CEIDS and The Power Delivery System of the Future

Clark W. Gellings
Electric Power Research Institute

CEIDS is pursuing a defining set of major power delivery system science and technology infrastructure requirements for the future.

Introduction

EPRI's Electricity Technology Roadmap describes a pathway to the future which begins with one of the most fundamental of electric functions: getting electricity from the point of generation to the point of use. Power delivery has been part of the utility industry for so long that it is hard to imagine that this process has not already been optimized. However, the power delivery function is changing and growing more complex with the exciting requirements of the digital economy, the onset of competitive power markets, the implementation of modern and self-generation, and the saturation of existing transmission and distribution capacity. Without accelerated investment and careful policy analysis, four vulnerabilities already present in today's power system will continue to degrade. The four vulnerabilities are: The Security of Power Delivery and Market Systems; The Quality of Power Supplied; The Reliability of Power Supplied; and The Availability of Affordable Energy Services. Resolving these vulnerabilities will yield benefits in the trillions of dollars annually for an investment of as little as $100 billion. However, numerous science and technology challenges remain before these investments can be made. Only actions taken today to increase the level of research and development will allow the needed developments to evolve. Without careful attention, the enormous benefits which an advanced power delivery system can bring to society – will never take effect.

Simply stated, today's electricity infrastructure is inadequate to meet rising consumer needs and expectations. Indeed, a sharp decline in critical infrastructure investment over the last decade has already left portions of the electric power system vulnerable to poor power quality service interruptions and market dislocations. Substantial system upgrades are thus needed just to bring service back to the level of reliability and quality already required and expected by consumers, and to allow markets to function efficiently so that consumers can realize the promised benefits of industry restructuring.

To assure that the science and technology is available to address the infrastructure needs, The Electric Power Research Institute (EPRI) and the Electricity Innovation Institute (E2I) have initiated an ambitious program. The Consortium for Electric Infrastructure to Support a Digital Society (CEIDS) will build public/private partnerships to meet the energy needs of tomorrow's society.

Restructuring and rise of the digital economy have set electricity price, quality and reliability on a collision course. The main riving force behind efforts to increase competition in both wholesale and retail power markets was the need to make inexpensive electricity more widely available – in particular, to reduce regional price inequities. Already the effects of deregulation are being seen in the wholesale market, with both prices and price differentials declining rapidly. The effect on retail markets will come more slowly, but over the next twenty years, the average real price of electricity in the U.S. is expected to fall buy 10% for residential customers, 17% for commercial customers, and 14% for industrial customers. At the same time, however, industry restructuring has not yet provided adequate financial incentives for utilities to make the investments necessary to maintain - much less improve – power delivery quality and reliability.

Meeting the energy requirements of society will require applying a combination of advanced technologies—from generating devices (e.g., conventional power plants, fuel cells, microturbines) to interface devices to end-use equipment and circuit boards. Simply "gold plating" the present delivery system would not be a feasible way to provide the level of security, quality, reliability, and availability required. Neither will the ultimate customers themselves find traditional utility solutions satisfactory or optimal in supplying the ever-increasing reliability and quality of electric power they demand.

In addition, new technology is needed if society is to leverage the ever-expanding opportunities of communications and electric utilities' natural connectivity to consumers to revolutionize both the role of a rapidly changing industry and the way consumers may be connected to electricity markets of the future. CEIDS can enable such a transformation and ushers the direction for building future infrastructure needed.

CEIDS can create and meet new levels of social expectations, business savvy and technical excellence by attracting players from the electric utility industry, manufacturers and end-users as well as federal and state agencies. In order to achieve this, CEIDS will be guided by the following key principles:

Vision:

To develop the science and technology that will ensure an adequate supply of high quality, reliable electricity to meet the energy needs of the digital society.

Mission:

CEIDS provides the science and technology that will power a digital economy and integrate energy users and markets through a unique collaboration of public, private, and governmental stakeholders.

The Power Delivery Infrastructure

Change in the power delivery and electric energy markets sector continues at significant pace. Traditional and emerging transmission, distribution, and retail entities are faced with an array of critical challenges that address, not only the everyday business issues, but more importantly, the long-term reliability, availability, quality, and security of electric power – the life-blood of our economy and the world. Open market access, the design and implementation of new market structures, an aging and inadequate transmission and distribution infrastructure, the lack of effective investment incentives, and the continued emergence of a more sophisticated "digital aged" end-use consumer are creating unprecedented, and often unpredictable, levels of complexity and risk. This is complicated by FERC actions, diverse regulatory pursuits at the state level, the fall-out of the ENRON bankruptcy, and a poor overall industry financial performance.

In today's business world, memories tend to be short. The state of California's soaring electricity prices and rolling blackouts of 2001 are forgotten – or at the least, perceived to have been resolved. However, the major factors underlying California's crisis are present today throughout much of the country.

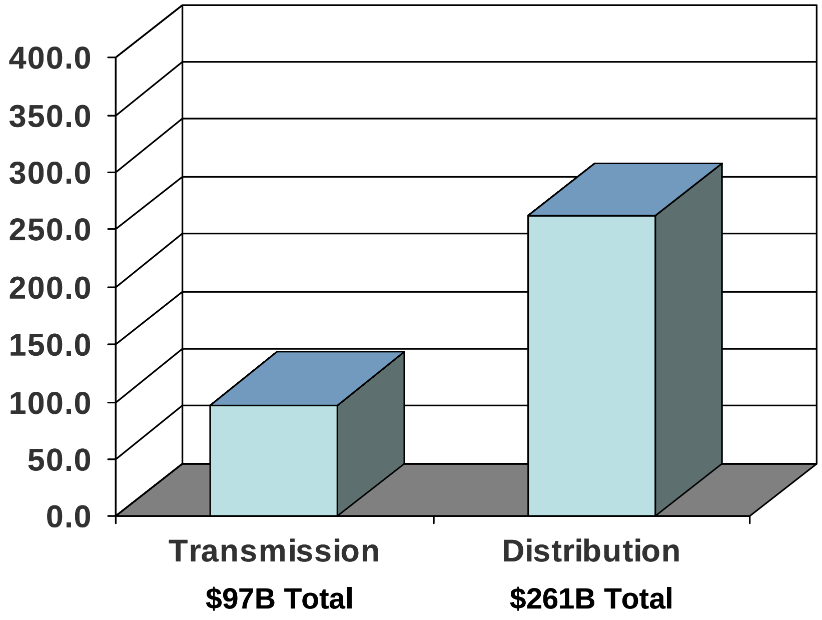
The power delivery infrastructure is literally a national treasure. It is largely responsible for the advancements society enjoys today. However, it is aging, constrained, underutilized and inadequate for tomorrow's economy. CEIDS has begun to identify a suite of technologies which have the potential to remedy these inadequacies and meet the needs of tomorrow's consumers.

An Aging Infrastructure

Today's aging electric power system is largely based on technology developed in the 1950s or before and installed over the last 30 – 50 years. As much as 25% of today's infrastructure will need to be replaced or upgraded over the next 10 years. Key questions surrounding this issue include: How can the exact condition of these assets be determined? How can the life of these assets be extended? What should be replaced vs. upgraded to minimize costs? The answers are not entirely clear and offer many opportunities for research and development.

