Stronger, Greener, More secure Smarter Power Grid: Toward increasingly efficient, secure, resilient and sustainable system

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Recent policies combined with potential for technological innovations and business opportunities, have attracted a high level of interest in smart grids. The potential for a highly distributed system with a high penetration of renewable sources that exhibit variable generation and non-dispatchability poses opportunities and challenges. How to retrofit and engineer a stable, resilient grid with large numbers of such unpredictable power sources? What roles will assets optimization, increased efficiency, energy storage, advanced power electronics, power quality, electrification of transportation, novel control algorithms, cyber security, and other technologies play in the grid of the future? What are the emerging technologies to enable new products, services, and markets?

The North American Electric Power Grid

In 1940, 10% of the energy consumption in America was used to produce electricity. By 1970, this had risen to 25%, and by 2002 it had risen to 40%. This grid now underlies every aspect of our economy and society, and it has been hailed by the National Academy of Engineering as the 20th century's engineering innovation most beneficial to our civilization.

Once "loosely" interconnected networks of largely local systems, electric power grids increasingly host large-scale, long-distance wheeling (movement of wholesale power) from one region or company to another. Likewise, the connection of distributed resources, primarily small generators at the moment, is growing rapidly. In terms of the sheer number of nodes, as well as the variety of sources, controls, and loads, electric power grids are among the most complex networks.

What is a smart grid?

The term "smart grid" refers to the use of computer, communication, sensing and control technology which operates in parallel with an electric power grid for the purpose of enhancing the reliability of electric power delivery, minimizing the cost of electric energy to consumers, and facilitating the interconnection of new generating sources to the grid.

A grid operator is similar to a pilot flying an aircraft, monitoring how the system is being affected, how the "environment" is affecting it, and having a solid sense of how to steer it in a stable fashion by keeping the transmission lines within their operating limits while helping a instantaneous balance between loads (demand) and available generation-- grid operators often make these quick decisions under considerable stress. Given that in recent decades we have reduced the generation and transmission capacity, we are indeed operating closer to the edge of the stability envelope.

As we look ahead, the electric power grid's emerging issues include 1) integration and management of renewable resources and "microgrids" (Figure 1); 2) use and management of the integrated infrastructure with an overlaid sensor network, secure communications and intelligent software agents; 3) active-control of high-voltage devices; 4) developing new business strategies for a deregulated energy market; and 5)

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ensuring system stability, reliability, robustness, and efficiency in a competitive marketplace and carbon-constrained world.

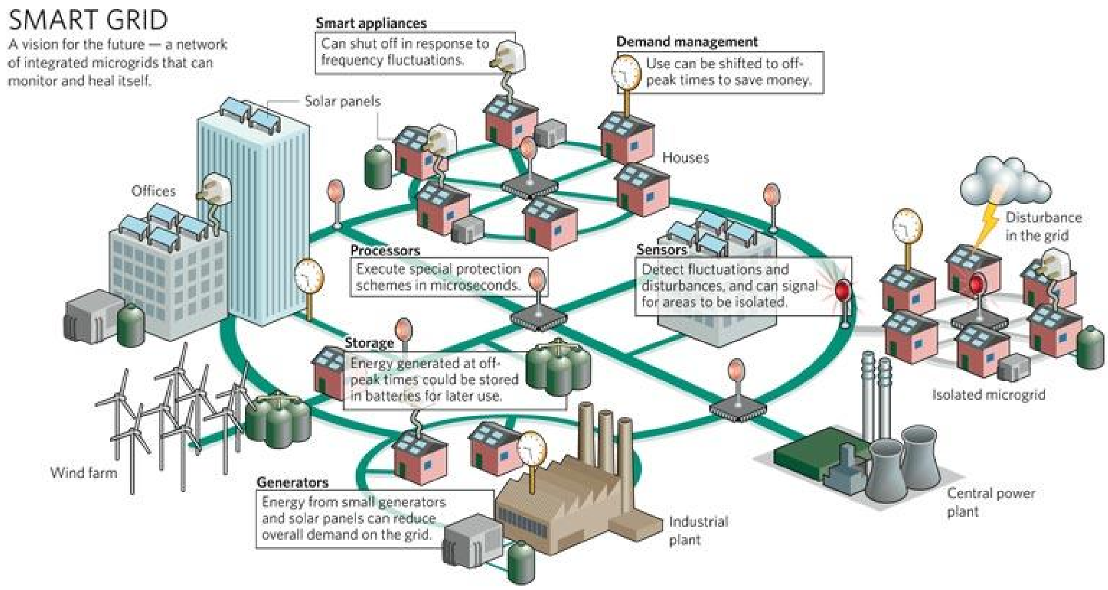

Figure 1: Infrastructure integration of microgrids and diverse generation/storage resources into a system of smart self-healing grid[b]

