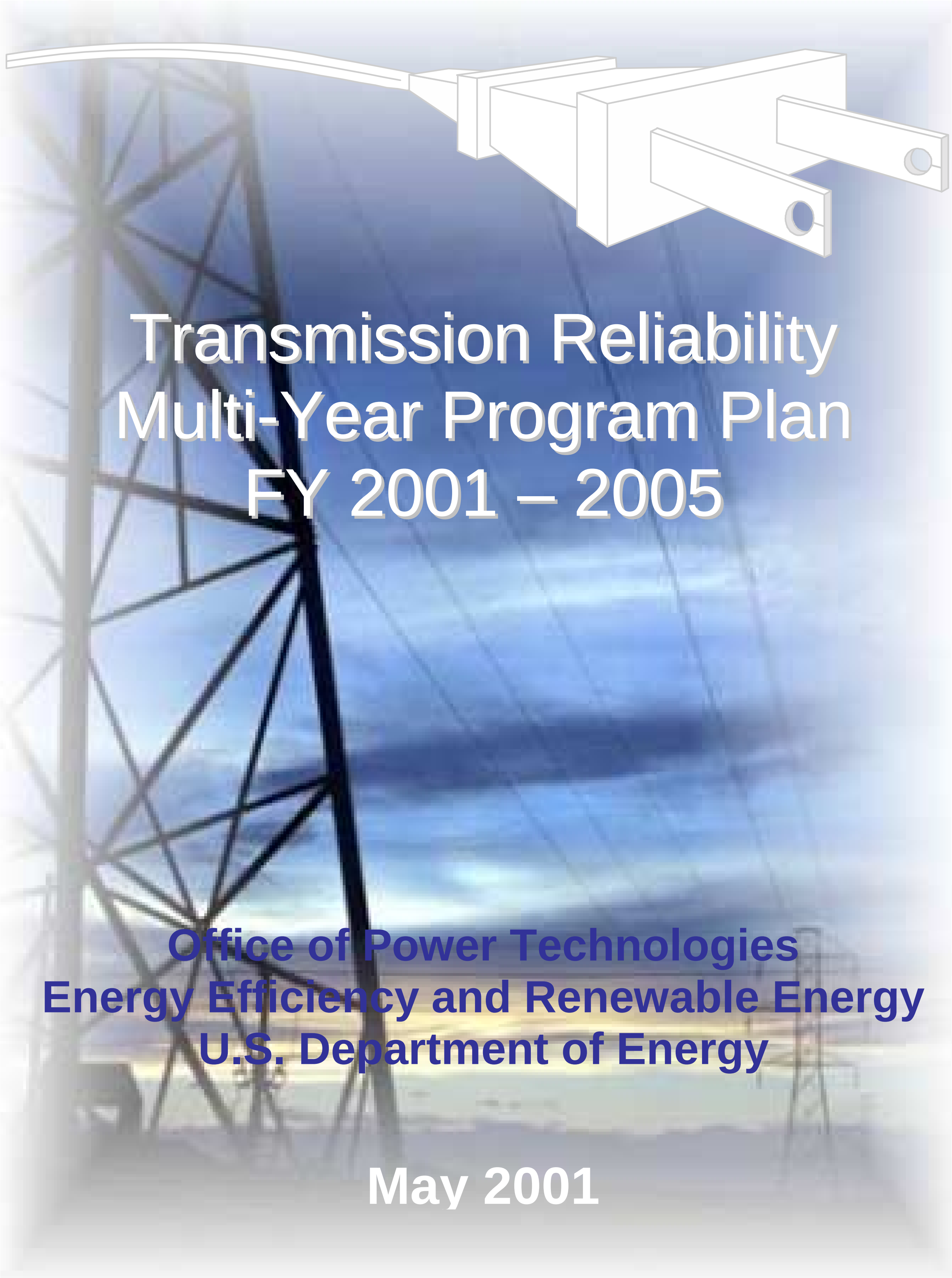

Transmission Reliability Multi-Year Program Plan FY 2001 – 2005

Office of Power Technologies
Energy Efficiency and Renewable Energy
U.S. Department of Energy

May 2001

The U.S. Department of Energy
Washington, DC 20585

Foreword

The reliability of electric energy services is vital to the continued growth of our nation's economy. The challenge of maintaining and enhancing reliability is especially great as our nation's electricity industry transitions from a regulated system to a competitive market. The U.S. Department of Energy (DOE) has established the Transmission Reliability (TR) Program as a key federal activity to meet this challenge. This program is a cornerstone of our newly established Distributed Energy Resources (DER) integrated program efforts.

The *Transmission Reliability Multi-Year Program Plan, FY 2001 – 2005*, reflects the current state of an ongoing planning effort by DOE working in partnership with industry stakeholders to define the tasks and approaches necessary to develop and deploy reliability technologies. This program plan outlines a five-year program and defines the R&D activities we propose to undertake in the areas of real-time grid reliability management, reliability and markets, integration of distributed energy resources, and reliability technology issues and needs assessment. The plan also defines how we intend to manage our program and the measures we will use to evaluate our success.

It is essential that industry and state and federal government work in partnership to maintain reliable electric service. This plan outlines the important activities that DOE believes *must* be undertaken during this critical period of industry restructuring. We look forward to continuing work with all of our partners to refine and implement this plan.

Robert K. Dixon
Deputy Assistant Secretary
Office of Power Technologies
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Transmission Reliability Multi-Year Program Plan
FY2001-2005

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Executive Summary

The U.S. electric power system is in the midst of a fundamental transition from one that has been centrally planned and controlled to one that will depend on competitive market forces to guide investment and operation. Unique features of electric power, including the need to match supply and demand in real time, the interconnectedness of the power networks, and the immediate propagation of disturbances throughout the system, have always posed challenges for reliability management. With today's changes underway, these challenges are even greater.

There is no prior experience to draw upon for guidance in managing the complexities of the electric power system during the transition to a market-based system. The transition is made even more complicated because the nation's demand for electricity and reliable electric service is increasing. As the events of recent years demonstrate, the reliability of the power grid and the integrity of the markets it supports are integral to the nation's economic wellbeing.

This program plan reflects DOE's current vision of the federal R&D priorities necessary to maintain and enhance reliability during the transition to competitive energy markets. The program has been shaped by extensive contributions of stakeholders participating in DOE workshops and white papers; this participation is expected to continue throughout the implementation of the plan. The plan and concomitant activities are organized to focus on the following four critical research areas:

Real-Time Grid Reliability Management: Recent advances in information technology, high-speed telecommunications, and advanced sensors and electronics offer unique opportunities to modernize the electric power grid. The unprecedented demands on the power grid, driven by dramatic increases in economic transactions, are stressing the power system beyond its original design limits. Modernizing the power grid will allow active system management – in contrast with the passive readiness embodied in control systems of the past – and enable increased, reliable power flow over existing corridors. This research area will include topic areas dedicated to the development of *operational decision support tools* to provide new software to system operators and security coordinators consistent with the needs of competitive markets. Hardware and software components will be developed under an *advanced measurements and controls* activity for advanced detection of and automatic responses to disturbances to ensure the reliability of the power system.

Reliability and Markets: Reliability can only be maintained in a competitive market if appropriate mechanisms and incentives are in place to ensure adequate investment in and safe operation of the interconnected power system. The reliability and markets research area will develop software tools and implementation approaches, as well as take a science-based approach to analysis of evolving institutions to ensure the market's efficacy in maintaining reliability. Topic areas to be addressed include *load as a reliability resource*, *market tools*, and *reliability-related impacts of market operations*.

Distributed Energy Resource (DER) Integration: Over the next 20 years, the nation's power system is expected to evolve into a more dispersed or distributed infrastructure with improved economics, efficiency, and reliability. Maintaining overall electric system reliability throughout this transition will require new design and control approaches that allow a gradual, staged transition from today's distribution infrastructure. The TR Program will be responsible for the system reliability-related aspects of DER integration (generation, energy storage, and load management) into the electric power system as part of the DER Program in the Office of Power Technologies (OPT). It will pioneer and demonstrate the *MicroGrid Concept*, which envisions a local electric grid with DER technologies that can either be integrated with or operated in isolation from the existing power system. A second topic, *DER Technology Integration,* will provide power system expertise and support to the technical integration of DER technologies into the existing electric distribution system either directly or as part of a MicroGrid.

Reliability Technology Issues and Needs Assessment: This research area recognizes the need to track, organize, coordinate, and communicate regularly with stakeholders in an ongoing process of strategic program planning. The *DOE Reliability R&D Planning* activity will provide a continuous dialogue with stakeholder and user groups to identify strategic issues and research gaps and then prioritize appropriate research needs. DOE will work with stakeholder groups to determine priority needs to make sure that limited resources address the most important issues.

1996 WSCC Outages

In 1996, utilities in the Western Systems Coordinating Council (WSCC) experienced several widespread transmission-level power outages. The WSCC is the North American Electric Reliability Council (NERC) member organization responsible for ensuring transmission reliability for much of the Western United States. The largest WSCC blackout occurred on August 10, 1996. A transmission line fault caused by a tree initiated a chain of responses that ultimately led to system-wide voltage collapse and "islanding" of the WSCC system. The outage affected 7.5 million people and cost the region's economy an estimated $2 billion.

The 1996 outages and other similar events over the past 10 years are indicative of a growing commonality of reliability issues in the North American power delivery system. These problems include:

- Mis-operation of protective controls such as relays and relay coordination;
- Lack of adequate models/response procedures to unexpected circumstances;
- Lack of real-time data to respond to unexpected events;
- Lack of awareness and understanding of some power system phenomena;
- Lack of effective feedback (active) controls;
- Poor maintenance procedures; and
- Operator error.

The following table illustrates the major milestones and activities planned for the next five years. For each of these areas, the activities to be performed in each area, the milestones to be reached, and the ways in which the TR Program will continue to build on existing activities are explored in the subsequent sections of this plan.

Milestones for Identified Research Areas in the TR Program
(Numbered milestones are keyed to their respective research areas, further explained in Section 4.)