Figure 1

T&D Plant-In-Service



The US power delivery system is valued at $358 billion, (year 2000 plant in service). While CEIDS science and technology development cannot attempt to remedy deteriorating devices and systems, CEIDS can support developments which would allow the industry to characterize the performance and longevity of all devices, reduce the stress on the infrastructure, and enhance flexibility in controlling it.

Grid Constraints

During the last decade, total electricity demand in the U.S. rose by nearly 30% but the nation's transmission network grew by only 15%. During the same period, there was an increase of 400% in the number of wholesale transactions. The outlook for the next decade is even lower: Demand is expected to grow by 20% but planned transmission system growth is only 3.5%. Investments in infrastructure upgrading will be needed. However, incentives for continued investments are inadequate. While those investments are not a research issue, they can be influenced by the availability of advanced technologies. The gap between demand growth and transmission capacity expansion is illustrated in Figure 2.

Figure 2.
Electricity Demand vs. Transmission Capacity Expansion

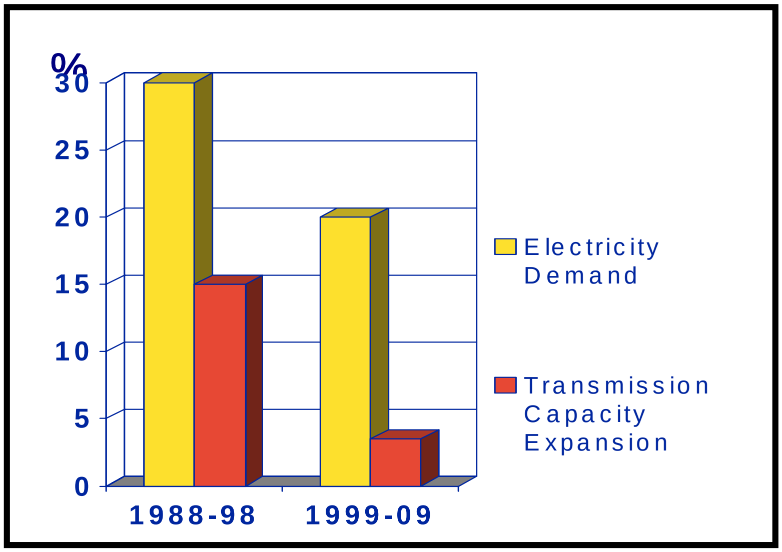
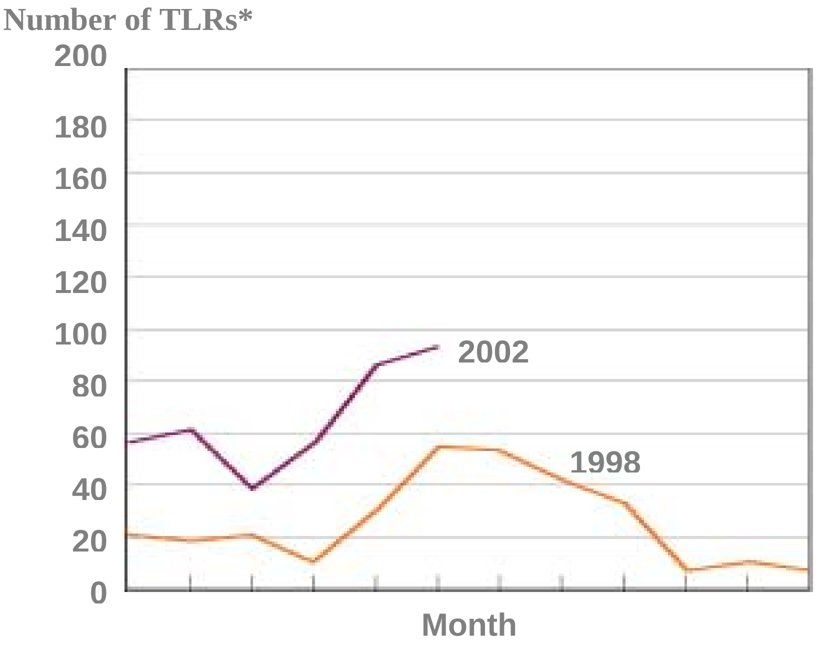


Figure 2 illustrates the number of level two or higher calls for Transmission Line Relief. This illustrates the increasing inability for the grid to handle open markets.

Figure 3
No. of Transmission Line Relief Requests

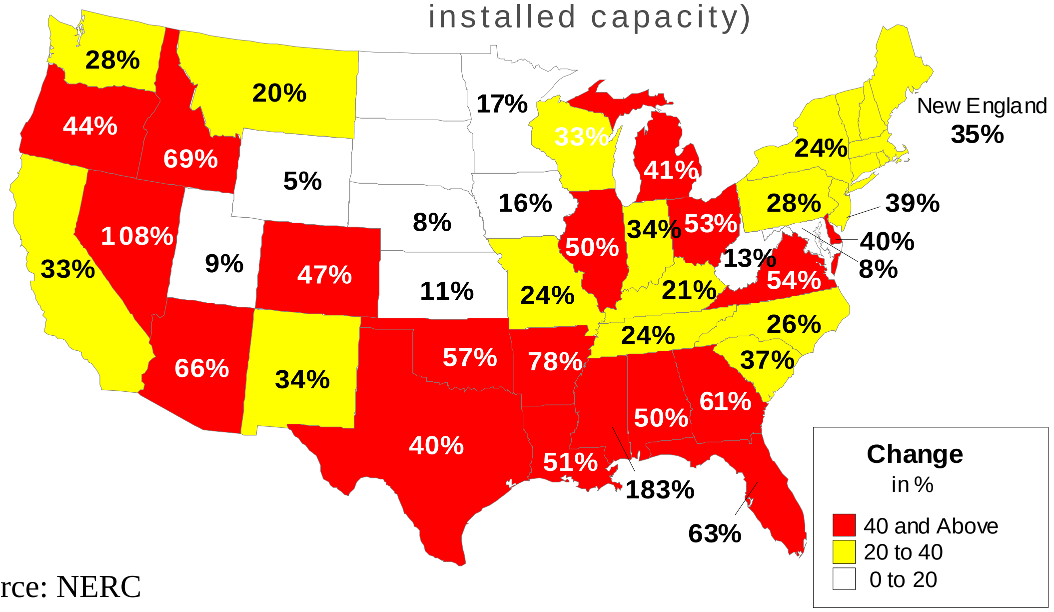


*Calls for Level 2 or higher Transmission Relief
Source: NERC

Figure 3 illustrates the constraints in the Midwest. Constraints are likely to increase if even only a portion of planned generation additions, as illustrated in Figure 4 are implemented.