The goal is to transform the current electric power infrastructures into one having energy-delivery, computer and communications networks with unprecedented robustness, reliability, efficiency and quality for customers and our society. This will require addressing challenges and developing tools, techniques, and integrated probabilistic risk assessment/impact analysis for wide-area sensing and control for digital-quality infrastructure-- sensors, communication and data management, as well as improved state estimation, monitoring and simulation linked to intelligent and robust controllers leading to improved protection and discrete-event control.

As an example, related to numerous major power outages, narrowly-programmed protection devices have sometimes contributed to worsening the severity and impact of the outage-- typically performing a simple on/off logic which acts locally while destabilizing a larger regional interconnection. With its millions of relays, controls and other components, the parameter settings and structures of the protection devices and controllers in the electricity infrastructure can be a crucial issue. It is analogous to the poem "for want of a horseshoe nail… the kingdom was lost." i.e. relying on an 'inexpensive 25 cent chip' and narrow control logic to operate and protect a multi-billion dollar machine.

There is a need to coordinate the protection actions of such relays and controllers with each other to achieve overall stability; a single controller or relay cannot do it all, and they are often tuned for worst cases, therefore control action may become excessive from a system wide perspective. On the other hand, they may be tuned for best case, and then the control action may not be adequate. This calls for a coordinating protection and control - neither device, using its local signal, can by itself stabilize a system;

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[b] Source: interview with Massoud Amin, "Upgrading the grid," *Nature*, 30 July 2008, pp 454, 570-573

but by building the devices to have intelligent agent abilities, multiple agents, each using its local signal, can stabilize the overall system.

It is important to note that the key elements and principles of operation for interconnected power systems were established in the first half of the twentieth century, prior to the emergence of extensive computer and communication networks. Computation is now heavily used in all levels of the power network-for planning and optimization, fast local control of equipment, and processing of field data. But coordination across the network happens on a slower time-scale. Some coordination occurs under computer control, but much of it is still based on telephone calls between system operators at the utility control centers, even (or especially!) during emergencies.

Equipment used to build a smart grid

Efforts in this area have developed, among other things, a new vision for integrated sensing, communications, protection and control of the power grid. Some of the pertinent issues are why/how to develop protection and control devices for centralized versus decentralized control and issues involving adaptive operation and robustness to various destabilizers. However, instead of performing in Vivo societal tests which can be disruptive, there have been extensive simulation of devices and policies in the context of the whole system along with prediction of unintended consequences of designs and policies to provide a greater understanding of how policies, economic designs and technology might fit into the continental grid, as well as guidance for their effective deployment and operation.

The equipment used to build a smart grid consists of communications, computers, sensors and control devices. The communications infrastructure enables the passing of information between all components of the power system, between individual customers and central computers, between sellers and buyers of electric power. The computers operate independently and process information as intelligent agents. Traditionally computers have been available in system control centers and power plants. The smart grid will extend computer capability to each component and each customer of the power system. Sensors will measure power system parameters such as voltage, current, temperature and power flows. The sensors will feed this information to the closest independent agent computers which will decide on where to send it or what actions to take. Control devices at customer locations can turn appliances on and off as well as change the temperature set point of heating and cooling systems. When using a Pluggable Hybrid Electric Vehicle (PHEV) charging and discharging can be regulated for benefit of the consumer and the power system.

