Project
Reliant Energy / HL&P	Tennessee Valley Authority
Steel Tube Institute of North America	TXU
Tri-State Generation and Transmission	Western Area Power Administration
U.S. Department of Energy	Wisconsin Electric Power Co.

ORGANIZATIONAL STRUCTURE

There are three central components to PSERC's organizational structure: Center Management comprised of the Director, Executive Director and Executive Committee; Industrial Advisory Board comprised of the industrial members of PSERC; and the Stem Committees. Figure 1 provides an overview the structure.

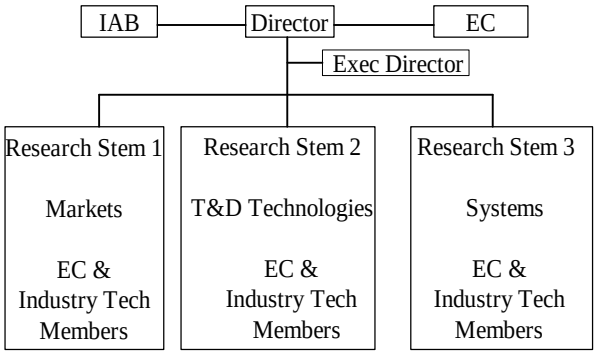

Figure 1. Organizational Structure

Center Management

The Director of PSERC is Robert J. Thomas who is at Cornell University. Cornell University is designated as the lead institution. The Director is responsible for overseeing all affairs of PSERC. A primary function of the Director is to represent the Center before its industrial members and the electric energy industry as a whole. The Director will also be responsible for recruiting and supervising Center staff at the lead university, ensuring smooth operation of the Center and the creation of a collaborative infrastructure. The Director is responsible for coordinating the assessment of the Center's quality through feedback from the IAB and the Evaluator. Executive Director, Dennis Ray, assists the Director in industry relations and Center management.

The Site Directors are PSERC's local campus representatives and spokesperson to the university faculty, staff and administration. The Director and Site Directors comprise PSERC's Executive Committee (EC). The EC is responsible for the day-to-day operation of the Center using the recommendations of the IAB. It recommends funding allocations to the Director. The EC is chaired by the PSERC Director.

Industrial Advisory Board

An Industrial Advisory Board provides the critical linkage between the industrial members and PSERC. The Board:

- ? Works with the universities to identify research and education needs
- ? Prioritizes projects and recommends project funding levels
- ? Reviews research results
- ? Addresses policy matters brought to it by the Director and Executive Committee of PSERC

The current officers of the Board are Dale Bradshaw (Chair), Tennessee Valley Authority and Mike Agee (Vice-Chair), Duke Energy.

The Industrial Advisory Board meets twice annually. At the meetings, industrial members meet researchers and students from the member universities, hear progress reports on research projects, engage in current issue discussions with researchers and other industrial members, and advance their professional development through tutorials.

Stem Committees

Each research stem has a committee that organizes the research activities of that stem. The stem committees facilitate the creation of research projects consistent with the PSERC research roadmap and work with project teams to achieve quality research products. Industrial members join researchers on the committees. The current stem committee chairs are:

? Markets: Shmuel Oren, University of California at Berkeley
? Transmission and Distribution Technologies: Mladen Kezunovic, Texas A&M University
? Systems: A. P. Meliopoulos, Georgia Institute of Technology

NEW PROJECTS

PSERC research projects will normally be initiated through the interaction of the stem committees with the EC, the IAB and the Director using the following process:

1. Stem leaders get input from the Director and the EC on priorities prior to the May IAB meeting.
2. The Stem committees produce a list of topics by July 1. Topics are reviewed by the IAB, the EC and the Director and comments are given to the Stem leaders and the Director by August 1
3. Pre-proposals and research teams are developed by mid August – usually just after the summer retreat. The retreat plays a major role in these developments.
4. The pre-proposals are due to the Director by September 1. These will be sent to the Stem committees for prioritization (within stems, not across stems). The result of this process is an invitation from the Director for full proposals. Full proposals should include task statements, budgets and milestones.
5. Full proposals are due October 1 for review by the EC the IAB and the Director.
6. Presentations of the proposals will be made at the December IAB meeting. Input from the EC and the IAB due to the Director one week after the meeting.
7. Decisions made by Jan 1. Using the criterion outlined below. The Director makes all final decisions about initiating new projects. Funding to begin May 1.

The following criteria are used by the stem committees, the IAB, the EC and the Director to make decisions about new project funding:

1. Industrial issues:
   a. Does the project have at least two companies interested and the names of two industry people that will devote time to work with PSERC on the project?
   b. Does the IAB rank the project high?

2. Center issues:
   a. Does the project properly fit the research roadmap?
   b. Are multiple Universities involved?

3. Quality issues:
   a. Is the project innovative and creative?
   b. Do the proposed investigators have good track records?

4. Budget and balance issues:
   a. Does the project contribute to equitable site distribution (lead towards an average funding of 120K/site over a 3-year moving window)?
   b. Does the project contribute to equitable investigator distribution?
   c. Does the project contribute to the balance of basic vs. applied research?
   d. Is the budget correct for the work proposed – typical 75K?
   e. Does the project have 1 leader, 1 co-leader from another university, and 2 industry participants?

CONCLUSION

PSERC's vision is one in which universities and industry collaborate in addressing the research and education needs of the new power industry. This vision challenges both university researchers and industry members to work in ways that may be new to them. Researchers must collaborate across universities and across disciplines so not only do they have to learn new ways of communicating concepts and insights to colleagues in different disciplines, but they also have to learn techniques of collaboration at a distance. A

challenge for industry members is that they not only have to consider the research and education needs from their company's perspective, but they also have to factor into their decisions the needs of the industry as a whole. Researchers and industry members both perceive the research and education needs to be tremendous as the industry restructures, so they are responding creatively and energetically to challenges they face in working together to address those needs.