Figure 4

Projected New Generator Additions 1998-2007 (as percentage of 1998 installed capacity)



Source: NERC

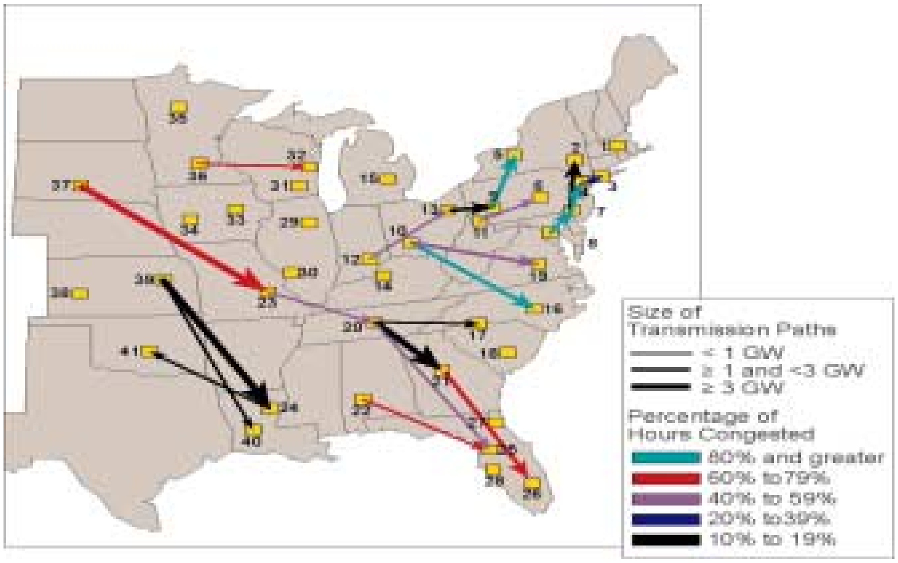
As an example of increasing stress on the power delivery system, Table 1 depicts violations of operating security limits for 1999 through 2001.

Table 1
Violations of Operating Security Limits

Measure	Number of Total Violations Measured		
	1999 Program	2000 Program	2001 Program
Control Performance Standard – CPS 1 and 2	32	22	43
Disturbance Control Standard – DCS	15	13	15
Recovery from operating security limit violation	Not Measured	25	217
Operators have necessary authority documented	Not Measured	29	25
Entities have NERC certified operators	Not Measured	10	192
Transactions implemented only between adjacent control areas	Not Measured	52	243
Transactions tags submitted to the IDC	Not Measured	2	1
Reliability coordinator performs next-day reliability study	Not Measured	4	19

The first solution mentioned to reduce grid constraints is to build new overhead transmission. However, it has become extremely difficult for any entity to site new transmission assets in the U.S. American Electric Power (AEP's) ten-year fight to install a 100+ mile, 765kv line in West Virginia is a prime example. There are no obvious solutions for this largely political and social issue. The difficulty in siting new overhead transmission assets results in an enhanced need for technologies that optimize the use of existing assets and that lower the cost of locating assets underground.

Figure 5
Transmission Bottlenecks Impacting the Midwest



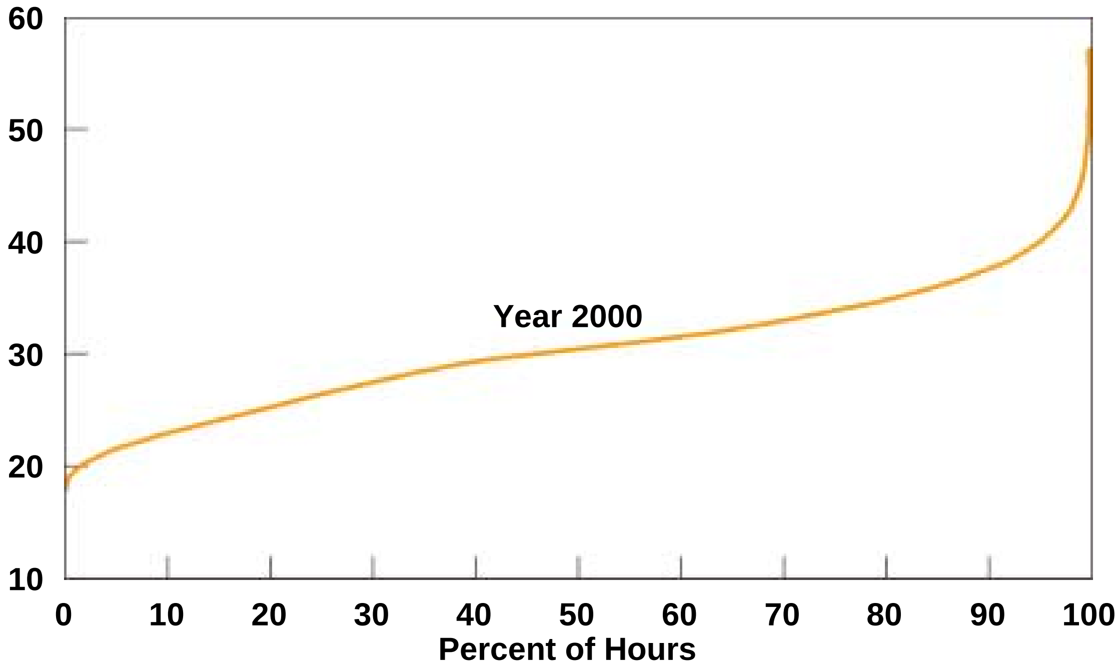
CEIDS cannot possibly promise to remedy all Grid constraints, but there are a number of advanced technologies which, if combined with an overall CEIDS architecture, could substantially impact constrained systems.

Asset Utilization

Power Delivery assets are sized for times of peak usage. Since usage varies by time of use and season, Power Delivery assets are necessarily oversized during most times of the day and most days of the year. Figure 6 is a load duration curve for the entire Pennsylvania-New Jersey-Maryland Interconnection Regional Transmission Operator. As the curve illustrates, assets are loaded 40% or less 90% of the time. This utilization is even lower at some specific circuits or substation levels.

Figure 6

PJM Load Duration Curve (MW x 1000)



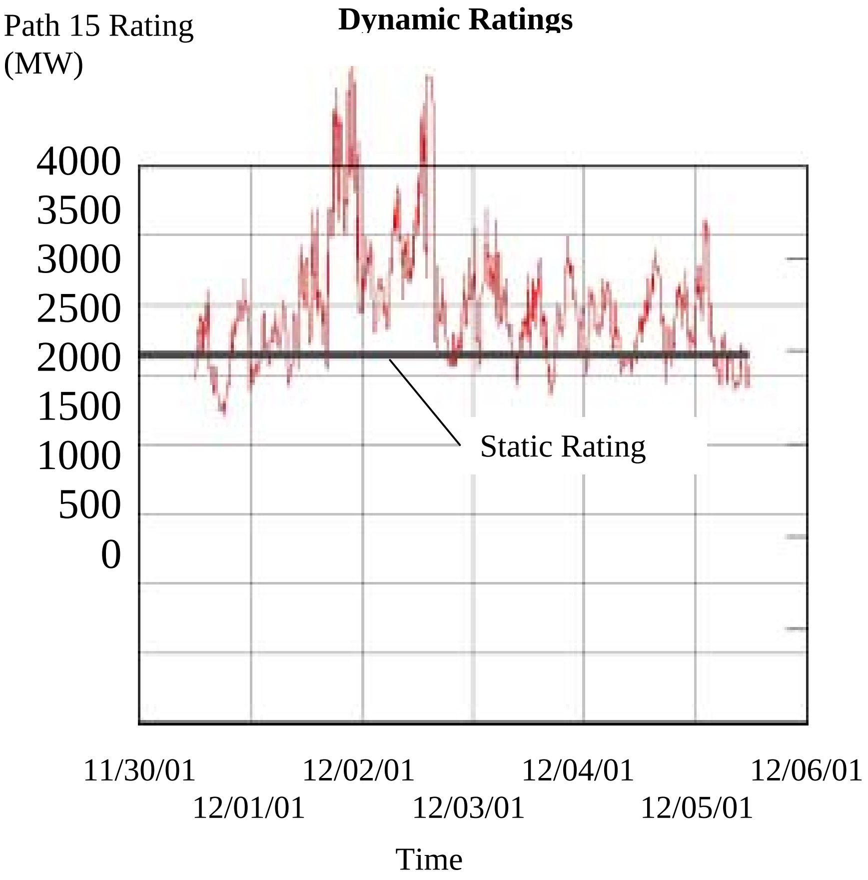
Maximizing utilization of transmission and distribution assets continues to be a priority issue for consumers. The relatively low utilization of assets is not a result of poor planning or management, but rather, the laws of physics and the practicality of customer usage habits. Principally this involves two issues: Sizing and Load Flow.