Advanced technology now under development or under consideration holds the promise of meeting the electricity needs of a robust digital economy. The architecture for this new technology framework is evolving through early research on concepts and the necessary enabling platforms. This architectural framework envisions an integrated, self-healing, electronically controlled electricity supply system of extreme resiliency and responsiveness—one that is fully capable of responding in real time to the billions of decisions made by consumers and their increasingly sophisticated agents. The potential exists to create an electricity system that provides the same efficiency, precision and interconnectivity as the billions of microprocessors that it will power

Smart grid benefits to the existing power system

Revolutionary developments in both information technology and material science and engineering promise significant improvement in the security, reliability, efficiency, and cost-effectiveness of all critical infrastructures.

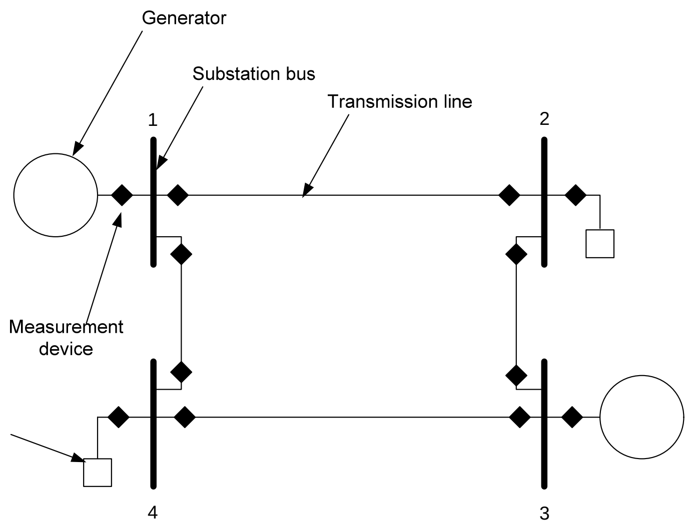


Figure 2: Power System Components

Having an intelligent computer agent built into each circuit breaker, transformer, capacitor, etc. in the power system will allow a complete data base to be built and maintained easily and automatically. It will allow central computers to know exactly what each component's parameters are and how that component is performing when parameters are measured and sent into the smart grid. This will allow electric companies to monitor and maintain all components much more closely than at present. At present control over the flows on a power grid is done primarily by operators in central location by adjusting generator outputs and switching lines in and out. When overloads occur it is almost impossible to force flow to go over differing paths. With a smart grid the loads themselves can be adjusted temporarily to give a much tighter control over the flows.

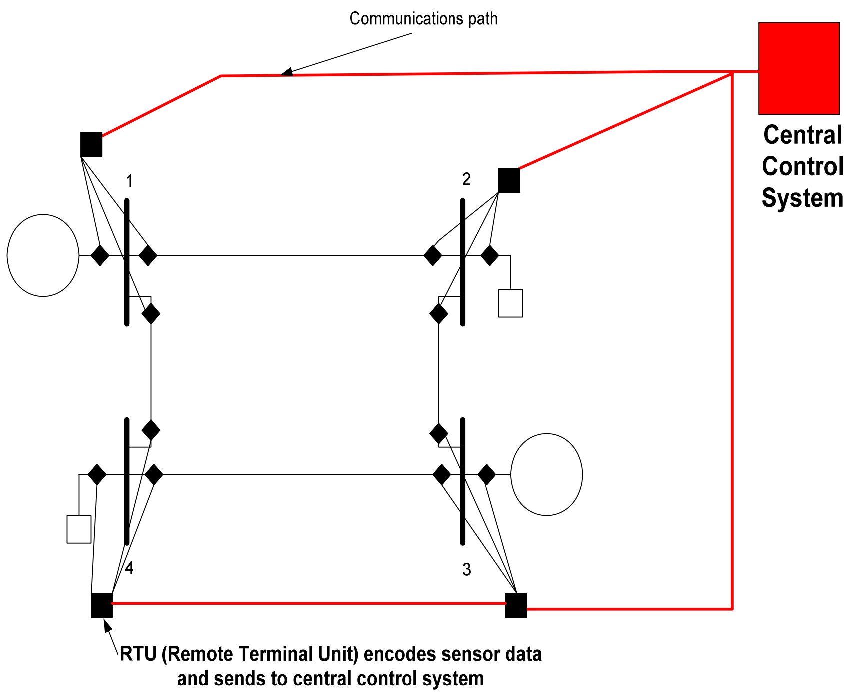


Figure3: Traditional power system communications, central control computers, and sensors