	2001	2002	2003	2004	2005
Real-Time Grid Reliability Management					
Operational Decision Support Tools and Information Visualization					
Reliability adequacy tools	1				
Area control and area interchange real-time monitoring prototypes	2				
Wide-area information visualization systems		3			
System Security Management Tools					
Integrated security analysis	4				
Congestion management	5				
Real-time security control for the future	6				
Advanced Measurements, Controls, and Tools					
Phasor-based workstations	7				
Stability nomogram improvements		8			
Fundamental control constraints	9				
New real-time wide-area control schemes	10				
High-performance grid demonstration					11
Dynamic information network	12				
Reliability and Markets					
Load as a Reliability Resource					
Available capabilities survey	1				
Demonstrate load as a reliability resource	2				
Measure the effectiveness of loads		3			
Market Tools: Creating and translating nomograms					
Survey existing nomogram methods	4				
Translate physical limits into market signals		5			
Implement and test nomograms			6		
Market Tools: National power auction experiment					
Investigate California market	7				
Test effect of load management	8				
Test performance of balancing markets	9				
Test ancillary service structures	10				

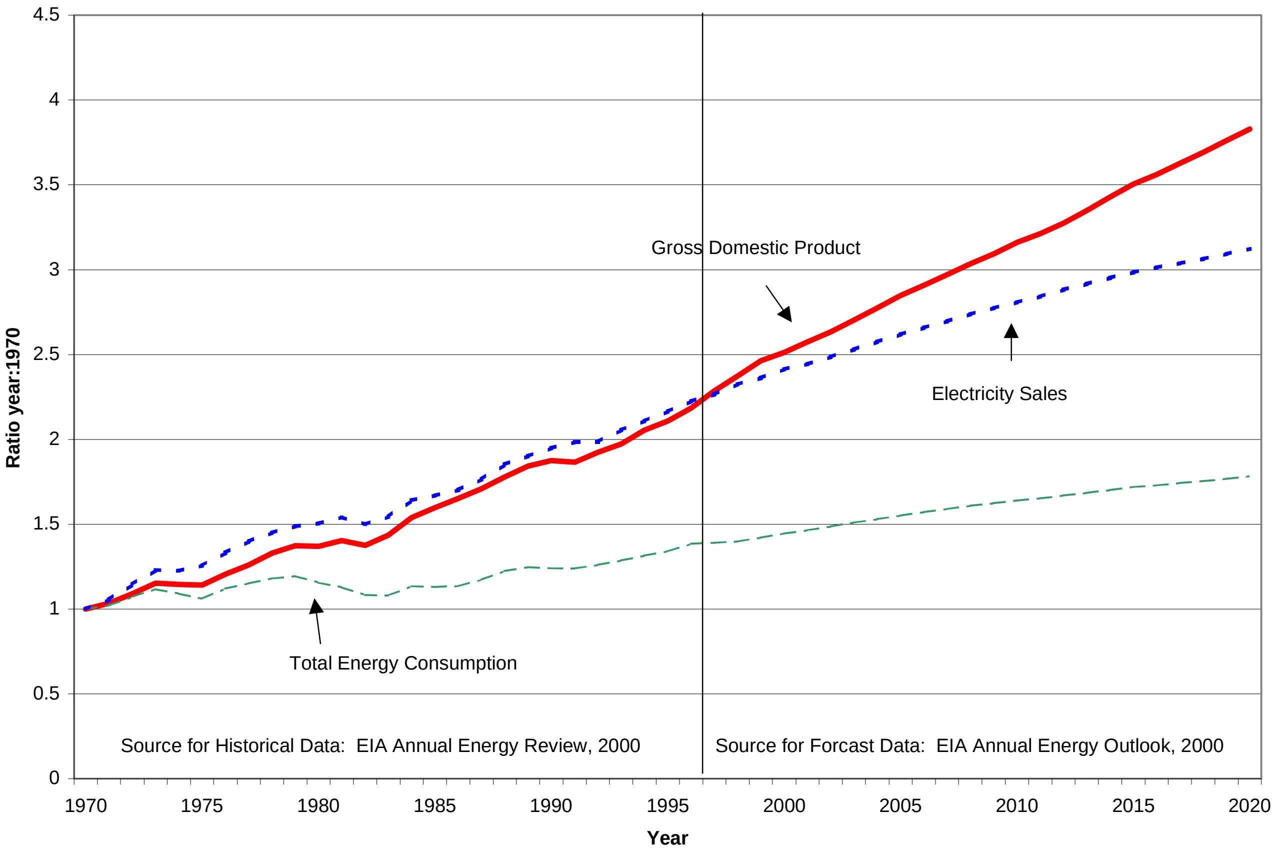
Milestones for Identified Research Areas in the TR Program–continued

	2001	2002	2003	2004	2005
Reliability Impacts of Market Operations					
Examine significant events	11				
Tools to study behavior and constraints	12				
Study market seams	13				
Connect reliability and markets	14				
Distributed Energy Resource Integration					
MicroGrid Demonstration					
Gain acceptance for the MicroGrid concept	1				
Analyze functional requirements	2				
Examine electric system integration – protection, control, modeling	3				
Demonstrate the MicroGrid		4			
DER Technology Integration	5				
Reliability Technology Issues and Needs Assessment					
DOE Reliability R&D Planning	1				

Maintaining Reliability during the Transition to Competitive Electricity Markets

During the 20th century, electricity emerged as a key driver for our nation's economy. The importance of electricity to the economy is reflected in the linkage between Gross Domestic Product (GDP) and electricity demand – a linkage that began more than 50 years ago. During the 21st century, the nation's "new economy" will be even more dependent on reliable electric power to deliver services via telecommunications and information technology. However, there is great concern that reliable power system operation may be at risk during the transition to competitive markets.

Figure 1 – Although the nation has made great strides in breaking the link between *energy* and GDP, the link between *electricity* growth and GDP remains strong as the needs of a digital economy create even greater demand for reliable electrical service.



The DOE Transmission Reliability (TR) Program is a focused national effort to undertake priority research that will contribute to ensuring that "the lights stay on" as the nation moves toward a competitive electricity market. Today's digital economy requires higher levels of reliability and power quality than was necessary in the past. Although the 99.9% or "three nines" reliability provided by the grid was adequate for the industrial economy, the digital economy warrants much higher levels of reliability, approaching 99.9999% or "six nines." The reliability emphasis is shifting from making sure that "the lights stay on" to making sure that "the lights stay on and never flicker."

The goal of the TR Program is to develop technologies and policy options that will contribute to maintaining and enhancing the reliability of the nation's electricity delivery system during the transition to competitive markets. The TR Program is projected to last 5 to 10 years, consistent with the expected duration of this transition. Priorities for the TR Program are to anticipate trends and evolve throughout the transition period as private incentives for R&D investments emerge in response to the development of new markets.

The TR Program is a major effort within DOE's Office of Energy Efficiency and Renewable Energy (EERE), Office of Power Technologies (OPT). *EERE's mission is to "lead the nation in the research, development, and deployment of advanced energy efficiency and clean power technologies and practices, providing Americans with a stronger economy, healthier environment, and more secure future."*

The TR Program supports EERE by:

- enabling customer choice in energy service, reliability, and power quality options;
- providing information needed for reliable operation of competitive electricity markets;
- enabling distributed energy resource options that integrate natural gas, renewable energy, and electric power delivery benefits;
- promoting information transparency regarding power systems conditions and prices to enable market-driven reliability management; and
- developing and demonstrating technologies and protocols for demand-side participation to manage reliability.

The TR Program is the government's primary R&D effort for electricity system reliability, and it plays an important part in related DOE activities:

Office of Distributed Energy Resources: This recently organized program within EERE is working to accelerate the introduction of fuel cells, microturbines, reciprocating engines, and other modular technologies into future energy systems. The TR Program is addressing the reliability-related electric system integration issues associated with large-scale deployment of these technologies.

Power Outage Study Team (POST): Researchers for the TR Program contributed power system expertise to a DOE-led team that investigated the Summer 1999 power outages and made recommendations to the Secretary of Energy. (See sidebar)

Power Outage Study Team

As part of the Secretary of Energy's Six Point Power Outage Prevention Initiative to help utilities prevent future heat-related outages, the Power Outage Study Team (POST) was created. It was comprised of 12 power systems experts drawn from DOE headquarters, National Laboratories, and universities. POST was tasked to carry out independent investigations of the East Coast and Midwestern United States power outages during the Summer of 1999, and make recommendations to the Secretary on appropriate actions for the Federal Government to assist industry in preventing future outages.

Recommendation I: Promote market-based approaches to ensure reliable electric services;
Recommendation II: Enable customer participation in competitive electricity markets;
Recommendation III: Remove barriers to distributed energy resources;
Recommendation IV: Support mandatory reliability standards for bulk-power systems;
Recommendation V: Support reporting and sharing of information on "best practices;"
Recommendation VI: Enhance emergency preparedness activities for low-probability, high-consequence events on bulk-power systems;
Recommendation VII: Demonstrate federal leadership through promotion of best reliability practices at federal utilities;
Recommendation VIII: Conduct public interest reliability-related research and development consistent with the needs of a restructuring electricity industry;
Recommendation IX: Facilitate and empower regional solutions to the siting of generation and transmission facilities;
Recommendation X: Promote public awareness of electric reliability issues;
Recommendation XI: Monitor and assess vulnerabilities to electric power system reliability; and
Recommendation XII: Encourage energy efficiency as a means for enhancing reliability.

For the full text of the POST Report, go to: http://www.eren.doe.gov/der/chp/pdfs/outage.pdf

Electric Reliability R&D Challenges For a 21st Century Economy

The U.S. electric power system is in the midst of a fundamental transition from one that has been centrally planned and controlled to one that will depend on competitive market forces to guide investment and operation. Unique features of electric power, including the need to match supply and demand in real time, the interconnectedness of the power networks, and the immediate propagation of disturbances throughout the system, have always posed challenges for reliability management. Today, these challenges are even greater. There is no prior experience to draw upon for guidance in relying on markets to manage the complexities of the electric power system. At the same time, the nation's demand for electricity and reliable electric service is increasing. As the events of recent years demonstrate, the reliability of the grid and the integrity of the markets it supports are integral to the nation's wellbeing.