> **Sizing** - Circuits are generally sized based on peak and variances in load due to weather, time of day, season, and day of the week. This results in circuits that are 100% loaded less than 5% of the time.
>
> **Load Flow** - Electrical system behavior is governed by Kirchoff's Law. Power flow ultimately is determined by system sources and sinks. Power flows through the grid following the path of least resistance or path impedance, and not necessarily along the contract path. As a result, many lines in the eastern U.S. are under utilized by 10% to 15%, and in the western U.S. by as much as 20% to 30%, even during system peak periods.

Transmission assets can be more fully utilized by applying advanced technologies such as FACTS (Flexible AC Transmission System), DTCR (Dynamic Thermal Circuit Rating), Video Sagometer, and advanced energy storage technologies that enable optimization of the use of existing assets during peak periods. These technologies are part of the CEIDS portfolio.

For example, the inability to operate circuits dynamically contributes to underutilized assets. Figure 7 depicts the power flow on infamous path 15 in California. The solid line depicts the static rating used by the system operator to gauge maximum power flow. However, if a system sensors and operating systems were deployed called Dynamic Thermal Circuit Rating or DTCR, the system could be operated dynamically as shown, resulting in the additional capacity shown by the difference between the upper and lower lines.

Figure 7



Reliability and Power Quality

Historically utilities have been concerned about the availability and reliability of power and have paid much less attention to the power quality of their systems. However, the digital revolution rides on the back of the development of new digital technologies that broadly influence improved energy efficiency, productivity, communications, and automation. These technologies, while opening whole new horizons of commerce and innovation, have also exposed vulnerabilities in the traditional technologies, and methods used to interface electric power delivery with digital systems, processes and enterprises.

A critical task is to optimize the interface between electric power delivery and the digital economy. Optimizing this interface will require a strategy that comprises all elements of the power delivery and end-use – from the power plant, to the interconnecting systems, to the response of the digital systems, processes, and ultimately, the enterprises themselves. Tactics that address a combination of implementation techniques, new technologies, and new approaches to interfacing electricity supply with all forms of digital applications will have to be explored.

The impact of digital technologies on modern society is profound and growing, and has broad influence on economic growth, energy efficiency, and productivity. Approximately 12% of U.S. electric energy in 2001 was delivered to digital devices, by enterprises making them, or by elements of modern society that would not exist except for digital technologies. Digital energy use will grow to 16% of the U.S. total by 2011. Poor power reliability already costs consumers over $120B/year. As the growth in digital devices continues, this cost will increase proportionately – unless power delivery technology evolves and is implemented.

There are clear economic and national security imperatives for the U.S. to understand the role that new digital technologies play in modern society, and to understand the, quality, reliability, and availability needs of these important technologies. CEIDS technologies are intended to include Reliability and Quality considerations.

Infrastructure Security

The electricity sector needs to develop a comprehensive strategy to address security threats across the industry value chain. Such a strategy must ensure the public that they are well protected, and free from threats posed by or to the electricity system. In addition, technologies need to be developed to ensure a rapid response capability from any threats that do materialize. While CEIDS cannot alone address security issues, it can be sure Security issues are addressed in modernizing the power system.

Open Markets

Open market access, the design and implementation of new wholesale market structures, and the promise of greater choice among electricity providers brought by competition provides enormous opportunities for delivering on the promise of choice. However, the impacts of the lag between demand and infrastructure investment are already being felt. In four of the last five years, the U.S. has faced serious reliability problems. In August 1996, voltage disturbances cascaded through the West Coast transmission system, causing widespread blackouts reportedly cost California more than $1 billion. In June 1998, transmission system constraints disrupted the wholesale power market in the Midwest, with pricing rising from an average of $30/MWh to peaks as high as $10,000/MWh. Similar price spikes also occurred in the summers of 1999 and 2000. In addition, today’s markets design cannot enable the requisite connectivity between consumers and the market without the substantial evolution of technology to enable consumer connectivity. This is an essential function embedded in the intended CEIDS architecture.

Restructuring

A considerable amount of uncertainty still exists across the electricity sector. FERC's issue of the giga NOPR and continued "push" toward the formation of Regional Transmission Organizations (RTO's) or Independent Transmission Providers (ITPs) has increased the uncertainties.

Utility Financial Performance

Many electric industry participants are under significant budgetary pressures due to their respective company stock prices, as well as, the fallout caused by the Enron bankruptcy and performance of the industry as a whole. The Dow Jones Utility index is down approximately 18%, and several once "high-performing" energy trading companies have ceased operations or dramatically scaled back operations (e.g. Aquila, Williams Energy). The market capitalization of the top 25 power companies has dropped 40% since January 2001 (note: eliminating ENRON reduces this decline to 25%). Today's investment climate today is blame-oriented with large fundamental investors not very active.

From an investor perspective, electricity has become one of the most complicated and least transparent sectors with unique accounting procedures. Most of the big stock declines have come from surprise disclosures including unknown bank covenants and undisclosed rating triggers. The poor history of investment by electric utilities continues to repeat itself with too many resulting write-offs. Only utility mergers/acquisitions, nuclear plants, and gas pipelines have consistently earned their cost of capital.

As a result of financial and risk management pressures, many electric enterprises are implementing mandatory budget reductions of 20% or more that ultimately impact investment in science and technology. In many restructured states, rate caps forced the downward trend. As a result, distribution system weaknesses have become apparent, as major local blackouts have affected customers in New York City, Chicago, and San Francisco—sometimes with long-lasting consequences. For example, the August 1999 outage that affected businesses and government offices Chicago's downtown "Loop" district has prompted the city's utility, Commonwealth Edison, to launch a $1.5 billion distribution system upgrade program.

While CEIDS cannot directly influence utilities poor financial performance, there are two dimensions which are important technology vectors. First, CEIDS will result in technologies which increase the utilization of the Power Delivery system. Increased asset utilization carries enormous financial benefit. Secondly, CEIDS will enhance the functionality of the Power Delivery system and enable a variety of electricity-related services. This dimension can provide the technologies which will allow us to break the commodity trap we are in.

Distributed Resources (DR)

Distributed Resources (small generation, storage and/or control) can play a significant role in addressing a number of the weaknesses in the power delivery system. DR can improve reliability, quality, enhance system stability and lower costs to consumers. However, the promise of DR cannot be met unless three critical DR-related technology issues are resolved.