One problem that is very difficult for power grid companies to deal with is locating, isolating and fixing failed components. With a smart grid and through the use of intelligent agents located a many locations the failure of a component will be much easier to monitor and locate so that repair crews can go directly to the component to repair or replace it. In addition, a smart grid would allow for switching the component out and if necessary alternate circuits are available the customers affected could be supplied through the alternate means. Sometimes a failed component forces the power system's own protective devices to open circuit breakers and this may result in large pieces of the system being disconnected from the main grid. A smart grid ought to be able to sense when this happens and confirm the exact location of the disconnections so that reconnection can proceed quickly.

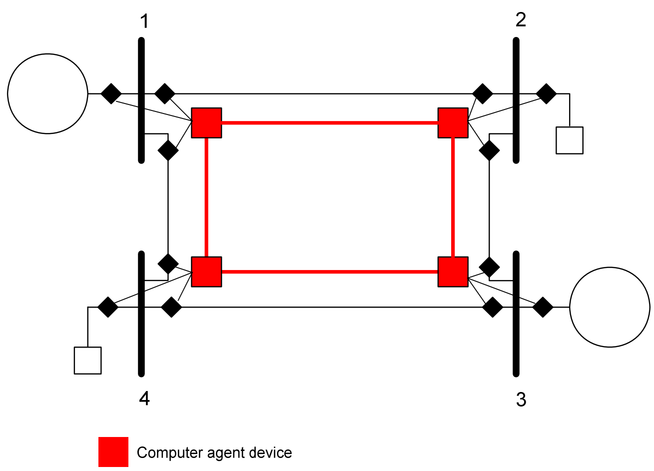


Figure 4: Power System with Smart Grid

The fact that the power grid would have thousands of independent computer agents located throughout its power plants, substations, and customer connections means that very large computational tasks could be carried out by these agents as a "distributed computer" system. Present power system computer tasks are done in central locations where data is brought in, sorted into a data base and then run through algorithms to analyze the system – by distributing this task throughout the smart grid we expect to see these tasks done much faster and more reliably.

The advent of PHEVs offers the power grid a means of unprecedented ability to control frequency and make adjustments as intermittent generation sources come on line and fall off line due to variations in wind or solar energy hitting solar cells.

Smart grid benefit to Consumers

Since power systems were deregulated in the late 1990s the price for delivery to a consumer is calculated on an hourly basis. At present, only wholesale buyers receive the pricing information and make use of it to adjust purchases. The economics of operating a power system become greatest when the customers themselves receive this pricing information and respond to it by lowering load in high price hours and then using power more heavily during lower priced periods. Studies have shown that customers can obtain a decrease in their electric bills if they were allowed to watch this price and schedule the use of electric power accordingly. However, this requires an hourly observation of the price and hourly adjustments of the power consumption. A smart grid would terminate at the customer's location in what has been called a *smart meter* that would not only measure kWh consumption but what price were being paid each hour. By coupling the smart meter with so called "smart appliances" that could be signaled by a wireless signal in the house or business, the appliances could be scheduled automatically by algorithms in the smart meter. When price changed significantly the use of electricity could likewise be changed to keep the customer's costs to a minimum. Such systems would allow the grid to "flatten" the load curve so that peaks were lower and equipment was not installed in the grid simply to supply power for short periods during peaks.

PHEV and Electric automobiles would benefit greatly from smart metering which could schedule and adjust the rate of charging to minimize costs. If the PHEV had the ability to send power back into the grid from its batteries it could be used as a storage device. Smart metering could then schedule when the customer bought and sold energy to minimize costs or even maximize profits. Similarly customers with large heating or cooling systems could buy and store thermal energy efficiently to minimize costs.

Smart grid integration of renewable energy devices
The biggest drawback to the use of renewable energy systems like wind generators or solar panel generation is the inability to schedule the wind and solar energy, these sources need to be coordinated with the power system as more of them come online or go off line. If large electric storage systems are available then the renewable energy can be stored until needed by the electric grid. If PHEVs are available in large numbers the rate of battery charge or discharge can be scheduled to coordinate with the variable wind and solar energy.