Electric System Reliability: Then and Now

The existing electricity network was designed to ensure reliability in an era when electric utilities were regulated monopolies. Utilities made generation, transmission, and distribution investments to provide *reliable* service to *all* customers in exchange for the opportunity to earn a fair rate of return.

Transmission lines evolved in this era as "pipelines" connecting generation from distant power plants to the loads where people lived and worked. As a result of the 1965 Northeast blackout, utilities increased transmission linkages among their systems in order to increase reliability. Interconnected networks emerged in which power could flow throughout the Eastern, Western, and Texas grids, not just from one fixed point to another.

Starting in the 1970s and continuing through the 1980s, utilities began to rely on these networks not only for reliability but also for economic exchanges of power. This shift, coupled with the exhaustion of economies of scale in central station generation technologies and the appearance of "qualifying facility" generators under the Public Utility Regulatory Policies Act of 1978 (PURPA), sowed the seeds for today's shift in the utility paradigm and electricity industry restructuring.

The electricity industry is undergoing significant and rapid changes as it transitions from a regulated to a competitive market system. The interconnected transmission system is being used as a common carrier over which it is assumed that generation from any source can be delivered to any load. Formal spot, forward, and futures markets for power trade have been established. Control of generation is being separated or unbundled from control of transmission. Grid operations are becoming institutionalized in Regional Transmission Organizations (RTOs), and the industry's voluntary reliability councils are being transformed into mandatory self-regulating reliability organizations with enforcement powers under federal oversight. Utilities' exclusive retail franchises are being opened up to give customers the right to choose suppliers and determine the best way to meet their energy and reliability needs. Finally, dramatic advances in small-scale or distributed energy technologies, fueled by increased customer demand for high-quality electric service, portend an even more fundamental change in the design and operation of the electric power system. In particular, technological advances in distributed generation, power electronics, storage, control, and communications has begun shifting the power system toward distributed solutions that profit from the economies of mass manufacturing, similar to the trend that has been seen in the computer and microelectronics industries during the past two decades.

Electric System Reliability Challenges

Rapid restructuring is raising concerns about the reliability of the nation's power grid. Transmission congestion, price spikes, voltage degradation, and outages are all indicators of stress on the system in which transmission investments have not kept pace with growth in electricity demand. Transmission investments have been limited by a number of forces, including strong public opposition to construction of new overhead transmission lines and an uncertain regulatory environment. Regulators, meanwhile, wait for the federal legislation necessary to clarify jurisdictional issues consistent with the needs of interstate electricity commerce.

While the nation waits for new transmission investments, region-wide trade of electricity is creating power flows never before encountered (or planned for) by system operators. Operators are being constantly challenged to manage these increasingly unpredictable power flows with an aging and inflexible transmission infrastructure. The tools and technologies available for this task – developed originally to support centrally planned, vertically integrated operations – are inadequate for managing reliability in competitive, region-wide electricity markets.

Although most parties agree that mandatory compliance with grid reliability standards and practices is essential to reliability management in a competitive market for electricity, compliance is voluntary in the current system. Recent flagrant abuses of historic "gentlemen's agreements" to maintain reliability are hardly surprising given the current economic stakes of wholesale trade.

As the transition moves forward (and at times backward), there is a widening gap between the industry's need for new tools, technologies, and systems to manage reliability in a competitive electricity market and industry's investments in them. Market participants are focused on profit maximization and not on reliability, which is viewed as a public good. The institutions – currently Independent System Operators (ISOs) and soon RTOs – charged with managing reliability are themselves either challenged by the rapid pace of the changes taking place in the industry or have not yet been fully formed.

Recent technological innovations in high-speed telecommunications, micro-electronics, sensors, and real-time computer processing can be applied to advanced transmission and distribution system reliability technologies. These technologies will offer tremendous economic benefits in the form of improved operating efficiencies, greater transmission capacities, lower environmental impacts, and increased system reliability.

However, the inherently public nature of these benefits makes it unlikely that the market, acting alone, will capture them during this time of industry transition. In the past, utilities were willing to fund these activities because they were guaranteed recovery of R&D spending. Today, as utilities prepare for a more competitive (and uncertain) electricity market, utility R&D spending has declined precipitously.

DOE accepts the challenge that, in view of the importance of reliable electric service to the nation's well-being and the rapid and unprecedented changes taking place in the electricity industry, a strong federal role is needed to monitor trends and, where gaps emerge, ensure that adequate and appropriate investments are made in reliability-related electric system R&D. This role must, necessarily, be developed in concert with industry stakeholders to ensure that the activities undertaken will support the emerging competitive market.

SEAB Recommendations

The Secretary of Energy Advisory Board's (SEAB) Task Force on Electric System Reliability was formed to address the major Western power outages during the Summer of 1996. Its responsibility was to "advise on the critical institutional, technical, and policy issues that need to be addressed in order to maintain bulk electric system reliability in the context of a more competitive industry."

Through a series of meetings from January 1997 through September 1998 the Task Force agreed that restructuring of the electricity industry offers economic benefits to the nation and was compatible with transmission-grid reliability in an open, competitive market. The Task Force felt that with modifications to the existing institutions and processes, reliability could be maintained in a "competitively neutral fashion."

However, to achieve this, the Task Force also agreed that appropriate steps must be taken: "The primary challenge to the bulk power system reliability does not lie in the end-state competition but in the transition itself."

The Task Force reached consensus on 28 specific recommendations targeted at multiple agencies. *"The main recommendation to DOE is the need to ensure that funding for reliability R&D is sustained and monitored. The strong potential exists for the development of a funding gap from traditional resources as the market transitions. Market forces alone may not provide the necessary funding to maintain long-term reliability R&D and, if this were to happen, a significant technology gap could develop."* It will be the primary undertaking of the TR Program to work with industry to define the R&D necessary and to monitor electric power reliability to ensure all issues are being addressed.

For the full text of the SEAB Task Force's final report, go to: www.hr.doe.gov/seab/electsys

Defining the Nation's Reliability Needs

The reliability-related R&D needs of the electricity industry are unique, multi-faceted, and currently in flux as a result of the fundamental transformation underway in the industry. Appropriate roles and priorities for federal reliability-related R&D span a continuum from basic to highly applied research. In the face of intractable uncertainty regarding the precise future of this industry in transition, stakeholder participation is essential for establishing federal R&D priorities. There are many visions for the future of the industry; only by hearing regularly from all stakeholders can DOE target its programs to address essential public-purpose reliability-related R&D needs. DOE is committed to continuing stakeholder involvement in its R&D planning and implementation process.

The Critical Role of Stakeholder Involvement

DOE's commitment to stakeholder involvement in shaping the TR Program began immediately following congressional authorization for the Program in 1998. DOE began by conducting a stakeholder workshop to establish priorities for the newly created program by reflecting on the recommendations of the Secretary of Energy Advisory Board (SEAB) Task Force on Electric System Reliability. In contrast to the hardware development priorities for DOE's Transmission and Distribution Technologies in the early 1990s,[1] stakeholders suggested a much broader focus for future DOE research in response to the dramatic changes being brought about by restructuring efforts across the country.

Stakeholders observed, in view of the difficulty of expanding the transmission system, a need to maximize power flows along existing transmission corridors. Needed improvements included better real-time information on the current state of the system and advanced communication, control systems, and technologies to operate the grid with a precise and continuously updated view of its true physical limits. Stakeholders also suggested that DOE's program formally recognize the emerging role of competitive market forces in ensuring reliable electricity service. Finally, they suggested that DOE take account of the fundamental changes in reliability planning and operations that could result from the widespread penetration of distributed energy resources.

DOE responded by initiating a seven-step process *(Figure 2)* to ensure stakeholder input into the formulation of the Transmission Reliability research program. The first phase began in early 1999 when DOE tasked the Consortium

[1] See, for example, "Transmission and Distribution Technologies, Multi-Year Program Plan, FY 1995-1999." U.S. Department of Energy. 1994.

for Electric Reliability Technology Solutions (CERTS)[2] to develop six white papers exploring the suggestions made by stakeholders and to establish a sound foundation for the development of this plan.[3] The draft white papers were circulated widely among industry stakeholders for comment, a process that culminated with a second DOE stakeholder workshop in September 1999, at which the white papers were presented and discussed.[4]

The second phase of DOE's stakeholder input process consisted of the preparation and review of a draft Multi-Year Program Plan. The draft plan used the white papers and cumulative stakeholder input to organize the highest research priorities into a coherent federal R&D program for electric system reliability consistent with available federal resources. The draft plan was posted on a secure website for easy access, review, and comment.

This final FY2001-2005 Transmission Reliability Multi-Year (TRMY) plan has been developed based on the feedback received from stakeholders through the

***Figure 2* – Chronology of Transmission Reliability Research Program**

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[2] CERTS was formed in 1998 in response to Congressional appropriations language as a partnership among the National Laboratories, universities, and the electricity industry 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." The members of CERTS include the Electric Power Group (EPG), Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Power Systems Engineering Research Center (PSERC), and Sandia National Laboratories (SNL). PSERC is a National Science Foundation Industry/University Cooperative Research Center.

[3] The white papers are: "The Federal Role in Electric Reliability RD&D During a Time of Industry Transition: An Application of Scenario Analysis," by J. Eto; "Review of Recent Reliability Issues and System Events," by J. Hauer and J. Dagle; "Review of the Structure of Bulk Power Markets," by B. Kirby and J. Kueck; "Accommodating Uncertainty in Planning and Operations," by M. Ivey, A. Akhil, D. Robinson, J. Stamp, K. Stamber, and K. Chu; "Real-Time Security Monitoring and Control of Power Systems," by G. Gross, A. Bose, C. Demarco, M. Pai, J. Thorp, and P. Varaiya; and "Interconnection and Controls for Reliable, Large Scale Integration of Distributed Energy Resources" by C. Martinez, V. Budhraja, J. Dyer, and M. Kondragunta. http://certs.lbl.gov

[4] "DOE Stakeholder Workshop for the Transmission Reliability Program" prepared by Sentech.

review process. The TR Program will continue to work with industry to update and revise the plan as frequently as is necessary and share research findings widely.

Translating Recommendations into Plans

The DOE TR Program has reviewed and incorporated stakeholder recommendations into a four-part program that will identify high-priority needs and close emerging research gaps.

