Power for a Digital Society

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Once or twice in a century, "enabling sectors" of the economy emerge which are so profound in their impact that they transform *all other* sectors of the economy. There are typically a few key "disruptive" technologies that underpin these enabling sectors and the creation of new economic structures. In this vein, the steam engine and telegraph transformed the 19th century through the creation of new transportation and communication networks. In the 20th century, electricity, by providing more precise and efficient energy, plus practical access to the electromagnetic spectrum (e.g., IR, UV, Xray, microwave), transformed every aspect of society. For this reason, the National Academy of Engineering recently voted the "vast networks of electrification" as the greatest engineering achievement of the 20th century.

Now, we are facing another transformative era. In the 21st century, the information networks relying upon integrated circuits (microprocessors) powered by electricity and linked by high-speed, broadband communication are envisioned to have a comparable, transformative role in creating the Digital Society. This technology revolution has progressed through three stages, each one more significant in its impact on society. The first stage began with computers, which revolutionized information processing and fundamentally transformed the way most businesses operate. The second followed as the cost of microprocessing capability plunged, and individual silicon chips began to appear in all sorts of unexpected places—from phones to car brakes. This embedded-processor phase of digitization has progressed to the point where today, for every chip *inside* a computer, there are 30 more in stand-alone applications.

The third phase involves linking these computers and microprocessors together into networks that allow economies of scale to grow exponentially. There are currently more than a million Web sites available on the Internet, potentially

[1]Note that the contents present the views of their authors, not necessarily those of the Department of Energy, RAND, or any other organization with which the authors may be affiliated.

available to some 300 million computers around the world. As a result, Internet-based commerce already represents about 2% of the American GDP, and by the end of next year the revenues from e-commerce are expected to exceed those of the entire U.S. electric power industry. Increasingly, stand-alone microprocessors are being linked to networks, supplying critical information on equipment operations and facilitating even more profound changes in daily life.

Electricity Requirements in the Digital Society

Together, microprocessors and the equipment they control have helped stimulate growth in the demand for electricity well beyond previous expectations. Information technology is the fastest growing market for electricity and now accounts for 10-13% of the electrical energy consumed in the U.S.

- Given the growth in the Internet's direct and indirect usage of electricity, the equivalent of 30%-50% of today's US power production may be needed to serve the needs of the booming digital society within the next decade or two.
- Power demand in Silicon Valley is indicative of the future of the digital society. For example, total demand growth in the valley is currently running at about 5%/year, much of it due to high-tech expansion. This is more than twice the national average. It is quickly absorbing capacity margins for both generation and power delivery are racing well ahead of capital spending by utilities.
- This demand growth is coming primarily from new end-users; particularly data centers and co-location facility providers, data storage providers, cellular, PCS and radio tower operators, and the optical components industry.

As recently as the 1970s, electricity accounted for only 25% of the energy consumption in the industrialized nations. By 2000 it had risen to more than 37%. During the next 25 years, electricity is likely to grow to provide more than 50% of the energy consumed in these nations, and even more if electrified transportation takes hold. In doing so, energy efficiency will also continue to grow with less and less energy needed to power the economy.

What is equally important, however, is *how* society will transform its use of electricity in the new millennium. Computers, the Internet, advanced automation, smart houses, critical care equipment, fiber optic communications, digital household appliances, e-commerce companies, wireless phone systems, the list of digital technologies goes on. Appliances and automated processes, linked via telecommunications services, will control energy purchases, metering, environmental control, lighting, and security, etc. Consumers will use the Internet economy to connect directly with energy markets, while buying and paying via electronic commerce.

This emerging Internet economy depends upon a server and fiber-optic based network whose power demands necessitate an extremely high level of reliability and quality. The growth in Internet-based commerce fundamentally depends on the reliability of its power supply backbone. What is digital-quality power? Realistically speaking, most of the electricity delivered in the US has a reliability of about 99.9% (based on average annual outage duration), with a variety of disturbances which reduce overall quality to something less. That is not good enough for a digital society. Interruptions and disturbances measuring less than one cycle (less than 1/60th of one second) are enough to crash servers, computers, intensive care and life support machines, automated equipment, and other microprocessor-based devices. For example, power disturbances around the world cause more than 17,000 computer disruptions every second, ranging from annoying frozen cursors to serious disruptions of equipment and products.

Proliferation of digital technology raises two challenges for those who must supply the necessary electric power—quality as well as quantity. On an annual basis, that means electricity must be available to the microprocessor at least 99.9999999% of the time—“9-nines reliability” as it’s sometimes called. Many of the measures required to achieve 9-nines entail devices that are on the customer’s side of the meter, but linked in seamless fashion to the power supply system. Economics is the primary driver.

Information technology companies already are taking steps to ensure their own supply of ultra high-quality electrical power. Oracle Corp., for example, has built their own substation, pointing out that their power costs could triple and not impact their product cost, whereas an outage carries heavy and growing costs. An Oracle spokesperson brought the point home. “What is self-sufficiency [to ensure power quality] worth to us? Millions of dollars per hour. It is so important that you can’t calculate the value to us and our customers.”