A smart grid would make it possible to island parts of the electric system from the main grid when the main grid prices are very high or when it is blacked out. Islanding would need intelligent agents to manage the island until reconnected to the grid.

Challenges: Power produced in one place and used hundreds of miles away. This creates new opportunities, especially in terms of encouraging the construction of new power generation, possibly transmission, and in making full use of the power produced, rights of way and assts, but it also creates challenges:

1) Regulatory Challenges: More than ever power transmission is an inter-state transaction. This has led to numerous conflicts between federal statutes applying to energy and rules set up by public utility commissions in the various states. Generally the federal goal is to maximize competition, even if this means that traditional utility companies should divest themselves of their own generators. Since the 1990s, the process of unbundling utility services has brought about a major change in the way that energy companies operate. On the other side, generally the goal of state regulators has been to provide reliable service and the lowest possible prices for customers in state.

2) Investment Challenge: Long-distance interstate routing, or "wheeling," of power, much encouraged by the federal government, has put the existing transmission network, largely built in the 1970 and 1980s in a time of sovereign utilities, under great stress. Money spent by power companies on research is much lower than in past decades. Reserve power capacity, the amount of power-making to be used in emergencies, 25-30% 25 years ago, are now at levels of 10-15%.

3) Security, Reliability, and Innovation Challenges: The August 2003 northeast blackout, when operators did not know of the perilous state of their grid and when a local power shutdown could propagate for hundreds of miles, leaving tens of millions in the dark, demonstrated the need for mandatory reliability rules governing the daily operation of the grid. Such rules are now coming into place.

4) Marketplace Challenges: Some parts of the power business operate now without regulations. Other parts, such as the distribution of power to customers might still be regulated in many states, but the current trend is toward removing rules. The hope here is that rival energy companies, competing for customers, will offer more services and keep their prices as low as possible. Unfortunately, in some markets, this has the risk of manipulating the market to create energy shortages, even requiring rolling blackouts, in an effort to push prices higher.

These are recognized by the power companies and stakeholders in a rapidly changing marketplace. The public, usually at times of dramatic blackouts, and the business community, which suffers losses of over $80 billion per year, have taken notice. Even Congress, which must negotiate the political fallout of power problems and establish laws governing the industry, takes up the problems of power transmission and distribution on a recurring basis, although usually in the context of the larger debate over energy policy. In the meantime, the US power grid has to be administered and electricity has be to delivered to millions of customers. Fortunately, many new remedies, software and hardware, are at hand.

The institutional and economic framework envisioned for the 21st Century Power System ultimately depends upon building new types and levels of functionality into today's power system.

In the coming decades, electricity's share of total energy is expected to continue to grow, as more efficient and intelligent processes are introduced into this network. Electric power is expected to be the fastest-growing source of end-use energy supply throughout the world. To meet global power projections, it is estimated by the U.S. DOE/EIA that over $1 trillion will have to be spent during the next 10 years. The electric power industry has undergone a substantial degree of privatization in a number of countries over the past few years. Power generation growth is expected to be particularly strong in the rapidly growing economies of Asia, with China leading the way.

Revolutionary developments in both information technology and material science and engineering promise significant improvement in the security, reliability, efficiency, and cost-effectiveness of all critical infrastructures. Steps taken now can ensure that critical infrastructures continue to support population growth and economic growth without environmental harm.

Funding and sustaining innovations, such as the smart self-healing grid, remain a challenge as utilities must meet many competing demands on precious resources while trying to be responsive to their stakeholders, who tend to limit R&D investments to immediate applications and short-term return on investment. In addition, utilities have little incentive to invest in the longer term. For regulated investor–owned utilities there is added pressure caused by Wall Street to increase dividends.

Several reports and studies have estimated that for existing technologies to evolve and for the innovative technologies to be realized, a sustained annual research and development investment of

$10 billion is required. However, the current level of R&D funding in the electric industry is at an all-time low. The investment rates for the electricity sector are the lowest rates of any major industrial sector with the exception of the pulp and paper industry. The electricity sector invests at most only a few tenths of a percent of sales in research — this in contrast to fields such as electronics and pharmaceuticals in which R&D investment rates have been running between 8 and 12 percent of net sales — and all of these industry sectors fundamentally depend on reliable electricity.