Real-Time Grid Reliability Management: Recent advances in information technology, high-speed telecommunications, and advanced sensors and electronics offer unique opportunities to modernize the electric power grid. The unprecedented demands on the power grid driven by dramatic increases in economic transactions are stressing the power system beyond its original design limits. Modernizing the power grid will allow active system management in contrast with the passive readiness control systems of the past, and enable increased, reliable power flow over existing corridors. This research area will include topic areas dedicated to the development of *operational decision support tools* to provide new software to system operators and security coordinators consistent with the needs of competitive markets. Hardware and software components will be developed under an *advanced measurements and controls* activity for advanced detection of and automatic responses to ensure the reliability of the power system.

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Reliability Technology Issues and Needs Assessment: This research area recognizes the need to track, organize, coordinate, and communicate regularly with stakeholders in an ongoing process of strategic program planning. The *DOE Reliability R&D Planning* activity will provide a continuous dialogue with stakeholder and user groups to identify strategic issues and research gaps and then prioritize appropriate research needs. The TR Program will work with stakeholder groups to determine priority needs to make sure that limited resources address the most important issues.

Realizing a Reliable Electricity Future

This section describes the current plans of the TR Program for the next five years. The Program is organized around four research areas: Real-Time Grid Reliability Management, Reliability and Markets, DER Integration, and Reliability Technology Issues and Needs Assessment. For each research area, a rationale is provided that defines the research need, research objectives are established, and specific topic areas and milestones are defined for the next five years.

Research Area 1: *Real-Time Grid Reliability Management*

Recent advances in information and visualization technologies, high-speed telecommunications, and advanced sensors and electronics offer unique opportunities to modernize management of the electric power grid to respond to the needs of competitive electricity markets. Recent, unprecedented demands on the power grid, driven by dramatic increases in economic transactions and by the redefinition and merger of traditional control areas, are stressing the power system beyond its original design limits. This new environment demands new, effective operational procedures and support tools that will support the transition from the passive readiness control systems of the past to active system management, allowing reliable, high-volume energy transfers among regions. This research area focuses on:

- research, development, and demonstration of *operational decision support tools* to provide software to monitor the adequacy of power supplies and system performance monitoring along with information visualization tools for use by system operators and security coordinators.
- research, development, and demonstration of *advanced measurements and controls*, leading to demonstration of advanced monitoring workstations based on synchronized phasors, for new processes to improve current stability nomograms and remedial action schemes, and for advanced detection and automatic responses ensuring the reliability of the power grid.

Rationale

The past emphasis on maintaining a highly reliable power grid led to development of strategies for managing operations in steady state. The conservatism inherent in this approach produced a highly reliable grid, but resulted in utilization of only 30% of the grid's physical capacity. Today, ISOs (and eventually, RTOs) use the same transmission system to operate new and larger control areas closer to design limits using new reliability management regimes. Traditional grid operations and reliability management strategies did not envision today's market-based environment, in which there is significant pressure on existing corridors to support greater trade. In particular, past strategies were not designed to accommodate the conditions imposed by reliance on competitive markets for buying and selling of electricity and reliability-related services. Already, system operators are being challenged to manage power supplies and flow configurations using new reliability models with which they have little or no experience. At the same time, some stakeholders protest that grid operation is too conservative and in conflict with their commercial interests, and regulators and merchants continue to debate whether the independence of operational security functions should be a reliability or energy policy issue.

To effectively accommodate the needs of a competitive market under new reliability models, it is essential to provide grid operation staff with reliability tools to effectively monitor the adequacy of resources and the security of the system, and to shift system control from passive readiness to active management based on a region-wide perspective. Real-time monitoring of resources, actual system dynamics, and market conditions could free up generation and transmission capacity reserves and enable increased power transfers without construction of new facilities. The market would become both more efficient and more stable.

Research Objectives

The Real-Time Grid Reliability Management research area will follow a progressive approach to provide a continuing output of useful grid reliability technologies and tools that are responsive to operational challenges posed by industry restructuring and development of competitive markets. The initial phases will be to:

- Identify current operational requirements and assess the suitability of current operational tools and security schemes for wide control areas operated in market-driven conditions;
- Develop, test, and evaluate new real-time performance monitoring, reliability adequacy, and security analysis schemes, tools, and operational procedures along with corresponding real-time control technologies based on advanced measurements;
- Demonstrate the above tools, schemes, and controls utilizing ISOs, RTOs, and Utilities as test beds;
- Improve information visualization systems and their availability, so that operators can rapidly understand and react to developing system problems in new market-based operational environments;
- Develop performance metrics to measure and monitor grid reliability for transmission and distribution systems; and
- Pursue a dissemination strategy to accelerate introduction of the operational tools and processes by making them readily available to industry.

Grid operation and applications tools and control requirements need to be enhanced to account for the region-wide scope of market activities and the shift in generation dispatch decision-making from vertically integrated utilities to market participants. Incorporating real-time intelligence on the actual state of the grid and its components will be essential so that system operators can determine true operational limits. In addition, developing new performance monitoring and reliability adequacy applications along with real-time and preventive control system approaches will facilitate making and executing more effective and reliable decisions in seconds.

Significant industry participation will be required to help define promising approaches, develop prototypes, and demonstrate and commercialize effective new strategies.

Topic Areas

- **Operational Decision Support Tools and Information Visualization**

Milestones:

1. *Develop and demonstrate prototypes for new, near real-time reliability adequacy tools for operators*

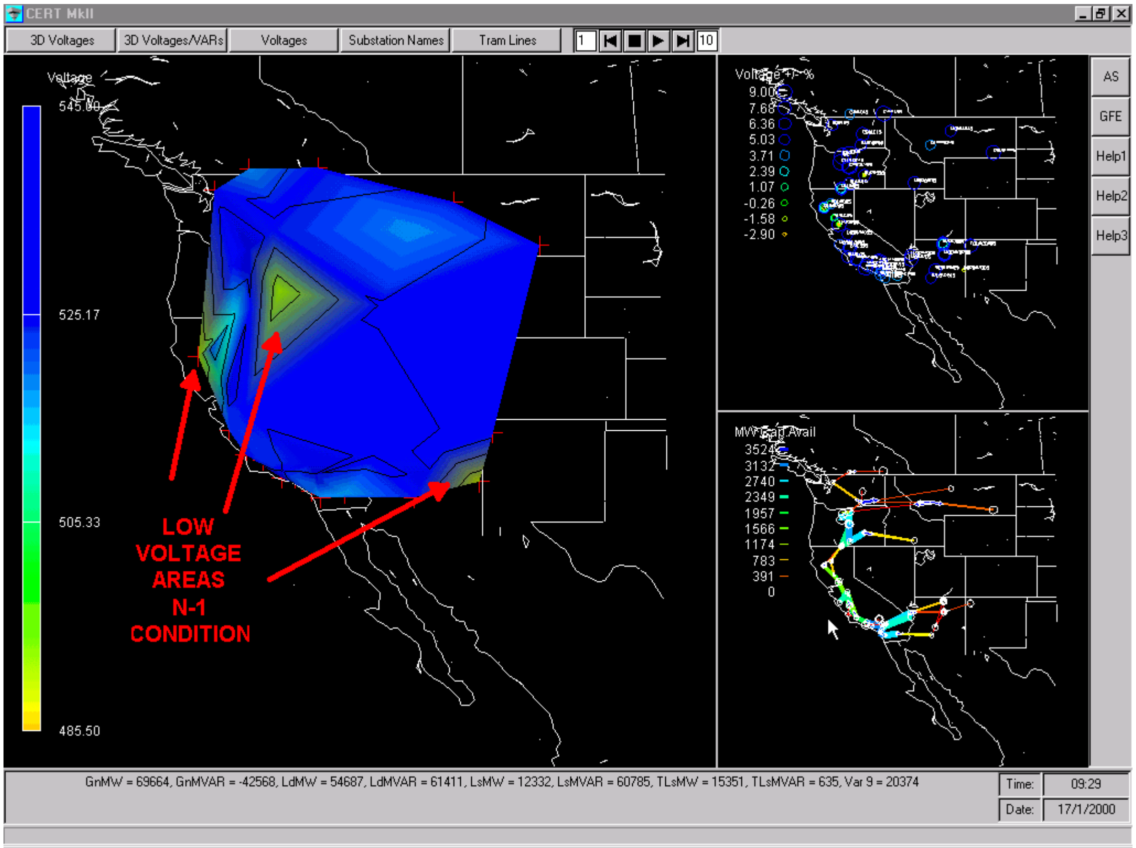
In today's restructured environment there is a special need for tools that allow operators to quickly assess the adequacy of supply and demand in a market environment and respond to potential threats to system reliability with appropriate preventive actions. The ability to measure, track, forecast, and implement protocols for near real-time management of ancillary services, and to perform risk analysis for load and equipment performance uncertainties, is critical. Tools that mine existing SCADA data, analyze it, and present and update it geographically and dynamically are needed to allow operators to manage operating margins effectively within their jurisdictions.

Today's operating reserve allocations are only time dependent; that is, they must be spinning or able to synchronize in pre-specified times. It is well known that, because a network can become constrained by voltage limits or real power flows, reserves must be spatially located strategically within the grid so that operators can handle all contingencies. To date, there is no demonstrated, scientific method for assigning reserves by taking into account these location-based considerations. Research is needed to develop and demonstrate a sound methodology for assigning locations for both real energy and reactive reserves.

2. *Develop and demonstrate prototypes for real-time monitoring, performance tracking for system area control, and area interchange errors for security coordination*

System frequency deterioration, as exemplified by the events during Summer 1999, should be prevented or minimized. Real-time operational tools and operator information visualization systems must be developed to help security coordinators effectively identify control areas causing large or long-term system frequency deviations, quickly determine the causes of the problems, and take swift action to remedy abnormal situations. Once developed, these tools must be demonstrated and disseminated.

Figure 3 *– VAR Monitoring Tool*



3. *Develop, test, and demonstrate wide-area information visualization systems for monitoring the grid accurately, identifying root causes of problems quickly, and taking swift action to remedy abnormal situations*

NERC security coordinators are the newest and highest operational level of oversight for monitoring grid reliability in real time. Traditional methods of displaying operations, such as tabular views and on-line diagrams, are no longer adequate for responding to new real-time wide-area monitoring needs in a competitive electricity market. Information visualization systems based on graphic-geographic technologies must be designed, developed, and demonstrated.

