

Project Title: Facilitating Environmental Initiatives While Maintaining Efficient Markets and Electric System Reliability

Summary	Recent governmental environmental initiatives, like mandates on the percentage of generation to be renewable-based or establishing regional limits on greenhouse gas emissions, can be implemented in a variety of ways. These choices can have profound effects on the efficient and reliable planning and operation of the power grid, and in turn on the resulting environmental consequences. Building on the prior PSERC analysis that identified the public goods aspects of reliability in designing efficient markets, this new project would consider a variety of environmental initiatives and examine their potential interaction with both electricity market performance and system reliability. Based upon an understanding of these relationships, systems of environmental regulations and/or permit trading regimes would be developed that complement efficient market design and system reliability, while respecting the natural laws that govern both the transmission of electricity and the dispersion of pollutants.			
Research Stem	Markets			
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Industry Team Members	NYISO (Jonathan Mayo), GE (Mark Sanford), Entergy (Floyd Galvin)			
Start Date and End Date When the Final Report will be Submitted for Publication	Start date: June 1, 2007 through August 31, 2009.			
Requested Funding from Base PSERC Budget	Researchers	CY 2007	CY 2008	Total
	Schuler			
	Schulze			
	Tylavsky			
	Cardell			
	Total			
Supplemental Funding				

Project Description: In addition to current regulations on the emissions of particulates, sulfur oxides and nitrogen oxides, several states have recently mandated the percentages of their electricity supplies that must be provided by renewable resources within a specific time horizon. It is likely that government initiatives resulting from global warming concerns will result in further reductions in permitted gas emissions—CO₂, and NO_x—but it is not clear what specific form these environmental regulations will

PSERC 2007 Solicitation

take, nor whether carbon emission permit trading will be permitted as is the case with SO_x. These environmental mandates will also affect the market environment, power system operations and dispatch, and the future distribution of and mix of generation that will be constructed, as well as its location. How will these changes affect the overall price of electricity, the relative operation of different types of generating units and system reliability? In turn, how will the consequent changes in unit dispatch and system operation affect the intended level of environmental benefits and their location?

One can think of environmental standards as being similar to reliability constraints since both have public goods aspects, but how will attempts to provide the one affect the other since both the transmission of electricity and the transport and dispersion of pollutants flow according to natural physical laws, but different ones, and not the laws of contract nor those rules established by regulators. These indirect feedbacks, together with attempts by system operators to redispatch generation in order to minimize the cost of supplying power, subject to all of these regulatory constraints, as well as the laws of physics, may well lead to some very unintended consequences. The purpose of this proposed research is to explore those interactions and potential consequences and to identify guiding principles for market design, reliable operating guidelines and for designing sound environmental regulations that will achieve society's combined objectives at the least possible cost.

Intensified environmental initiatives may also influence the nature and rate of adoption of emerging technologies, particularly those based upon renewable resources, and thereby have further ramifications on the reliability and cost of grid operations, and therefore indirectly upon the environment. As an example many small-scale generation sources are non-dispatchable and/or distributed more widely throughout the power grid than traditional generating sources. If there are residual effluents from these distributed sources, what are the potential adverse human impacts as compared to siting large central-station facilities, and how will reliability criteria and operating practices change if there is widespread distributed generation? A goal of this research is to provide insights about potential changes in market structures and operating practices that might be desirable so that ISO/RTOs, utilities, regulators and buyers and sellers can position themselves to accommodate to these changes.

Substantial research has analyzed the effects of location, reliability and penetration of renewable generating sources—principally solar and wind—on system stability and reserve margins. Little research has been directed at the market and operations aspects when governments establish mandates on the penetration of renewables and limits on greenhouse gas emissions. The pressure these mandates will put on markets, system planning, operation and reliability is unknown. Furthermore, if these environmentally based initiatives were also to encourage the wider use of geographically distributed sources of generation, the subsequent interactions with system reliability, cost, and ultimately the environment at different locations, is not well understood.

One goal of this research is to build a realistic electrical test bed for measuring the impact these environmental initiatives have on the value of generation, VAR support, reliability, etc for different anticipated scenarios. This system model must be capable of simulating a wide range of anticipated regulatory changes and on measuring the effects on system operations, cost and reliability.

The work proposed builds on prior PSERC research—aimed at identifying the public good aspects of the constituent components of service reliability—by adapting the existing optimization procedures to an electric power system of a more realistic scale and complexity. In this extended analysis, a minimum of four busses must be included in the system with parallel transmission paths over a portion of the system and a long leg to reach an isolated load bus where distributed generation might be located (as well as at busses within the networked part of the grid).