Challenges to the realization of the smart grid: There are many unanswered questions relating to the smart grid. Who will build the smart grid? Should electric companies build the smart grid when in fact it may reduce their income? If consumers are to pay for the consumer end of the smart grid, how is that to be financed? What is the overall cost-benefit analysis of a smart grid? Where are the greatest savings to be had, where are the greatest costs that will be incurred? Finally, the US electric industry, computer, communication and electronics industries need to begin to develop standards for communication, computer message structure, sensing and control device interfaces before the smart grid can be built.

A balanced, cost-effective approach to investments and use of technology can make a sizable difference in mitigating the risk. Electricity shall prevail at the quality, efficiency, and reliability that customers demand and are willing to pay for. On the one hand, the question is, “Who provides it?” on the other hand, it is important to note that achieving the grid performance, security, and reliability are a profitable national investment, not a cost burden on the taxpayer. The economic payback is three to seven times greater than the money invested. Further, the payback starts with the completion of each sequence of grid improvement. The issue is not merely who invests money, because that is ultimately the public, but whether it’s invested through taxes or kWh rates. Considering the impact of regulatory agencies, they should be capable of inducing the electricity producers to plan and fund the process; this may be the most efficient way to get it in operation. The current absence of a coordinated national decision-making body is a major obstacle. State's rights, and State PUC regulators have removed the individual State's utility motivation for a national plan. Investor utilities face either collaboration on a national level or a forced nationalization of the industry.

Given economic, societal, and quality-of-life issues and the ever-increasing interdependencies among infrastructures, a key challenge before us is whether the electricity infrastructure will evolve to become the primary support for the 21st century’s digital society — a smart grid with self-healing capabilities — or be left behind as an 20th century industrial relic?

References

1. “THE SMART GRID, AN INTRODUCTION” US Department of Energy, 2008

2. Amin, S.M., "For the Good of the Grid: Toward Increased Efficiencies and Integration of Renewable Resources for Future Electric Power Networks," IEEE Power & Energy Magazine, Vol. 6, Number 6, pp. 48-59, November/December 2008

3. Amin, S.M. and Wollenberg, B.F., "Toward a Smart Grid: Power Delivery for the 21st century," IEEE Power and Energy Magazine, Vol. 3, No. 5, pp. 34-41, Sept/Oct. 2005

4. Amin, S.M., “Toward Self-Healing Energy Infrastructure Systems,” cover feature in the *IEEE Computer Applications in Power*, pp. 20-28, Vol. 14, No. 1, January 2001

Appendix: Additional Frequently Asked Questions and Answers:

1) How does a self-healing power grid work?

Answer: Please see the two-page graphical illustration of the preventing blackouts and self-healing grid in the SciAm article from May 2007, here is a summary:

The first step in making the smart self-healing grid is to build a processor into each component of a substation. That is, each breaker, switch, transformer, busbar, etc. has an associated processor that can communicate with other such devices. Each high voltage connection to the device must have a parallel information connection. These processors have permanent information on device parameters as well as device status and analog measurements from sensors built into the component.

When a new device is added to a substation - the new device automatically reports to the central control computers such data as device parameters and device interconnects. The central control computers thus get updated data as soon as the component is connected and do not have to wait until the database is updated by central control personnel.

During 1998-2002, while at EPRI and in partnership with the DOD, I had the privilege of creating six university research groups consisting of 108 faculty members and over 220 researchers involved in the joint Electric Power Research Institute (EPRI) and U.S. Department of Defense (DOD) program, through the Complex Interactive Networks/Systems Initiative (CIN/SI). We studied a broad spectrum of challenges to the power grid, energy and communication infrastructures and developed modeling, simulation, analysis, and synthesis tools for damage-resilient control of the electric power grid and interdependent infrastructures connected to it.

This work showed that the grid can be operated close to the limit of stability given adequate situational awareness combined with better secure communication and controls.

As part of enabling a self-healing grid, we have developed adaptive protection and coordination methods that minimize impact on the whole system performance (load dropped as well as robust rapid restoration). There is a need to coordinate the protection actions of such relays and controllers with each other to achieve overall stability; single controller or relay cannot do all, and they are often tuned for worst cases, therefore control action may become excessive from a system wide perspective. On the other hand, they may be tuned for best case, and then the control action may not be adequate. This calls for a coordinating protection and control - neither agent, using its local signal, can by itself stabilize a system; but with coordination, multiple agents, each using its local signal, can stabilize the overall system.