- **System Security Management Tools**

Milestones:

4. *Research, develop, and demonstrate integrated security analysis infrastructures responsive to the changing conditions and increased rate and number of transactions that are part of a competitive market*

This milestone complements the milestones listed above under topic 1, thereby extending the functionality of tools so that they not only monitor the adequacy of supply and demand, but also include real-time security features for security coordinators and dispatchers. Current security analysis consists of numerous software tools (some off-line and some on-line) that predict system conditions in response to proposed contingencies. Alternative frameworks must be investigated for integrating these tools into a comprehensive package that can respond effectively to changing conditions, simultaneous transactions, and new reliability models.

5. *Evaluate and assess current congestion management methods employed by ISOs. Research, develop, compare, and demonstrate alternate methods to address the impact of unanticipated flows and predict their impacts on system security and reliability*

In a dynamic, competitive market, grid security limit margins can be reduced and even violated as weather conditions shift from region to region causing changes in load, generation and interchange transaction patterns, and unanticipated outages. These limitations cause congestion that affects transaction scheduling and market efficiency. Tools are needed to deal with congestion so that reliability and security are maintained. Current ISO congestion management models must be assessed, and methods to enhance and simplify those processes should be investigated and demonstrated.

6. *Research real-time security control for the future*

This milestone will investigate and assess the complex dynamics of cascading power grid failures with the goal of controlling future system disturbances. The research will establish models and tools for a new global approach to cascading failures in stressed power systems, which will complement efforts to analyze cascading events on an individual cause-and-effect basis.

- **Advanced Measurements and Controls**

Milestones:

7. *Develop and demonstrate prototype post-disturbance workstations for operators and operating engineers at ISOs, RTOs, and utilities*

Synchronized phasor measurements provide detailed information on the state of the grid that can be used to augment current knowledge of system conditions and detect the precursors to system collapse. Identifying these precursors in historic events is the first step toward developing systems that can anticipate problems and respond appropriately to future disturbances.

8. *Research, develop, and demonstrate prototypes for improving or replacing current static stability nomograms and remedial action schemes that utilize SCADA real-time information on the overall state of the grid*

The focus of these efforts will be applying data from phasor and other advanced measurement technologies to develop prototype schemes that will complement (and ultimately replace) deterministic methods of predicting operational stability limitations, and that will improve or replace current deterministic remedial action schemes.

9. *Quantify fundamental constraints on wide-area control*

This effort will evaluate the fundamental limitations to providing real-time control of complex interactive networks and likely technological limitations of advanced methods of control and communication.

10. *Research and develop new control methods for real-time wide-area control*

High-quality system SCADA data and information available from synchronized phasor measurements and other advanced monitoring sources and techniques for responding to real-time changes will be combined with developments in computational capability to develop a controller that dramatically improves effectiveness and stability in the network. Ultimately, this controller will be able to detect and analyze system disturbances and initiate action to suppress them in real time with minimal operator intervention. The control system might be coupled with existing equipment and with load control or other system reconfiguration mechanisms to take full advantage of transmission system transfer capacity.

11. *Develop a prototype and simulate and demonstrate the responsive and reliable high-performance grid concept*

This milestone demonstrates the concepts described above by implementing selected technologies in a real power system and evaluating their effectiveness. The robustness of these technologies must be assured through extensive testing and evaluation. The ultimate objective is a power grid that is both responsive to changing conditions and resilient to system disturbances.

12. Establish a wide-area dynamic information network

This is an advanced demonstration project building on the wide area measurement system (WAMS) effort as well as on federal technologies for data mining, visualization, and advanced computing. Core technologies also include centralized phasor measurements, mathematical system theory, advanced signal analysis, and secure distributed information processing. This dynamic information network will provide a test bed for new technology and will also provide information to other wide-area control projects. Focus issues include direct examination and assessment of power system behavior, systematic validation and refinement of computer models, and sharing of WAMS technologies developed for these purposes. This milestone will involve extensive cooperation and collaboration with electric utilities adopting these technologies. Note that work in this area will support the development of near-term operator tools described above.

Real-Time Grid Reliability Management

	2001	2002	2003	2004	2005
Topic Areas:					
Operational Decision Support Tools and Information Visualization					
Reliability adequacy tools	1				
Area control and area interchange real-time monitoring prototypes	2				
Wide-area information visualization systems		3			
System Security Management Tools					
Integrated security analysis	4				
Congestion management	5				
Real-time security control for the future	6				
Advanced Measurements, Controls, and Tools					
Phasor-based workstations	7				
Stability nomogram improvements		8			
Fundamental control constraints	9				
New real-time wide-area control schemes	10				
High-performance grid demonstration					11
Dynamic information network	12				

Research Area 2: *Reliability and Markets*

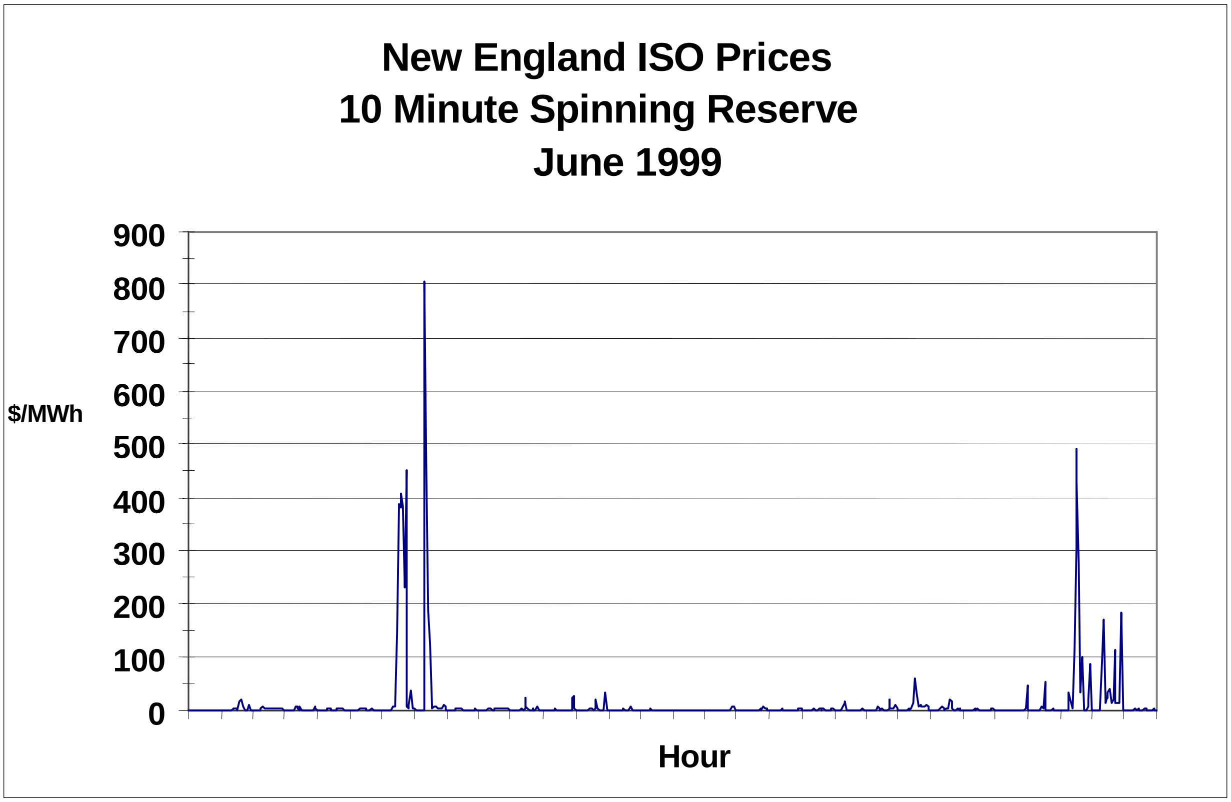
Reliability can only be maintained in a competitive market if appropriate mechanisms and incentives are in place to ensure adequate investment in (and safe operation of) the interconnected power system. The reliability and markets research area will develop software tools and implementation approaches, as well as take a science-based approach to the analysis of evolving institutions to ensure the market's efficacy in maintaining reliability. Topic areas to be addressed include *load as a reliability resource, market tools,* and *reliability-related impacts of market operations.*

Rationale

Reliable power system operation depends critically on the availability of sufficient reliability-related (or ancillary) services to the system operator. Previously, under regulated markets, these services were self-provided by vertically integrated utilities, who recovered the costs through bundled rates. Under electricity market restructuring (through FERC orders 888,889, and now 2000) these services will now be acquired through market-based approaches. The early markets being created around the country, however, are proceeding by a trial and error approach. For the most part, markets have not been designed at all but implemented in response to political consensus. As a result, price caps (and in some cases the suspension of market operations) have been instituted as a quick fix in response to politically unacceptable high prices. However, price caps do not address or correct underlying structural flaws in the market designs that led to these high prices. It is important to establish a sound theoretical and empirical foundation for competitive markets to assure an efficient and reliable electric system. *(*See *Figure 4)*

Part of the cause for the poor performance of some competitive markets is that demand has largely been ignored. Absence of price transparency and the lack of incentives for load to participate in markets is aggravating reliability problems. For the most part, there is only half a market – supply responding to price but fixed demand. The price spikes observed in recent years are a reflection of the apparent inelasticity of demand. Technologies that allow market participants to adjust their demand in response to market prices are the key enabling step currently missing from this process. Equally important, both system operators and participants need to improve their understanding of the institutional and market forces that will guide the development of these markets. A variety of market participants, ranging from utilities with existing load management programs to end-use customers to new entrants, such as Energy Service Companies (ESCOs), power marketers, and load aggregators, are all seeking opportunities to participate in bulk power markets for load as a reliability resource.

Figure 4



During June 1999, an early heat-wave caught members of the NE ISO with numerous assets off-line for maintenance. The resulting strain on ancillary services is indicated by the above chart, showing hourly prices for 10 minute spinning reserve during this month. The peak price of over $800/MWh is 800 times greater than the median price of $1.00/MWh and 70 times greater than the average price of $11/MWh.