PSERC 2007 Solicitation

Anticipated areas of analysis and integration that are needed to accomplish the research objectives are:

1. Design a stylized network, capable of representing the essential features of both electricity systems and environmental dispersion characteristics and patterns, that are suitable for both analytic and numerical solutions. (At a minimum, a three-node, triangular network is required with at least one radial stub to a fourth load node that also could represent a peripheral site for distributed, renewable-based generation.)
2. Develop and calibrate economic, environmental and reliability-related performance characteristics for conventional large central station facilities, as well as for emerging distributed sources of generation, both to include the correct features in the analytic structure and to calibrate numerical simulations properly.
3. Perform qualitative social welfare maximizing analyses of system performance that includes the costs of service disruption, of low-voltage and of a degraded environment, as well as the cost of energy, as a benchmark for comparison with the consequences of alternative regulatory prescriptions.
4. Devise likely regulatory mechanisms to simulate their direct and indirect impacts on the environment, reliability and cost.
5. Perform numerical simulations of alternative regulatory scenarios, selected after consultation with industry team members, and compare results with qualitative analytic insights gained in 3).
6. Design and develop a computational platform, since the execution times with existing optimization routines is quite long, even for the small 4-bus system that was used in the current PSERC "Reliability as Public or Private Good" project. (These long execution times may be unwieldy for analyzing larger scale systems and cannot now be used in a real-time operational environment. The large-scale parallel processing initiative at ASU provides this project an enhanced capability for generating numerical simulations of system performance. This work also permits a projection of the extent of distributed processing that may be necessary to translate the methods and analyses developed in this project to a real-time production environment.)
7. Analyze results and in consultation with industry team members, establish a priority in terms of performance of alternative regulations and implementation practices for achieving environmental standards.

Potential Benefits: Industry members should benefit in numerous ways:

- Conclusions from this research on more flexible power system designs and operation will allow the industry to begin to plan for and take advantage of new regulatory environments while maintaining efficient markets and system integrity. The project results should provide insights on how emerging technologies that are less environmentally intrusive, and/or rely on renewable resources, might fit into and interact with the electrical system, so it can guide the future planning of suppliers, both generators and transmission and generation companies, and of system operators and market coordinators like ISOs/RTOs. By exploring the impacts of both central station and distributed generation in terms of the relative impacts on different sets of customers distributed throughout the service area, the differential impacts on cost, reliability and environmental quality can be gauged for alternative configurations of production.
- By demonstrating the differential relative impacts of various forms of environmental regulations on the environment, reliability and electricity price, the potential public impact from and response to these various initiatives might be inferred, so these results should prove to be useful information for policy makers when provided before they establish environmental compliance mechanisms.
- In the end, the public would benefit the most from insights derived from this analysis by receiving improved air quality at a reasonable price with a high level of service reliability.

PSERC 2007 Solicitation

Expected Outcomes: The interactions between electric power system markets, planning and operations will be illustrated and analyzed, allowing involved parties to prepare for changes necessitated by environmental initiatives and mandates. The main deliverables from this project will be paper(s) to be published that summarize the findings from this research. In addition, software packages will be written, most likely in the Matlab programming language, to conduct simulations in support of analytic results. This software will extend the already existing Matpower package, and it would be available for further use, simulations and extensions by other researchers and industry members interested in exploring impacts that might be representative of their own locations.

Potential Applications: The results might inform market designs and system operation procedures at RTOs/ISOs. It should also guide generators on the choice of technologies and facility locations in light of potential enhanced environmental regulations. The results should also provide insights to policymakers who are developing environmental regulations so they can understand and respond to far-flung indirect consequences, particularly those that may have unintended feedback consequences for the environment.

Technical Approach:

- Building on the existing model and software developed by Bill Schulze and his Cornell research team for their current PSERC project, analytic techniques will be used to generalize and extend this model and to analyze the implications for the electrical and environmental systems
- Engineering cost data and empirical techniques will be used to calibrate these models and their components, including the development of estimated cost, operational and environmental characteristics for particular emerging technologies.
- Numerous numerical simulations will be conducted under alternative scenarios of technological innovation and environmental regulation mechanisms, These results will be used to test the sensitivity of analytic results, and the probable practical outcomes of pursuing alternative regulatory paths in support of the environment.
- In terms of computational techniques, the use of ASU's parallel processing capability will be explored to gauge the potential for adapting these complex optimization techniques for use in a real time environment.