It is important to note that the key elements and principles of operation for interconnected power systems were established in the 1960s prior to the emergence of extensive computer and communication networks. Computation is now heavily used in all levels of the power network-for planning and optimization, fast local control of equipment, processing of field data. But coordination across the network happens on a slower time-scale. Some coordination occurs under computer control, but much of it is still based on telephone calls between system operators at the utility control centers, even-or especially! -during emergencies.

From a broader perspective, any critical national infrastructure typically has many layers and decision-making units and is vulnerable to various types of disturbances. Effective, intelligent, distributed control is required that would enable parts of the constituent networks to remain operational and even automatically reconfigure in the event of local failures or threats of failure. In any situation subject to rapid changes, completely centralized control requires multiple, high-data-rate, two-way communication links, a powerful central computing facility, and an elaborate operations control center. But all of these are liable to disruption at the very time when they are most needed (i.e., when the system is stressed by natural disasters, purposeful attack, or unusually high demand).

When failures occur at various locations in such a network, the whole system breaks into isolated "islands," each of which must then fend for itself. With the intelligence distributed, and the components acting as independent agents, those in each island have the ability to reorganize themselves and make efficient use of whatever local resources remain to them in ways consonant with the established global goals to minimize adverse impact on the overall network. Local controllers will guide the isolated areas to operate independently while preparing them to rejoin the network, without creating unacceptable local conditions either during or after the transition. A network of local controllers can act as a parallel, distributed computer, communicating via microwaves, optical cables, or the power lines themselves, and intelligently limiting their messages to only that information necessary to achieve global optimization and facilitate recovery after failure.

To provide a context for this, the EPRI/DOD CIN/SI aimed to develop modeling, simulation, analysis, and synthesis tools for robust, adaptive, and reconfigurable control of the electric power grid and infrastructures connected to it. In part this work showed that the grid can be operated close to the limit of stability given adequate situational awareness combined with better sensing of system conditions, communication, controls and. A grid operator is similar to a pilot flying the aircraft, monitoring how the system is being affected, how the "environment" is affecting it and having a solid sense of how to steer it in a stable fashion by keeping the lines within their operating limits while helping a instantaneous balance between loads (demand) and available generation-- grid operators often make these quick decisions under considerable stress. Given that in recent decades we have reduced the generation and transmission capacity, we are indeed flying closer to the edge of the stability envelope.

As an example, one aspect of the Intelligrid program is aimed at enabling grid operators greater look-ahead capability and foresight into the road-ahead overcoming limitations of the current schemes which at best have over 30 seconds' delay in assessing system behavior-- analogous to driving to the car by looking into the rear-view mirror instead of the road ahead. This tool using advanced sensing, communication and software module was proposed during 2000-2001 and the program was initiated in 2002 by me while at EPRI under the "Fast Simulation and Modeling" (or FSM) program,.   This advanced simulation and modeling pro program promotes greater grid self-awareness and resilience in times of crisis in three ways: by providing faster-than-real-time, look-ahead simulations (analogous to master chess players rapidly expanding and evaluating their various options under time constraints) and thus avoiding previously unforeseen disturbances; by performing what-if analysis for large-region power systems from both operations and planning points of view; and by integrating market, policy and risk analysis into system models, and quantify their integrated effects on system security and reliability.

Had the results of this project been in place at the time of the August 2003 blackout, the events might have unfolded very differently. For example, fault anticipators located at one end of the high voltage transmission lines would have detected abnormal signals, and making adaptive reconfiguration of the system to sectionalize the disturbance and minimize impact components failures several hours before the line failed. The look-ahead simulations would have identified the line as having a higher than normal probability of failure. Quickly, cognitive agents (implemented as distributed software and hardware in the infrastructure components and in control centers) would have run failure scenarios on their virtual system models to determine the ideal corrective response. When the high-voltage line actually failed, the sensor network would have detected the voltage fluctuation and communicate the information to reactive agents located at substations. The reactive agents would have executed the pre-determined corrective actions, isolating the high-voltage line and re-routed power to other parts of the grid. No customer in the wider area would even be aware that a catastrophic event had impended, or had seen a few flickers in the light.