The problems of price volatility and price spikes are not the only new challenges for reliable grid operation in a competitive market. Whereas in the past trade was minimal and the resulting patterns of power flows were well established, today trade has grown (and will continue to grow) significantly and flows of power have become far less predictable. Operators must now routinely manage grid operations for power flow patterns that are unfamiliar and that can change at the last minute from previously conducted planning studies. Also, market participants are criticizing the conservative cost-insensitive approaches of current reliability management (e.g., transmission load relief procedures) for unfairly restricting trade. A better understanding of market operation can minimize market interference and guide operation decisions for both improved reliability and market performance. Specifically, market simulation tools that predict hour-ahead and day-ahead market operations (most likely in a probabilistic manner) would greatly assist system planners and operators in managing the grid reliably. In principle, these tools could also help market participants anticipate and respond to system needs through market-based approaches.

Finally, there is a role for science-based analysis of reliability-related market issues by an unbiased non-market participant to guide the formation of appropriate public policies. A market analysis capability is needed to provide ongoing, physically and economically consistent evaluations of market operations in order to better understand current market events (e.g., price spikes) and to examine the likely effects of potential market design changes.

Research Objectives

The Reliability and Markets research area endeavors to support fair market operation, while ensuring potential service suppliers have the proper information and adequate incentives to maintain reliability. Areas of research and development include:

- Technologies to enable customer participation in providing reliability resources;
- Market tools to guide decision-making by system operators; and
- Assessment of effectiveness of emerging market mechanisms to meet reliability needs.

Topic Areas

- **Load as a Reliability Resource**

Milestones:

1. *Assess the capabilities available for using load as a reliability resource*

Complete a survey of present uses of load as a reliability resource, with particular attention paid to those resources that are under utility control. Establish a list of sites and locations identified as candidates for use as experimental sites, complete with the size of load, a description of the site characteristics that make it suitable for the demonstration, and the communication and/or control requirements necessary to make this site act in a “load as a resource” category.

2. *Demonstrate the use of load as a reliability resource*

Secure sites to participate in the experimental demonstration of capabilities. Install necessary equipment suitable to have load respond to prices or reliability event signals. Perform testing of the capability and its performance.

3. *Measure the effectiveness of load as a reliability resource*

Verify and report on findings regarding the use of load as a reliability resource by inspecting data from incidents where load may have been used to enhance reliability, both in the experimental sites and in other sites where load may have been used to enhance system reliability. Measure, quantify, and report results.

- **Market Tools: Creating and translating nomograms**

Milestones:

4. Survey existing nomogram-like methods and system limits

The two main systems to be surveyed include the various published NERC protocols and those published by the CAISO. Also consult with FERC. Obtain a comprehensive list of all limits that are anticipated for that particular system and also identify all the actions that one may take to prevent the violation of each limit.

5. Analyze means for translating physical limits into market price signals

Investigate various means for translating every conceivable physical limit of the power system and convert it into an appropriate market signal. When multiple limits must be taken into consideration, the result will be a nomogram-like structure that can be passed along to the market. A theoretical analysis of means for translating every possible physical system limit into a market price signal is essential to have markets respond correctly to system needs. A comprehensive effort will be directed to considering how to translate every possible physical limit into a reasonably accurate market signal.

6. Work with operators and market participants to implement nomograms

Prior to actual work with systems and operators, work with experimental scientists to test ideas of nomogram-based market design. After appropriate testing in an experimental setting, work with at least one system operator and one market participant to implement the ideas in this project. Report on the results about the suitability of a particular nomogram structure.

- **Market Tools: A National Electric Power Auction Experiment**

Milestones:

7. Investigate specific proposed changes to the California Market

This work will have an immediate focus of ascertaining, using experimental economics within the context of simulated power systems, the anticipated effect of the various proposed rule changes to the California Market. The outcome will be a report with descriptions of anticipated effects.

8. Test the effects of a load demand market

This milestone will integrate demand management and demand bidding into experimental markets and ascertain the effect that these can have on price spikes and other system abnormalities. The impact of load demand on reliability enhancement will also be assessed.

9. Test the performance of day-ahead/balancing markets

New experiments will be conducted that test the behavior of markets under various rules having to do with the balancing market.

10. Test alternative market structures for ancillary services

The experiments will be extended to incorporate the effect of both sequential and simultaneous market clearing of various ancillary services.

- **Reliability Impact of Market Operations: Economic-Based Coordination**

Milestones:

11. Examine significant market events

Efficiency and reliability of emerging electricity markets hinges on the development of efficient real-time markets that provide the settlement mechanism for a broad-based decentralized and liquid forward markets for electricity. This project will examine significant market events (such as circumstances where inadequate reserves or price spikes have been detected) to determine their cause and suggest possible solutions.

12. Create tools that capture system constraints and participant behavior

This milestone will contribute analytical tools focused on longer-term issues of reliability metrics and market performance, and will coordinate with experimental economic analyses of key market design issues in ways that both incorporate the physical constraints of grid operations and realistically capture the behavior of market participants. Prior analysis of market events (such as price spikes) has shown these events to be at least in part the result of narrowing reserve margins. The project will address reliability definitions and market design issues. It will study the differences that various market structures are likely to have on reserve margins and reliability.

13. Determine the behavior of markets at the "seams"

Of particular concern will be the impact of operating distinct markets (the "seams" in the markets), which can give rise to reliability problems as a result of lack of coordination, and the integration of energy markets with reserve markets in multiple time frames. At the core of such coordination is congestion management. Examine the present operation of various markets vis-à-vis reserves and unit commitment, and identify ways to integrate markets for reserves with markets for real energy so that criteria for system reliability and economic efficiency are met.

14. Connect reliability concepts to market concepts

Re-examine existing definitions of reliability and the NERC requirements. The principal objective of this milestone is to show how to use markets to establish and improve reliability to commercially viable levels.

Reliability and Markets

	2001	2002	2003	2004	2005
Topic Areas					
Load as a Reliability Resource					
Available capabilities survey	1				
Demonstrate load as a reliability resource	2				
Measure the effectiveness of loads		3			
Market Tools: Creating and translating nomograms					
Survey existing nomogram methods	4				
Translate physical limits into market signals		5			
Implement and test nomograms			6		
Market Tools: A national power auction experiment					
Investigate California market	7				
Test effect of load management	8				
Test performance of balancing markets	9				
Test ancillary service structures	10				
Reliability Impacts of Market Operations					
Examine significant events	11				
Tools to study behavior and constraints	12				
Study market seams	13				
Connect reliability and markets	14				

Research Area 3: *Distributed Energy Resource (DER) Integration*

Over the next 20 years, the nation's power system is expected to evolve into a more dispersed or distributed infrastructure with improved economics, efficiency, and reliability. Maintaining overall electric system reliability throughout this transition will require new design and control approaches that allow a gradual, staged transition from today's distribution infrastructure. The TR Program will address aspects of integrating distributed energy resources that impact the reliability and stability of the national power grid. It will pioneer and demonstrate the *MicroGrid Concept*, which envisions a local electric grid with multiple small (< 200 kW) DER technologies that can either be integrated with or operated in isolation from the existing power system. Through *DER Technology Integration*, the program will also support the activities of the DER Office within the Office of Power Technologies by providing power system expertise and support for reliability-related technical integration issues associated with all DER technologies.

Rationale

DER, such as micro-turbines and fuel cells, are in transition from the lab to the market. A defining characteristic of these technologies is that they are active devices installed on distribution systems as opposed to transmission systems. While no specific size range has been defined, most distribution systems would have difficulty accommodating generating resources larger than 10 MW/MVA at any single location; many systems may have even lower limits. DER includes generation resources such as fuel cells, micro-turbines, photovoltaics, and hybrid power plants; storage technologies such as batteries, flywheels, ultra capacitors, and superconducting magnetic energy storage; and customer end-use load controls. DER may be installed by the distribution utility in support of local system management goals or by customers to meet needs for increased power quality and reliability – neither, however, have an express intent to support the entire system considering both sides of the meter as an integrated whole.

Current projections call for dramatic increases in distributed energy resources – as much as 15-20% of new capacity by 2010.[5] Large-scale adoption of DER represents a significant technical challenge because it requires a fundamental re-thinking of the design and operation of distribution systems. Distribution systems are normally designed and constructed based on the assumption of radial operation, in which power is assumed to flow in one direction, from an identified source to the load. (This is different from standard transmission practices, which are typically based upon networked operation.)

[5] See, for example, Strategic Plan for Distributed Energy Resources, US DOE, September 2000

Research Objectives

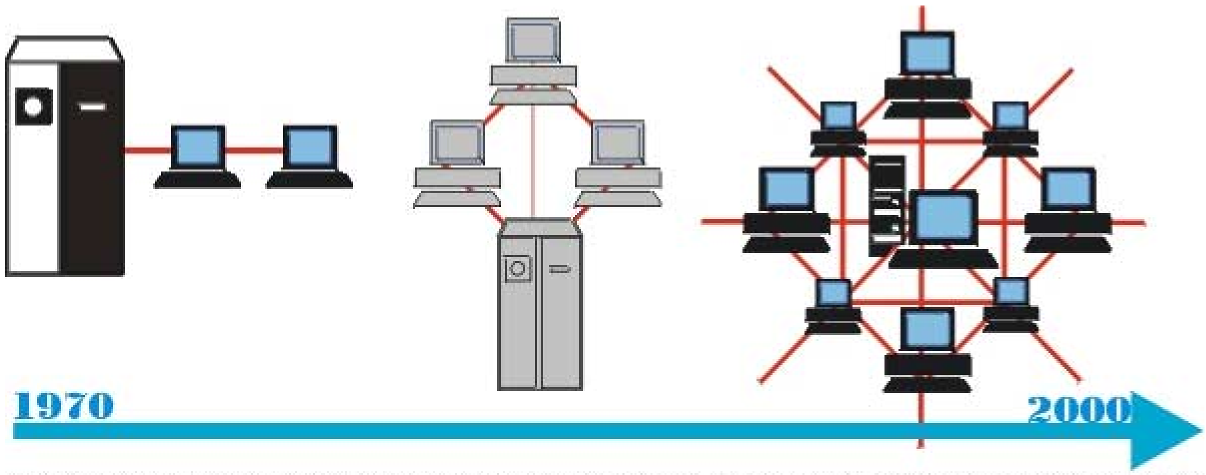
In the area of DER Integration, the TR Program will develop and demonstrate the reliability-related technical requirements and technologies necessary to support large-scale penetration of distributed energy resources into the existing distribution system infrastructure. Research will focus on:

- Demonstrating the MicroGrid concept, which involves decentralized operation of multiple, small (< 200 kW) DERs both in parallel with and in isolation from the grid.
- Supporting reliability-related system integration activities of the DER Office within the Office of Power Technologies.