Work Plan: Five major thrusts that will be pursued in parallel throughout this two year project, together with the responsible major participants are:

1. Design a stylized network that reflects electric system operation, reliability and economic characteristics together with emerging configurations and problems that might arise from proposed environmental regulations. Effluent transport models will be incorporated that are separate from but related to the electric transmission system configuration (All).
2. Perform and interpret analytic qualitative welfare maximizing solutions of a reliable electric system, including environmental consequences, to devise fundamental principles (Schulze).
3. Analyze and develop realistic parameters for existing and emerging generation technologies that describe operating characteristics, costs, efficient scales, and environmental characteristics (Cardell).
4. Develop software and utilize advanced computational techniques, possibly including parallel processing, to provide numerical simulations of alternative scenarios in order to weigh the likely consequences and implications of the analytically-derived insights (Tyvalesky).
5. Overall project guidance and coordination, with a particular focus on the likely implications both for industry response to different environmental regulatory instruments and on the complex social consequences, estimates of which might guide further policy development (Schuler).

PSERC 2007 Solicitation

The projected work schedule with associated responsibilities assigned above is:

<u>by (date)</u>	<u>Thrusts (Tasks)</u>
Sept. '07	1,3 & 5 - - complete trial stylized network
Dec. '07	2 & 4 - - preliminary analytic solutions + trial simulation platform prepared
May '08	4 & 5 - - select trial environmental constraints, explore enhanced computational techniques, and develop numerical simulations of scenarios.
Sept. '08	1,3 & 5 - - evaluate all inputs, assumptions and the stylized network design in light of numerical results in order to recalibrate procedures and analyses, review trial results and scenarios with industry advisors.
Dec. '08	2,4 & 5- - revise welfare maximizing analytic solutions, revise trial environmental instruments, and develop enhanced computational procedures
May '09	3,4& 5 - - finalize numerical simulations, interpret results and detail consequences in terms of alternative environmental regulatory forms; summarize policy implications.
June '09	Review results w/ Ind. Advisors; write final report (All participants)

Work Supported by Additional Membership Funds: At the end of the first year following the numerical simulations of the initial stylized systems, the results will be reviewed with the industry team members. Depending on the outcomes and the industry interest that is generated by these generic analyses, additional technology- or locational-specific simulations might be performed as supported by those particular sponsors. Also, to the extent that particular potential users desire enhanced, rapid computational methodologies, separate support could be arranged to pursue that application effort.

Related Work: A substantial literature exists on efficient environmental regulations that accomplish their objectives at the least cost and provide incentives for desirable innovation. Many other game-theoretic-based analyses examine mechanisms for implementing environmental standards, but rarely do they consider the dispersion characteristics of effluents when considering permit-trading regimes. The separate ongoing work of Schulze, et. al. on electricity supply systems integrates complex reliability considerations with power quality and economic cost considerations, and it is useful for guiding the development of a least cost, optimally reliable system, that considers the unique transport characteristics of electricity.

How this Work Differs from Related Work: This analysis begins by combining the separate threads described above and by developing an integrated stylized model that can not only suggest a socially optimal set of rules and policies, but can also simulate both the direct and indirect consequences of individual policies. As an example, it can suggest which aspects of desired environmental standards might be achieved through a decentralized cap and trade mechanism, and which need strictly enforced standards, together with the impact of both upon system cost. It could also provide estimates of the environmental and cost consequences of a new tighter electricity reliability standard, as an example.

Collaboration Plan: The Cornell team (faculty, research staff and students) meets routinely once a week to discuss, review and coordinate its electricity system-related research projects. While on sabbatical leave at Cornell this semester, Judy Cardell is participating in this process and it is anticipated that the relationship will be continued electronically. The initial phases of the project would be conducted while Dan Tylavsky is on sabbatical leave at Cornell during part of year 2007-2008. Between the Cornell, ASU and Smith teams and their students, the communication and coordination will be handled via monthly videoconferences over the internet. Reviews will be scheduled with the industrial team members to ensure

PSERC 2007 Solicitation

their full participation both with respect to inclusion of essential features in the model and the selection of scenarios for numerical simulation, as described in the work plan. The results of the work will be in the form of technical papers and a project report that will be posted on PSERC's web site.

Relationship of this Work to the Research Plan and Topic Areas for this Solicitation: This work advances the industry's capability in two of the four focus areas that are listed under the market stem in the 2007 solicitation statement: 1) new market products for reliability (here in response to potential environmental regulations), and 2) develop flexible physical and market systems to accommodate diverse technical innovations and regulatory interventions. This analysis should also provide industry members with a tool and estimates that might be used to guide the evolution of environmental policy and instruments that are minimally invasive and cost-effective.