The first involves the connectivity of DR to utility and consumer systems. At present there is no standard method by which one can integrate the protection and permit synchronous operation. At present, each DR installation has to be custom engineered. This raises the cost and reduces the flexibility of DR.

The second involves control, dispatch and communications of DR. Communications protocols and devices need to be developed and standardized to enable dispatch and control of DR.

The third involves increasing fault currents. If distributed generation (DG) proliferates even at a modest rate, the fault current limits of existing system circuit breakers will be inadequate. New technologies that effectively limit the fault currents from numerous DG sources will be required.

DR is an important element of the Power Delivery System of the future and while CEIDS cannot afford to duplicate the enormous efforts underway to evolve these technologies – it can be sure to identify the needed elements to assure infrastructure integration.

Aging and Reduced Staff

Utility resources and work forces in the areas of System Operations, Transmission, Distribution, and Customer Services areas have been the focus of reductions through lay-offs and early retirements. As experienced staff exits, so does an extensive level of expertise. Resources and technologies that provide guidelines, information and data mining and management capabilities, and that essentially retain the expertise that would be lost through staff reductions, will be required. Any CEIDS developments must consider how new technologies can be deployed in the face of reduced utility staff.

Consumer Focus

While the consumer is the ultimate source of money that flows to the rest of the value chain in the electricity industry – the margins realized in serving them are “thin” and not evenly disbursed between generators, wires providers, operators, distributors and retail companies. At present, there remains no adequate incentive for retail and distribution providers to provide more than “bare-bones” service to consumers. As a result, there is no current incentive for the industry to invest in any new/improved energy consuming devices and appliances or in value-added electricity services. A renewed industry focus on customer service will occur over time. As CEIDS considers enhancing the functionality of the Power Delivery Infrastructure, it will design system architectures to more fully integrate consumers.

Efficiency

Although end-use devices and appliances have improved substantially, there are ample opportunities to reduce overall electricity demand. While restructuring and the lack of cohesive national programs have not allowed the industry to coalesce around this opportunity, substantial opportunities exist to transform end-use energy – consuming devices and appliances.

The EPRI Technology Roadmap challenges the U.S. to a 25 percent reduction in national energy intensity over the next 50 years through accelerated improvements in energy consumption efficiency. Other industry studies indicate that load management alone could account for a 6.4% reduction in peak generation requirements (45,000 MW). As high-technology industries and businesses increasingly rely on an ever-increasing number of digitally based technologies, their electric energy consumption continues to increase. For example, in California electric usage has increased an average of 7% per year between 1993 and 1999 -- even though California is one of the nation’s most conservative energy users (as measured on a per capita basis). Improved energy-use efficiencies would reduce high technology industries’ and businesses’ operating costs better enabling these industries to reach the productivity levels required to succeed in very competitive markets. Furthermore, enhanced overall industrial and commercial energy-use efficiencies would increase national economic productivity and boost national prosperity.

Recent power supply and transmission problems in parts of the western and eastern United States have dramatically illustrated the weaknesses of an electric system that is operating at very low reserve margins and with constrained transmission and distribution networks. Increased energy-use efficiency and the resulting reduction in energy consumption will contribute to enhance the overall reliability and availability of the national electric system. Any developments in New Power System technology must consider the role efficiency will play.

CEIDS Formation

CEIDS has been formed as a $250 million five-year public-private partnership to respond to the issues elucidated above.

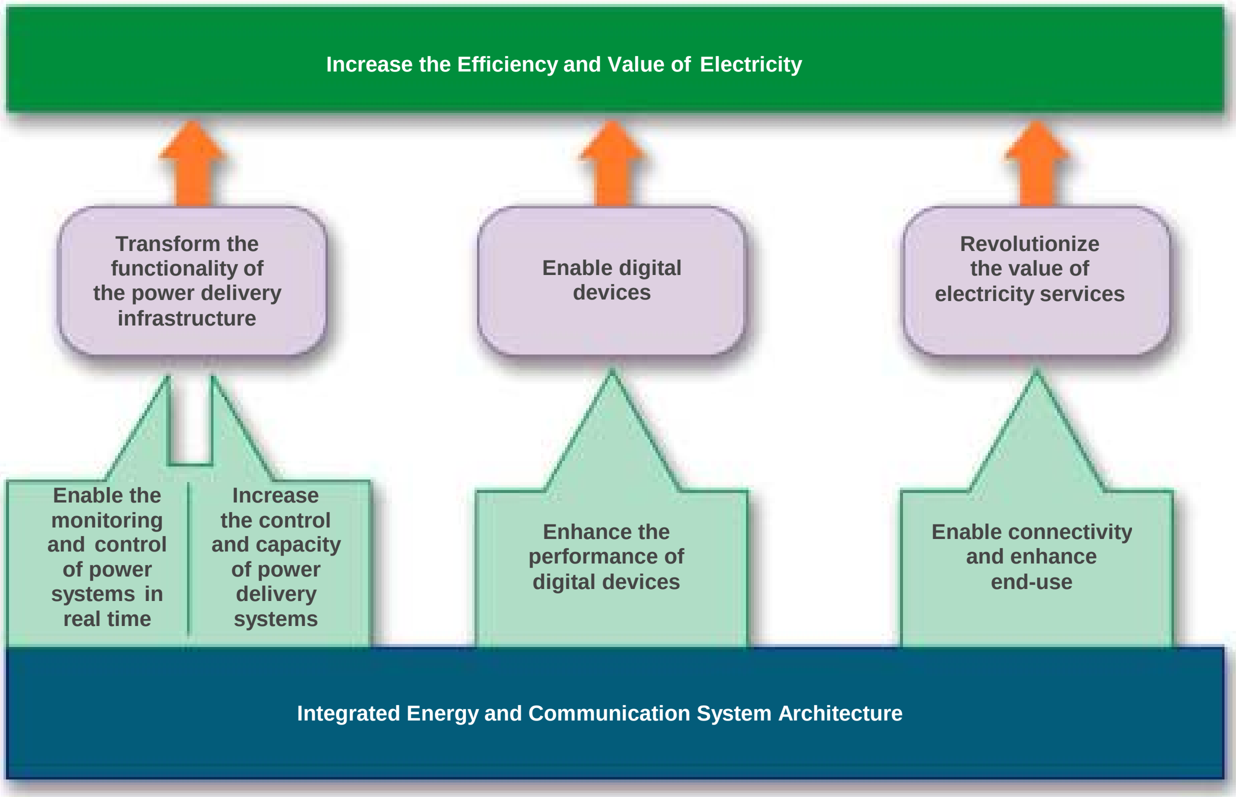
Meeting the needs of an increasingly transactional society so as to enable continued productivity growth, enhance the quality of life and minimize environment impact will require substantial changes in several areas of technology.

Figure 8 describes these areas. All of the elements involve evolving today’s power delivery infrastructure so as to fundamentally increase the Efficiency and Value of Electricity. The basis of these improvements is a communications architecture overlayed on today's power system. This architecture is an Integrated Energy and Communications System Architecture (IECSA).