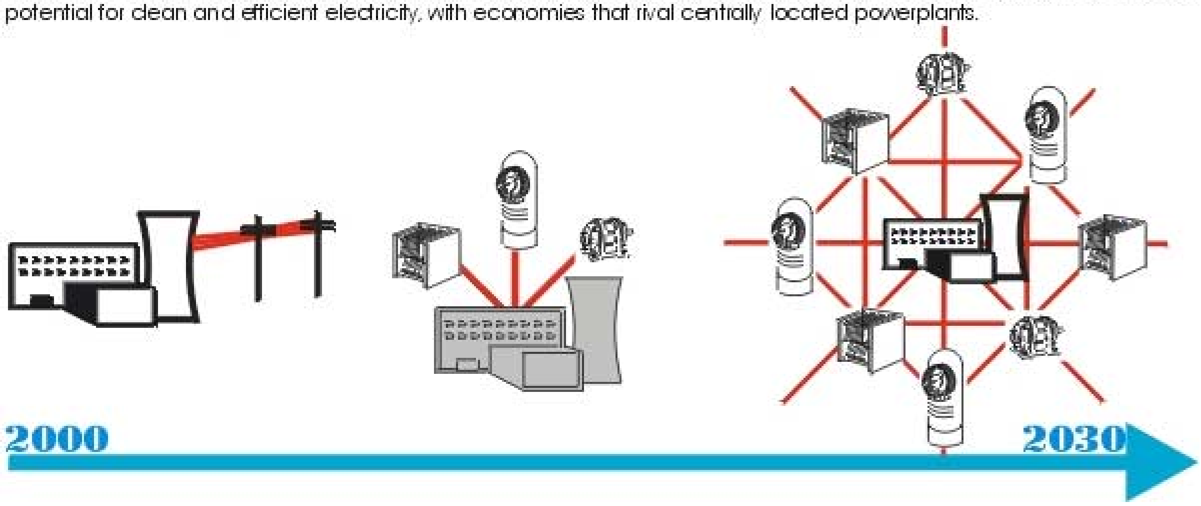
The radial assumption affects all aspects of distribution design and operation, from voltage regulation to fault current protection. Interconnected distributed resources violate the radial assumption by introducing active sources throughout the distribution system. At low penetrations of distributed resources, which is typical of the applications currently in operation, system disturbances are accommodated simply by forcing the distributed resource off-line until steady state conditions are resumed. At high penetrations of distributed resources, design and operational schemes that manage reliability locally must be explored.

A key concept for achieving this is the development of adaptive system islands or “MicroGrids.” Under this vision, integrated clusters of small (< 200 kW) DER provide firm power with a guaranteed level of power quality through operation in either grid-connected or island modes. Realizing this vision will require the development of methods (ideally, decentralized rather than centralized) for management of electric grids with high penetrations of DER. It is essential to develop design approaches that not only accommodate high penetrations of DER, but also allow a gradual, staged transition from today’s distribution system infrastructure. *(Figure 5)*

Figure 5



Technology advances allowed information processing to evolve from a centralized, linear system to a more flexible and lower cost interconnected network (above). Over the next thirty years, many predict a similar path for power production (below). Our current electric network connects users to central station powerplants via an array of transmission and distribution wires. The emerging distributed power options (fuel cells, microturbines, engines, photovoltaics, etc.) offer the potential for clean and efficient electricity, with economies that rival centrally located powerplants.



Topic Areas

- **MicroGrid Demonstration**

Milestones:

1. Industry recognition of and participation in advancement of the MicroGrid concept

Describing a well-grounded vision of the MicroGrid concept and engaging stakeholder interest and support for it is the first step toward demonstration of the most promising options in the field. Engagement of the manufacturers and developers at this stage is likely to influence how they perceive their products will operate in the real world and the functional requirements their systems will have to meet. A key objective is to engage distributed generation (DG) hardware and software developers/vendors in this dialogue to constructively influence their design decisions as they develop the commercial products for the DG market. The current stage of pre-commercial development of smaller DG technologies (<200 kW), such as microturbines and fuel cells, is very timely to the interjection of the MicroGrid concept. Similarly, power park developers, including UC Irvine, will be engaged in this effort to discuss the MicroGrid concept and offer collaborative design assistance to develop both the operating requirements and the economic analysis from a MicroGrid perspective.

2. *Functional Requirements of the MicroGrid to Ensure it Operates as a "Good" or "Model" Citizen of the Grid*

This topic area focuses on the "single entity" concept that the MicroGrid presents to the power system. The MicroGrid as a whole can respond to central control signals without the central controller's intervention to dispatch 10s to 100s of micro-sources within the MicroGrid. An important question is, "What economic and reliability benefits can a MicroGrid can bring to the power grid?"

It will be necessary to specify both the minimum requirements that will make the MicroGrid a "good citizen," and the desirable characteristics that can make it a "model citizen," by improving the reliability, security, and economics of the power grid. Current efforts to establish interconnection guidelines for DER are derived from the experience of the traditional distribution utility point-of-view. This topic area will expand the discussion to examine the interconnection issues for a "good citizen" perspective, consider alternative interconnection rules for a MicroGrid, and specify the interface hardware requirements.

The "good citizen" MicroGrid is a passive but benign actor in the distribution system, whereas the "model citizen" MicroGrid actively attempts to achieve efficient and reliable operation of the wider power system. Beyond obeying the rules, activity in this area will evaluate the potential contributions of the MicroGrid to the overall health of the grid and the nature of economic and engineering structures that would make this possible. The final objective is to define an aggregate model of the MicroGrid that will be used to study the impact of MicroGrids on the wide-area power network.

3. *Develop MicroGrid study tools and related model data*

These activities focus on the internal functionality of the MicroGrid to meet customer needs by addressing the critical requirements within the MicroGrid's own boundaries. These include control, protection, use of waste heat, quality of power to meet the internal customer needs, and tools to design a MicroGrid.

The near-term activity in this area is comprised of coupled research projects that will address: protection, control as it relates to the internal operation of the MicroGrid, including an understanding of the use of combined heat and power, and related design tools.

The protection area will study the unique internal protection requirements presented by MicroGrids. It is evident that the protection requirements are different than traditional utility considerations and the protection requirements for MicroGrids, both at the grid interface and internally, need to be addressed early on in the development of the concept. While traditional protection schemes may be adequate at the interface, a different set of considerations may govern the protection internal to the MicroGrid, which is highly dependent upon the short circuit currents provided by the micro-sources and power grid.

The control area will study the internal operation and control of the MicroGrid to define the requirements and specify their design. The basic assumption is that of plug-and-play for the fast response needs and a control/communication system to provide the "acceptable characteristics" to the grid for slower responses. The MicroGrid should appear as an autonomous power system that meets the requirements of the customer. Voltage, reliability performance, and quality of power should be those that support the customers' objectives. From a control prospective, techniques will be developed to significantly lower the system complexity encountered with the addition of extra micro-sources to a MicroGrid. The presence of inverter interfaces in fuel cells, photovoltaics, micro-turbines, and storage technologies creates a different situation when compared to more conventional synchronous generator sources in power sources and standby emergency power systems. Taking advantage of the properties of the power electronic interface to provide additional functionality to the MicroGrid and localized inverter control technology, along with a minimal amount of short energy storage at the dc bus, forms the basis for the approach. Various features of the inverter control could include: plug-and-play, seamless connection and isolation from the electric grid, independent control of reactive and active power, and ability to correct voltage sags and system imbalances. All are critical for the creation of a MicroGrid.

The penetration of DER hinges on the availability of study tools that can adequately treat significant penetration of microsources in the power distribution network as well as handle the unique features of the MicroGrid. Tools must be capable of addressing not only central generation feeding power to the distribution network via the substations (as they do currently), but also MicroGrids (multiple microsources locally controlled in a coordinated fashion via central network control signals), centrally controlled microsources not clustered in a MicroGrid, and finally microsources randomly placed by customers. The required tools are principally steady-state, but ultimately small signal dynamics tools will also be developed. The tools must be capable of assessing various loading scenarios (change in load demand — electric and thermal — with the time of day and time of year) and assessing multiple generating/loading scenarios for analyzing optimal locations, etc.

4. Demonstrate the MicroGrid concept

One or more demonstrations of MicroGrid concepts will be initiated in FY02. The TR Program is currently in discussions with a variety of stakeholders, including UC Irvine and NRECA.

- **DER Technology Integration**

Milestones:

5. Serve as a technical resource to the DER Office for reliability-related system integration issues associated with DER

The recently formed DER Office is consolidating and coordinating a variety of DOE DER research and demonstration activities to not only facilitate the early and smooth implementation of distributed technologies, but also to assess the benefits and impacts on the electric grid and the barriers to implementation. The TR program will provide technical support for the reliability-related issues associated with system integration of DER, including support to broader roadmapping activities; technical review and participation in selection committees for solicitations; assistance in articulating modeling data requirements from related field and laboratory demonstrations; participation in relevant industry committees; and related activities as directed by the DER Office.

Distributed Energy Resource Integration

	2001	2002	2003	2004	2005
MicroGrid Demonstration					
Gain acceptance for the MicroGrid concept	1				
Analyze functional requirements	2				
Study electric system integration – protection, control, modeling	3				
Demonstrate the MicroGrid		4			
DER Technology Integration	5				

Research Area 4: *Reliability Technology Issues and Needs Assessment*

This research area recognizes the need to communicate regularly with stakeholders in an ongoing process of strategic program planning and outreach. The *DOE Reliability R&D Planning* activity will provide a continuous dialogue with stakeholder and user groups to identify strategic issues and research gaps, prioritize appropriate research needs, and – most important of all – ensure smooth transfer of research results to industry applications. The TR Program will work closely with stakeholder groups to ensure that limited program resources address the most important needs, consistent with the appropriate federal role in addressing them.