Another sign of the need for digital-quality power is rapid growth of the power conditioning industry. Bank of America Securities recently issued a report showing the demand for Internet quality power increasing at a compound rate of 17%/year through at least 2010, roughly in line with shipments of high-end servers. Coupled to this is an emerging “energy technology” industry, focused on the use of power conditioning, uninterruptible power systems (UPS) based on battery storage, and distributed power resources that can provide ultra high-quality power for the Internet. This “silicon power plant” industry is expected to grow from a few billion dollars in sales today to $50 billion / year by 2005, to $100 billion / year by 2010.

Creating the Needed Electrical Infrastructure

The North American bulk electricity delivery system is not keeping pace with the escalating demands of competition, or with the exacting requirements of a rapidly expanding digital society. For example, over the past decade, electricity demand in the US has grown by roughly 30% while additional transmission capacity has only grown by 15%. In the next decade, US demand is expected to grow by 20%, while planned transmission system growth is expected to be only 3.5%. If the bulk power delivery system cannot dependably supply the so-called "silicon power plants," which raise the reliability level of bulk power to the digital level of reliability and quality, then it will be displaced as the primary energy supplier for the digital society.

The power delivery infrastructure is already a complex, interactive network. But if it is to keep pace with the digital revolution, it too must become much more interactive and complex. Today's infrastructure, composed of relatively few large power plant nodes and limited real-time connectivity, must expand to provide greater precision and efficiency to meet the needs of the microchip networks it serves. In terms of energy supply, the emerging infrastructure requires the incorporation of smaller stationary and mobile distributed power supply and storage nodes. For example, five truck-mounted diesel generators have just been approved for use in meeting peak demand in the San Francisco Bay area next summer. This will result in a more nearly seamless electricity / natural gas network infrastructure with power available at a myriad of locations. It is paradoxical that the very electricity industry that made others obsolete (e.g.. gas light and ice refrigeration) in the 20th century, is itself threatened by a new wave of disruptive technological change as we enter the 21st century.

In the digital economy there will also be a new level of customer involvement in energy markets. This new concept engages customers directly with Internet-based information on energy availability, prices, and assets. The digital information economy enables all players in the market to be tied together through instantaneous and ubiquitous communication, forming a dynamic network, opening up the possibility for new and more creative relationships between buyers and sellers.

A three-step, electricity infrastructure transformation is thus envisioned:

1. The first order of business is to keep the lights on.

2. The second is to use existing technology to upgrade the power delivery system to handle the new volume and patterns of traffic created by wholesale and retail electricity competition.
3. The third is to begin the process of transformation of the entire power system so that all elements, from generation to end-use, form the equivalent of an integrated circuit, able to respond at the speed of light while retaining the necessary levels of power stability in all parts of the system.

The high-power electronics needed to complete this transformation are about 20 years behind micro-circuitry but are now becoming available (e.g., solid state transfer switches, FACTS, custom power, etc.). The research goals are to drive down the capital costs of these high-power electronics, to saturate the entire system with low-cost sensors and feedback loops, and to develop the wide-area management systems for continental-scale integration and control.

A similar, synergistic technology transformation opened up the telecommunications business. For example, microwave transmission enabled new companies to build long distance telephone networks. This was followed by digital switching that allowed telephone companies to offer new services, and to process the information needed to coordinate traffic from different service providers. Next, fiber optics enabled competitive local networks, while wireless enabled users to bypass traditional services. Most recently, the Internet offers all the conventional communications capabilities plus more, and it is leading to unlimited real-time connectivity and plunging transaction costs.

From the standpoint of technology, business and policy alike, the telecommunications transformation is stimulating a corresponding transformation in electricity service. Digitalization of all forms of communication is also driving convergence among the networked utility industries. Conversely, the emergence of full-fledged wholesale and retail power wheeling will require enormous amounts of data to be captured, processed, and made available to buyers and sellers of power, thus placing new demands on telecommunications.

Infrastructure Convergence

Four forces are creating convergence among diverse utility services: digital information technology, energy utility economics, deregulation, and consumer demand.

- In the near-term, for example, this means that electricity and gas services may merge aspects of common infrastructure, including operations, maintenance, customer service, and billing. Further in the future, communications technologies may be added to this mix.

- Ultimately, the converged utility infrastructure may, in turn, help facilitate other urban services, such as high-speed transportation networks.

This trend toward convergence was recognized recently by a forum of the Consumer Energy Council of America, which stated:

> The potential of a nationwide broadband network and all of its advanced capabilities will be bringing together some of the largest communication concerns in the world as telephone, cable, satellite and wireless converge to transform the information superhighway into a high-speed communications vehicle delivering advanced Internet applications. For those who have access to the network, broadband technology promises to drastically alter and enhance the way people live their lives and how the nation's business is conducted.