IECSA enables four areas of technology to evolve:

- Technologies which allow monitoring and control of power systems in real time.
- Technologies which increase the control and capacity of power delivery systems. Together these developments will transform the functionality of the power delivery infrastructure enabling such concepts as the "Smart Grid" incorporating self-healing concepts.
- Technologies which enhance the performance of digital devices enabling tomorrow's digital society to be supported.
- Technologies which enable connectivity and enhance end-use thereby revolutionizing the value of electricity services.

Figure 8
A Descriptive Framework



Development of tomorrow's electric infrastructure, one which includes a self-healing transmission and distribution system – capable of automatically anticipating and responding to disturbances, while continually optimizing its own performance – will be critical for meeting the future electricity needs of an increasingly transactional society. According to EPRI's *Electricity Technology Roadmap*, "By 2020, the demand for premium power – now just developing – will be pervasive throughout every sector of the economy."

The power of a self-healing grid can best be illustrated by showing how it could have helped prevent the massive blackout of the Western grid on August 10, 1996. A transmission-class fault anticipator located at one end of the Keeler-Allston 500 kV line would have detected tree contact with the line several hours before it finally shorted out that day. Then a network of distributed data processors, communicating with the regional operations center, would have identified the line as having an increased risk of failure, and simulations would have been run to determine the optimal corrective response. When failure occurred, a network of sensors would instantly have detected the resulting voltage fluctuation and communicated this information to intelligent relays and other equipment located at substations. These relays would have automatically executed corrective actions based on current information about the status of the whole power system, isolating the 500 kV line and re-routing power to other parts of the grid. No customer would even have been aware that a potentially catastrophic event had occurred.

Much of the theoretical foundation for the self-healing grid has been developed under the joint EPRI – US Department of Defense Complex Interactive Networks/Systems Initiative (CIN/SI) that was concluded in 2001. This 3-year, $15.5 million program of Government Industry Collaborative University Research (GICUR) was funded equally by EPRI and the United States Department of Defense through the Army Research Office. The objective of CIN/SI was to produce significant, strategic advancements in the robustness, reliability and efficiency of the interdependent energy, communications, financial, and transportation infrastructures. A key concern was the avoidance of widespread network failure due to cascading and interactive effects – threats included intentional disturbances by an enemy, natural disasters, and material failures. Work focused on advancing basic knowledge and developing breakthrough concepts in modeling and simulation; measurement, sensing, and visualization; control systems; and operations and management.

The objective of this CEIDS initiative is to continue the technological development required for the self-healing grid and demonstrate the technical feasibility and value of the concept. It is also the objective of this initiative to identify complementary work being performed by others and to serve as a coordinator and integrator of activities.

Objectives of the Self-Healing Grid

The ultimate goal of this initiative is to create a new self-healing paradigm for power delivery systems, with automated capabilities that can anticipate many potential problems, reduce recovery time when unexpected disturbances actually occur, and enhance performance of normal operations.

To reach this goal, three primary objectives of the self-healing grid need to be achieved:

- Dynamically optimize the performance and robustness of the system.

- Quickly react to disturbances in such a way as to minimize impact.

- Effectively restore the system to a stable operating region after a disturbance.

Integrated Energy and Communications System Architecture (IECSA)

The initial step in developing the Self Healing Grid is to define clearly the scope of the requirements of the power system functions and to identify all the roles of the stakeholders. These must then be included in an Integrated Energy and Communications System Architecture. There are many power system applications and a large number of potential stakeholders who already participate in power system operations. In the future more stakeholders, such as customers responding to real-time process, DR owners selling energy and ancillary services into the electricity marketplace, and consumers demanding high quality, will actively participate in power system operations. At the same time, new and expanded applications will be needed to respond to the increased pressures for managing power system reliability as market forces push the system to its limits. Power system security has also been recognized as crucial in the increasingly digital economy. The key is to identify and categorize all of these elements so that their requirements can be understood, their information needs can be identified and eventually synergies among these information needs can be determined. One of the most powerful methodologies for identifying and organizing the pieces in this puzzle is to develop business models that identifies a strawman set of entities and addresses the key interactions between these entities. These business models will establish a set of working relationships between industry entities in the present and the future, including intermediate steps from vertical operations to restructures operations. The business models will include, but not limited to, the following:

- **Market operations**, including energy transactions, power system scheduling, congestion management, emergency power system management, metering, settlements and auditing.
- **Transmission operations**, including optimal operations under normal conditions, prevention of harmful contingencies, short term operations planning, emergency control operations, transmission maintenance operations and support of distribution system operations.
- **Distribution operations**, including coordinate volt/var control, automated distribution operation analysis, fault location/isolation, power restoration, feeder reconfiguration, DR management, and outage scheduling and data maintenance.
- **Customer services**, including Automatic Meter Reading (AMR), time-of-use and real-time pricing, meter management, aggregation for market participation, power quality monitoring, outage management and, in-building services and services using communications with end-use loads within customer facilities.
- **Generation at the transmission level**, including automatic generation control, generation maintenance scheduling and coordination of wind farms.
- **Distributed resources at the distribution level**, including participation of DR in market operations, DR monitoring and control by non-utility stakeholders,

microgrid management and DR maintenance management. These business models will be analyzed and used to define the initial process boundaries for subsequent tasks. Business process diagrams will be used to illustrate the more complex interactions.

The scope of IECSA architecture will encompass the power system from the generator to the end-use load. In other words the IECSA architecture extends as far as the electric energy extends to do useful work. This means the IECSA architecture includes the distributed computing environments in in-building environments as well as interaction with the foreseen operation of intelligent end-use subsystems and loads within the customers' facility.

The business models should include the issues surrounding RTO/ISO operations and the seams issues between entities serving restructured as well as vertical markets. This includes business operations that span across domains such as customer participation in ancillary service functions as well as self-healing grid functionality. Standard documentation languages such as Unified Modeling Language (UML), High Level Architecture (HLA), and others shall be used as appropriate. The intent here is to make the resulting information useful for the various stakeholder groups. Business entities should include but not be limited to vertical utilities, as well as business entities anticipated to participate in a fully restructured electric and energy service industry. The business models should also include key communications business models that could provide either common services or private network infrastructures to support the power industry through the IECSA architecture. The business models for communications should include generic communications business functions that may have roles in the ultimate implementation of the IECSA including but not limited to common carrier services and the provision of access network technologies to customers. These business models would address the application of new communications technologies that exhibit self-healing capabilities similar to that proposed for the power system.

Fast Simulation and Modeling

Once the FECSA begins to be deployed, then the industry's computational capability must be enhanced. In order to enable the functionality of the Power Delivery System, a capability which allows Fast Simulation & Modeling (FSM) will need to evolve in order to assure the mathematical underpinning and look-ahead capability for a Self-Healing Grid (SHG) – one capable of automatically anticipating and responding to power system disturbances, while continually optimizing its own performance. Creating a SHG will require the judicious use of numerous intelligent sensors and communication devices that will be integrated with power system control through a new architecture that is being developed by CEIDS. This new architecture will provide a framework for fundamentally changing system functionality as required in the future. The FSM project will augment these capabilities in three ways:

- Provide faster-than-real-time, look-ahead simulations and thus be able to avoid previously unforeseen disturbances;

- Perform what-if analysis for large-region power systems from both operations and planning points of view;

- Integrate market, policy and risk analysis into system models, and quantify their effects on system security and reliability.