Rationale

As utilities prepare for a more competitive electricity market, industry R&D spending has declined dramatically. The objective of DOE's TR program is to identify and support critical public goods through reliability R&D activities that will not or cannot be supported by today's industry. Prioritizing these activities must be informed by on-going assessments of the need and role of federal support in ensuring timely development of needed reliability technologies and systems.

Research Objectives

In the area of Reliability Technology Issues and Needs Assessment, the TR Program will conduct a strategic planning activity that:

- identifies emerging critical issues for the reliability of the U.S. interconnected electric power system,
- analyzes these issues to identify gaps in needed (or enabling) reliability technology research and development, and
- prioritizes and initiates planning for needed federal research and technology development.

Topic Areas

- **DOE Reliability R&D Planning**

Milestones:

1. *Milestones for this activity are ongoing in response to industry and DOE needs. This activity will form the conceptual basis and conduct the market assessments necessary to ground future research and technology development activities. Thus, the practical value of work in this area will be the successful implementation of recommendations for future R&D.*

For example, DOE's POST recently identified industry needs for research in cable monitoring and diagnostic techniques, and in "best practices" for maintaining system reliability as a high priority. At the same time, POST also reported that significant industry activity to address these needs is already underway.[6]

Similarly, recent interest in distributed energy resources is creating demands for the development of low-cost, highly reliable power electronics interfaces to the grid as a key enabling technology. Strategic assessments of these activities, conducted with industry stakeholders and in coordination with the DER Office, are essential for crafting meaningful and appropriate federal enhancements to current private sector activities.

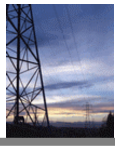
Another topic under this research area is the need for transmission upgrades and expansion to relieve congestion and facilitate competitive markets. Power flows for which the system was not designed are creating bottlenecks and strain on the transmission system. These bottlenecks are causing price excursions and, in some cases, rolling blackouts. This complex assessment will involve examination of the economic, regulatory, technical, and environmental issues surrounding the design of market structures to provide appropriate incentives for transmission system expansion.

In some cases, the results of these strategic assessments will lead to the creation of new Advanced Technology R&D activities for the TR Program. It would be premature to identify these activities at this time until the assessments are complete. However, it is appropriate to reflect the likely need for program resources that in future years will be required to support them.

Reliability Planning and Management

	2001	2002	2003	2004	2005
Support DOE R&D Planning	1				

[6] For example, EPRI has announced a Reliability Initiative that will among other things foster information sharing on "best practices" for maintaining system reliability.



Managing for Success

Organizing the Program

The organization and implementation of the TR Program are structured to take advantage of the recommendations of our nation’s scientific, regulatory, political, academic, industry, and consumer leaders. Participation by such a wide variety of stakeholders necessitates a management structure attuned to the interests of these stakeholder groups.

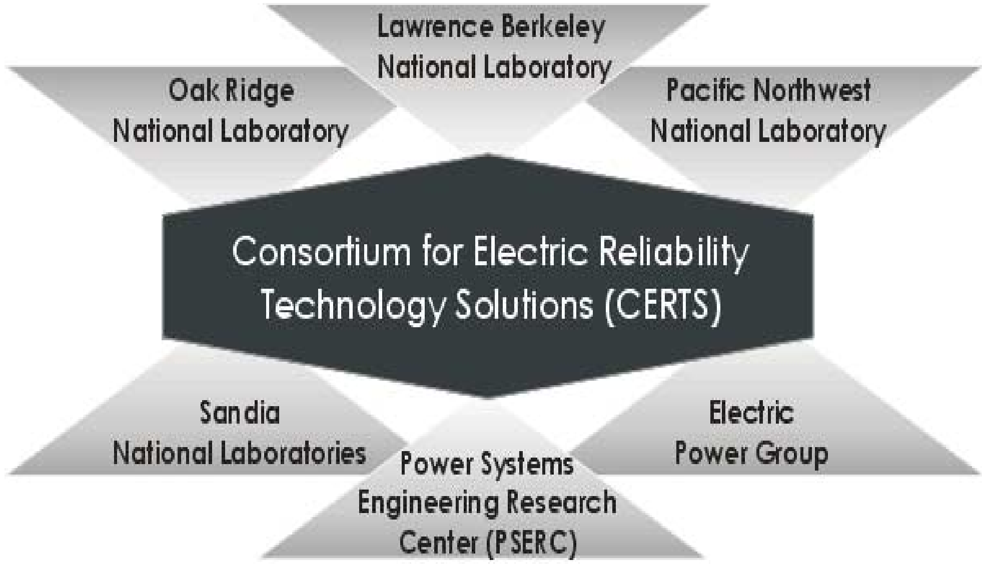
Program management for TR resides within DOE’s Office of Energy Efficiency and Renewable Energy under the Deputy Assistant Secretary for Power Technologies. The program develops R&D plans and budgets that respond to established policies and goals as set forth in the Office of Power Technologies Strategic Plan. The program also develops an annual operating plan consistent with allocated resources, directs the implementation of the plan, and conducts reviews of the program’s progress.

TR Program Management has the additional responsibility of coordinating activities throughout DOE and the Federal Government. This includes:

- Coordination with DOE’s programs on Critical Infrastructure Protection and Natural Gas Delivery and Storage for developing technologies and systems to maintain and enhance the reliability and security of the nation's complex electricity and natural gas delivery infrastructure.
- Participation as a member of the DER Office to achieve the goal of reducing costs and emissions, and increasing the efficiency of DER to provide 20% of new generating capacity additions in the U.S. by 2010.
- Participation in POST, to independently investigate selected power events as needed (see text box on page 3).
- Coordination in planning with the Distributed Power and Energy Storage programs.

DOE has tasked the Consortium for Electric Reliability Technology Solutions (CERTS) to assist in implementation and operational management of the program. CERTS combines the resources of national laboratories, industry, and universities into an organization that carries out the day-to-day operations of the program (*Figure 6*). In this capacity, CERTS is responsible for assisting DOE in strategic and annual planning for the program, monitoring the technical aspects of the program (including meeting established goals), coordinating with researchers, and presenting results in the form of progress reports and technical reviews. At the direction of DOE, CERTS may also be responsible for forming R&D partnerships and managing subcontracts. CERTS has established an industry advisory board to seek input on the direction and management of the program.

Figure 6: *Organization of CERTS*



Working with Our Partners

The TR Program works with a variety of private and public sector partners to improve electric system reliability. Market participants and organizations that represent manufacturers, electricity suppliers, and policy makers have already provided their views on requirements, and DOE looks forward to their continued participation. These participants include the North American Electric Reliability Council (NERC), Institute for Electrical and Electronics Engineers (IEEE), Edison Electric Institute (EEI), National Association of Regulatory Utility Commissioners (NARUC), American Public Power Association (APPA), National Rural Electric Cooperative Association (NRECA), Electric Power Research Institute (EPRI), and Power Marketing Administrations (PMA), which includes the Bonneville Power Administration, Western Area Power Administration, and Tennessee Valley Authority (TVA).

Starting in 2000, TR Program activities were extended through funding provided to CERTS by the California Energy Commission's Public Interest Energy Research (PIER) program. Among other activities, the PIER program is sponsoring demonstrations of DOE-funded prototype reliability tools at the California ISO that will assist system operators in managing reliability starting in Summer 2001.

TR Program Management will work attentively with these and other organizations responsible for electricity service reliability to ensure that research results are timely and meet the needs of the emerging competitive market. One example of this interaction is working with ISOs, control area operators and, eventually, RTOs to demonstrate new software innovations that predict transmission problems and allow operators to re-route or restore power flows. Federal research efforts will yield advanced diagnostic and control techniques to assist Security Coordinators and others with their responsibilities for reliability management. DOE is already working closely with NERC to assure that all operators are aware of these tools and are properly trained to use them.

Funding the Program

In 1998, Congress directed DOE to renew its involvement in electric system reliability R&D and appropriated $2.5 million for FY 1999. Congress continued the effort by providing $2.4 million in FY 2000 and $5 million in FY 2001. DOE has requested $7.0 million for FY 2002.

DOE will continue to request additional funding over the next four years to establish expanded support for the *Real-Time Grid Reliability Management* and *Distributed Energy Resource Integration* research areas. The *Reliability and Markets* area is expected to peak in FY 2002 and diminish as software tools are incorporated by industry and more mature markets are established that can sustain a reliable power grid. Finally, basic research advances coupled with identified research gaps in the *Reliability Technology Issues and Needs Assessment* area are expected to necessitate *Advanced Technology Research* by 2003 on topics such as power electronics. Thus, funding for Transmission Reliability is expected to grow, reaching $10.0 million in FY 2005. *(Figures 7 and 8)*

Figure 7 *– Expected Transmission Reliability Funding Growth by 2005 ($ in Millions)*

Research Area	2000	2001	2002	2003	2004	2005
Real-Time Grid Reliability Management	0.7	2.2	2.2	3.0	3.4	3.4
Reliability and Markets	0.7	1.3	1.3	2.4	2.0	1.5
Distributed Energy Resources Integration	0.8	0.8	0.6	2.0	2.5	3.0
Reliability Technology Issues and Needs Assessment	0.2	0.2	0.2	0.6	0.6	0.6
Advanced Technology Development	--	--	0.2	1.0	0.5	1.5
TOTAL	2.4	4.5	4.5	9.0	9.0	10.0

Measuring Our Success

Federal support for the TR Program is highly leveraged with industry-supported research and development to accelerate the introduction of new software and hardware. The ultimate goal is to maintain and enhance the level of service reliability during the electricity market transition; programmatic metrics have been established to aid in assessing progress. These metrics include:

- Number of industry partners, which is indicative of broad participation in the federal TR research effort;
- Amount of industry cost-sharing that leverages federal funding and confirms that federal R&D identified in cooperation with industry is on a path toward commercial use; and
- Number and dollar value of software and hardware products transferred and being used by reliability management organizations (e.g., ISOs) and institutions (e.g., NERC).

Figure 8