Similarly, the Morgan Stanley Dean Witter Global Electricity Team has concluded:

> In our view, a natural union exists between electric utilities and telecom industries due to electrics' existing infrastructure, primarily related to their rights of way (ROW) and internal communication systems…. Specifically, by using these assets, the utilities' average network construction costs are 14% below those of new entrants and 58% below private market purchases of ROW access. Achieving even a 0.1% share of the long-haul telecom market would increase annual revenue by $100 million.

In the digital society, consumers will likely purchase energy as part of an integrated service package. Currently, consumers have an electric meter, a gas meter and pay for gasoline at a metered pump. In the future, consumers will be able to pay for all energy and other essential community services with a single identification number, regardless of the point source of the energy or resource. Delivery of power and information (telecommunications) will become completely interwoven. Finally, just as telecommunications are delivered in a two-way setting, power will increasingly be delivered two-way, as households and industrial enterprises are increasingly able to sell power back to the grid.

Technology Considerations

Technology is central to the successful development of an electrical infrastructure to support a digital society. Its primary role is to ensure that the underlying infrastructure itself does not become the limiting factor in the growth of the network economy. Electricity is arguably the most critical of the infrastructures because it is the lifeblood of all other systems. However, in the broadest sense, technology needs will be driven by distinct reliability goals for power transmission and for power distribution. Clearly the solution will involve a combination of options: *Simply "gold plating" the present power delivery system would not be an effective, way* to provide high-reliability power for the digital economy. Rather, four distinct infrastructure reliability goals need to be considered:

1. Improvements in high-voltage transmission networks need to focus on increasing capacity and enhancing reliability enough to support a stable wholesale power market. Specifically, new technologies need to be deployed that can prevent cascading outages and price spikes like those that have occurred recently. Such infrastructure improvements will ensure that the U.S. transmission grid can provide lowest-cost power evenly across wide regions of the country.
2. Improvements in utility distribution systems need to focus on integrating low-cost power from the transmission system with an increasing number of local generation and storage options—collectively known as distributed resources (DR)—which will play a vital role in providing high reliability retail electricity, whether deployed by power providers or by customers themselves. It is likely that an increasing amount of Internet power will be delivered on-site, as well as uninterruptible power supply (UPS) systems incorporating storage and DR.
3. The very character of digitally based electric energy devices and appliances must be subject to more standardization as to their installation, compatibility, and sensitivity to reliability and other distortions in electricity. For example, lack of electromagnetic compatibility causes wireless radiated power quality disturbances that increasingly lead to improper operation of industrial control devices. Furthermore, adequate guidelines, let alone standards, do not exist for even wiring a digital infrastructure-ready building.
4. Net metering (buying and selling power through an "smart" electronic meter) and real-time pricing must also be encouraged to facilitate price-signals and demand-response in the retail electricity market. Lacking such advances, there is no economic incentive for customers to conserve at times of high demand (and high generation cost) or to sell electricity back to the utility from distributed generation sources.

Meeting these goals will require adoption of separate strategies for improving the reliability of transmission and distribution systems as well as the performance of end-use devices. Both sets of strategies rely heavily on the use of new technology, but important choices must still be made about how best to apply these technologies to meet reliability and economic goals.

First Steps Toward Meeting the Need

EPRI is responding to this need by launching a bold, two-phase plan aimed at mobilizing all stakeholders in a unified endeavor to improve overall power system reliability—from generator to end-user—in the most cost-effective manner. The first phase of the plan, called the Power Delivery Reliability Initiative, is well underway and has focused on making immediate, clearly needed improvements in utility transmission and distribution systems. Already, the Initiative has supplied new tools to transmission system operators to help avoid the spread of regional disturbances, and distribution system owners are benefiting from identification of common problems that can contribute to local outages.

The second phase will commence early in 2001 with formation of the Consortium for Electric Infrastructure to Support a Digital Society (CEIDS), a broadly based effort to find long-term solutions to the challenges of reliability. Specifically, CEIDS will focus on three reliability goals:

1. Preparing high-voltage transmission networks to have the increased capacity and enhanced reliability needed to support a stable wholesale power market.
2. Determining how distribution systems can best integrate low-cost power from the transmission system with an increasing number of local generation and storage options.
3. Analyzing ways to provide digital equipment, such as computers, with an appropriate level of built-in protection.

EPRI has 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. By promoting judicious use of these technologies, CEIDS can make a significant contribution to electric reliability in ways that could potentially contribute billions of dollars in increased productivity to the American economy.

With this in mind, the authors believe that DOE should join EPRI in supporting this public/private consortium, to develop the technologies necessary to support the electric reliability needs of a rapidly expanding digital society. Specifically, EPRI hopes to fund CEIDS by raising $20 million a year for four years from utility sources and high-tech companies concerned about the future of electric power reliability. Matching funds from DOE could provide the support needed to make CEIDS a truly national effort—an important public-private consortium addressing one of the most critical energy issues of our time.