The next step in creating a SHG will involve addition of Intelligent Network Agents (INAs) that gather and communicate system data, make decisions about local control functions (such as switching a protective relay), and coordinate such decisions with overall system requirements. Because most control agents on today's power systems are simply programmed to respond to disturbances in pre-determined ways – for example, by switching off a relay at a certain voltage – their activity may actually make an incipient problem worse and contribute to a cascading outage. The new simulation tools developed in the FSM project will help prevent such cascading effects by creating better system models that use real-time data coming from INAs over a wide area and in turn coordinate the control functions of the INAs for overall system benefit, instead of the benefit of one circuit or one device. As discussed later, having such improved modeling capability will also enable planners to better determine the effects of various market designs or policy changes on power system reliability.

To reach these goals, the FSM project will focus on the following three areas:

- **Multi-Resolution Modeling**. New modeling capabilities will be developed that provide much faster analysis of system conditions and offer operators the ability to "zoom" in or out to visualize parts of a system with lower or higher degrees of resolution. This off-line modeling activity will be the focus of work during the first two years of the project.

- **Modeling of Market and Policy Impacts on Reliability**. The recent western states power "crisis" dramatically illustrated how untested policies and market dynamics can affect power system reliability. The new modeling capabilities being developed in this project will allow planners and policy makers to simulate the effects of their activities before actually putting them into practice. This effort will be conducted in parallel with the previous Project, beginning in the first year, and then integrated with the multi-resolution system models.

- **Validation of Integrated Models with Real-Time Data.** Once the new, integrated models have been thoroughly tested off-line, they will be validated and enhanced using real-time data from major power systems. This work will begin in the third year and continue through the end of the project. Full integration with on-line network control functions and INAs will be left to a follow-on project.

Unified integration architecture is the key enabler to successfully, and inexpensively, deploying advanced functions. This architecture must be robust enough to meet the numerous disparate requirements for power system operations and be flexible enough to handle changing needs. The focus of this project is to identify and propose potential solutions for enterprise and industry-wide architectural issues that will arise from the high levels of integration and management foreseen by this project. The concepts and functions defined in the IECSA will support the development and deployment of distributed applications that reach to and across a great number of applications and stakeholders. The IECSA is required to integrate customer interaction, power system monitoring and control, energy trading, and business systems. It will reach across customers, feeders, substation, control centers, and energy traders. The IECSA must also provide a scalable and cohesive way to access resources across the wide spectrum of applications while at the same time providing the means to filter out unwanted data.

Open Communication Architecture for Distributed Energy Resources in Advanced Automation

A subset of the work on an Integrated Energy and Communications System Architecture is the development of an Open Communication Architecture for Distributed Energy Resources (DER) in Advanced Distribution Automation (ADA) or DER/ADA Architecture.

The DER/ADA Architecture Project will develop the object models for integration of specific DER types into the open communication architecture that is being developed through the companion CEIDS project known as the Integrated Energy and Communications Systems Architecture (IECSA) Project. Whereas the IECSA project is concerned with the broad requirements for the architecture, the DER/ADA Architecture Project is focused on a very specific, but very important, piece of the whole—object models for DER devices.

It is important to note that the term DER has various definitions and is used ambiguously in different situations. The broadest use of the term includes distributed generation, storage, load management, combined heat and power, and other technologies involved in electricity supply, both in stand-alone (off-grid) applications and in applications involving interconnection with power distribution systems. Another term, distributed resources (DR), is similarly used in an ambiguous manner. For the current phase of the project addressed by this plan, the scope is limited to object models for distributed generation and storage. DER types selected for object model development by the stakeholder team (defined later) will be limited to frontrunner distributed generation and storage types.

Eventually, object models will also be needed for other DER types besides distributed generation and storage. To the extent these models are not being developed in other forums, they may be brought to the CEIDS steering committee for consideration for funding in future projects. But only work on object models for distributed generation and storage will be done in this project, as initially approved for funding. Hence, for the remainder of this plan document, DER is used for brevity to denote distributed generation and storage.

Key benefits that will be derived from the object model development in this project and from the broader open architecture development in the IECSA project include:

- Increasing the functionality and value of DER in distribution system operations, which benefits both the utility and the consumer of electricity.

- Growing the market for DER equipment vendors.

- Providing a large market to communication and control equipment providers for sale of their products to help build the infrastructure for the open architecture.

Increased Power Flow

Real and reactive power flows in large integrated power transmission systems are constrained by voltage and power stability criteria. In many cases the limits dictated by these stability criteria are far below the "inherited" thermal capacity of transmission corridors. Even with the adoption of stability measures, power flow levels could still below the thermal limit due to the "uncontrolled" flow levels as determined by the power transfer law which is governed by the line impedance, voltage magnitudes and angle difference at the transmission corridor ends.

Real and reactive power flow according to physical laws which, in many transmission systems, results in under utilization of transmission lines. Some lines may have a flow close to their thermal limits while others are not fully loaded. Another problem of the "uncontrolled" power flow is what is known as "loop flow" or parallel flow" where less than 100% of a contractual power flows over the designated path and the rest of the power flow strands over other transmission paths. As a result, the permitted, uncontrolled, power transfer level is lower than the inherited thermal limits.

The challenge is, therefore, to be able to load all transmission lines up to the thermal limits while maintaining overall system reliability. In other words, to bring up the stability limit to be closer or even equal to the thermal limit. Overcoming this challenge means a great percentage increase (30-60%) of power transfer capability, depending on the specifics of considered transmission system.

The technological solution that was envisioned by EPRI to deal with the above described challenge aims at enabling control of the parameters governing the real and reactive power flow on transmission lines. As shown in Figure 1, these parameters are the transmission voltage, transmission line impedance and the phase angle difference. Dynamic control of these parameters transforms the transmission lines from being passive elements to become active elements which could independently adapted to share a predetermined real and reactive power flow levels without any negative impact on the transmission voltage quality. The key thrust of this technological solution is the development of power-electronics based controllers which use high power, high voltage kV and high current kA, solid switches. These solid state switches are employed to synthesize controlled current and voltage components that are injected into the transmission system. The controlled injected current and voltage components result in controlling transmission voltage and the apparent transmission impedance. Therefore, controlling the real and reactive power flows on transmission lines. This means a full control of a point to point real and reactive power flow, with no loop flows or parallel flows. Furthermore, these controlled injected current and voltage components could be used to relieve transmission “bottlenecks” without the need of building “by-pass” transmission lines.

This technological solution is named FACTS (Flexible AC Transmission System). The use of FACTS Controllers helps preserve system integrity during the short-term major system disturbances and/or to fully direct and control real and reactive power flows on transmission corridors.

As global businesses connect more and more different electronic systems into industrial, commercial, and residential sectors, the problem of electrical incompatibilities will grow. With the proliferation of embedded processors and other sensitive digital equipment, the customer is in effect constantly monitoring and reacting to power variations. Therefore, it is crucial that the electric power industry better monitor and assess the performance of its electrical power delivery systems. Conventional measures, such as utility-reliability data and indices, measure outage duration and frequency but ignore a host of other quantifiable phenomena particularly voltage sags, inter-harmonics, momentary interruptions, and transients affecting majority of customers.

There is a fundamental difference in assessment of electrical system for near real time modeling and simulation for on-line dynamic security assessment and developing an optimal balance between load compatibility and power system performance criteria for precision electricity users. The time scale of assessment for precision electricity users is in the range of milliseconds, whereas for power system stability assessment the time scale is more in the order of seconds. As microprocessor based controllers are embedded into a wide variety of residential, commercial, and industrial equipment, reliability and stability of the grid alone will not be able to meet the customer expectation and requirement for perfect power. The SQRA (Security, Quality, Reliability, and Availability) method, which was developed as part of an earlier CEIDS initiative, provides a unique platform to assess the optimum balance of load immunity and power system performance requirement for precision electricity users.

The advanced electrical assessment project will result in a detailed knowledgebase from which the Mean Time Between Failure (MTBF) values for electrical environment can be derived based on different quality levels. The SQRA analysis approach then can be applied to identify target immunity levels that the manufacturer standards organizations and equipment designers are able to consider power system compatibility in the design of the next generation digital equipment. A secondary but very important value chain of this project is to feed the appropriate data to the other CEIDS initiative on real time modeling and simulation. Because of the inherent difference in the characteristics of data needed for conducting SQRA analysis and real time modeling, a subset of the advanced electrical assessment data will feed the modeling project. This effort will also result in developing a framework for “monitors” so that in the future the data quality from monitors conform to the need of various functional needs that are currently being met by different hardware platforms.

Over the past two decades, unprecedented technological progress has been achieved in the development of solid-state, power electronic-based transmission and distribution (T&D) controllers and systems, which enable a degree of precision, high-speed control over electricity flow on utility grids that is analogous to that afforded by microelectronics in computers. But despite the technical success thus far, power electronics technology is at a critical crossroad. The initial technology, based on silicon thyristors (or silicon controlled rectifier) in various circuit and device configurations, is relatively mature and standardized among major electrical equipment manufacturers. Emerging, new technology based on voltage-source converters is coming into view, offering enormous potential for reducing the complexity, size, weight, and cost of highly sophisticated, multifunctional controllers for T&D systems.

The research program described in this document will address the two primary obstacles preventing the widespread deployment of voltage source converter-based transmission and distribution (T&D) controller technology - cost and reliability.

Value-Added Electricity Services

There is enormous consumer advantage to develop, and implement technologies that will enable traditional and non-traditional energy providers and service providers as well as their customers the ability to access a variety of electricity-related value added service (VAS) opportunities, including real connecting to electricity markets.

Create e-business-enabled opportunities by providing timesaving on-site, on-line services, based on the integration of electricity with communication systems. These services can be offered by anyone and will improve the digital economy’s competitiveness and performance through better integration of power, communications, and entertainment-delivery as well as emerging wireless communication technologies. Convergence of these technologies and capabilities will create new value within the traditional electricity industry and remove delays and complexities in decision-making by transforming the current “getting-connected” model into a fast and efficient “on-line” model. Consumers would enjoy a great deal of benefit if suppliers were able to offer a menu of services related to the “new” electricity.

Electric utilities will be able to expand the portfolio of their business services to include communication, Internet access, real-time on-line monitoring, and other associated services.

The customers will gain real time access to energy markets thus better control energy cost and energy utilization. Integrated communication and control will be available to expedite data exchange.

Facilitate wide public access to an integrated communication and power system through better utilization of existing and future infrastructure,

A variety of experiments and start-up ventures have chased the dream of providing home automation, automated security, Internet access and similar services. On the other hand, the complexity of choice in owning and operating a high-tech complex e-business leads to delays in decision making, lack of information to make the most economic choices for power and data services; and own, lease or buy decisions with respect to energy and power quality equipment. Most services today are specialized in a single aspect of business such as energy or even energy by type (natural gas, electric and fuel) or telephone or fiber services. These resources need to be evaluated together to optimize price and value to e-business.

There is also a need to develop innovative technologies and services that can provide options for consumers to use energy more efficiently and bolster their ability to withstand disruptions in the delivery of electric power. The digital business sector relies heavily on linkages between power, data transfer, and communications. As these technologies converge, new opportunities will emerge for digital devices and technologies that not only optimize energy use, but also anticipate and mitigate the effects of power disturbances. Options will include application of solid-state electronics for the control of industrial processes and equipment, development of more efficient and reliable motors and drives, and development of lighting and HVAC technologies that are not only more efficient but also have little or no harmful environmental effects.

End-users will increase productivity of their systems by 30 to 40 percent over the next 3-5 years due to rapid technological advances while improving energy efficiency. Utilities will be able to considerably minimize political and market pressures to invest in new energy generation and transmission. Federal and state government agencies will be able to influence improvement of individual’s quality of life.

Deregulation of the electric industry has diverted attention away from energy efficiency programs. The shift away from longer-term public benefit R&D has reduced funding available for energy efficient technology development. It is thus imperative to conduct R&D programs that are aimed to provide the digital economy sector with more energy efficient and reliable technologies.

- There is a need to develop load management technologies, communication protocols and interoperability, and electronic equipment such as direct digital control systems that combine power, data, and communication equipment to provide real-time control of integrated systems that integrate HVAC, lighting, and process systems with on-site energy generation and storage systems.

- Industrial motor systems represent the largest single electrical end use in the American economy. Industrial electric motor systems and motors used in industrial space heating, cooling, and ventilation systems use roughly 25 percent of all electricity sold in the United States Research is needed to develop motors that use energy more efficiently and are able to ride through a variety of power quality disturbances. In addition, better control systems that enable motors to follow the load more closely by adjusting the amount of power delivered to the motor on a continuous basis need to be developed

- Lighting accounts for 20 to 30 percent of all commercial electricity use in the U.S. Research is needed to develop lighting systems based on novel lighting sources, such as ultra-violet vertical-cavity surface-emitting lasers (UV VCSEL) and light emitting polymers (LEPs). These technologies produce higher output levels per unit of energy which can be precisely controlled under a variety of control scenarios, thus resulting in reduced heat generation within the lighting system.

- The microprocessors and other digital components used by high-technology industries and businesses require special environmental conditions for their proper operation. HVAC systems and components that use energy more efficiency and do not rely on environmentally harmful refrigerants need to be developed. In addition, enhanced control technologies are needed to enable HVAC systems to better follow air conditioning loads and to allow the seamless integration of HVAC and advanced thermal energy storage systems.

CONCLUSION

Clearly, improving the power quality and reliability needs of the emerging digital society will integrate energy with information services and systems will require widespread cooperation among public and private interests. EPRI is in a unique position to form a consortium that could bring together these diverse interests and fulfill the goals discussed earlier. Among other strengths and experiences relevant to this effort, EPRI has been a traditional leader in developing the standards needed to integrate various types of equipment from numerous vendors into a smoothly functioning power system. EPRI has also pioneered many of the advanced technologies that are now being considered for widespread deployment on transmission and distribution networks and in end-use devices as a way to increase overall system reliability. Finally, EPRI’s credibility can be decisive in attracting sufficient support from diverse private and public sources to form CEIDS and enable it to make a significant contribution in ways that could potentially contribute billions of dollars in increased productivity to the American economy.