Such an approach provides expanded stability region with larger operational range; as the operating point nears the limit to how much the grid could have adapted (e.g. by automatically rerouting power and/or balancing dropping a small amount of load or generation), rather than cascading failures and large-scale regional system blackouts, the system will be reconfigured to minimize severity/size of outages, to shorten duration of brownouts/blackouts, and to enable rapid/efficient restoration.
This kind of distributed grid control has many advantages if coordination, communication, bandwidth, and security can be assured. This is especially true when the major components are geographically dispersed, as in a large telecommunications, transportation, or computer network. It is almost always preferable to delegate to the local level, as much of the control as is practical.

The simplest kind of distributed control would combine remote sensors and actuators to form regulators (e.g., intelligent electronically controlled secure devices), and adjust their set points or biases with signals from a central location. Such an approach requires a different way of modeling -- of thinking about, organizing and designing -- the control of a complex, distributed system. Recent research results from a variety of fields, including nonlinear dynamical systems, artificial intelligence, game theory, and software engineering have led to a general theory of complex adaptive systems (CAS). Mathematical and computational techniques originally developed and enhanced for the scientific study of CAS provide new tools for the engineering design of distributed control so that both centralized decision-making and the communication burden it creates can be minimized. The basic approach to analyzing a CAS is to model its components as independent adaptive software and hardware "agents" -- partly cooperating and partly competing with each other in their local operations while pursuing global goals set by a minimal supervisory function.

2) Explain the concept of "restructuring"

Answer: In what follows I'll provide a brief overview of "Deregulation, Restructuring, Re-Regulation and New Institutions":

In 1978, the United States Federal Government began the movement toward deregulation by allowing competition in several strategic sectors of the economy, starting with the airlines and followed by railroads, trucking, shipping, telecommunications, natural gas and banking. Adam Smith succinctly stated the philosophy behind this movement in 1776: "Market competition is the only form of organization, which can afford a large measure of freedom to the individual. By pursuing his own interest, he frequently promotes that of society more effectively than when he really intends to promote it." More recently, Prof. Alfred Kahn of Cornell University, who guided the airline deregulation as the head of the Civil Aeronautics Board, expressed it in a different way: "Deregulation is an admission that no one is smart enough to create systems that can substitute for markets."

Throughout most of the history of electric power, the institutions that furnished it have tended to be vertically integrated monopolies, each within its own geographic area. They have taken the form of government departments, quasi-government corporations or privately owned companies subjected to detailed government regulation in exchange for their monopoly status. Selling or borrowing electric power among these entities has been carried out through bilateral agreements between two utilities (most often neighbors). Such agreements have been used both for economy and for emergency backup. The gradual growth of these agreements has had the effect that larger areas made up of many independent organizations have become physically connected for their own mutual support.

In recent years, some of the local monopolies have found it beneficial to be net buyers of power from less costly producers and the latter have found this to be a profitable addition to their operations. For instance, it is typical in the western United States and Canada for surplus hydroelectric power to be transmitted south for air conditioning in the summer; while less expensive nuclear power is transmitted northward in the winter when the reservoirs are low or frozen and only nighttime heating is needed in the south. These wide area sales and the wheeling of power through non-participant transmission systems are international in extent, especially in Europe and the Americas. There is evidence of a worldwide drive to use these interconnections intentionally:

- To create competition and choice, with the hope of decreasing prices,
- To get governments out of operating, subsidizing or setting the price of electric power, and
- To create market-oriented solutions in order to deliver increases in efficiency and reductions in prices.

In order to unbundle the monopoly structure of electric power generation in the United States, Congress passed the National Energy Policy Act of 1992. National monopolies in the United Kingdom, Norway and Sweden have been de-nationalized and unbundled into separate generation, transmission and distribution/delivery companies. In most approaches to deregulation, transmission is kept as a centrally managed entity, but generation is broken into multiple independent power producers (IPP), and delivery is left to local option. New IPP are encouraged or, at least, permitted, as are load aggregators and electric power brokers, both of whom own no equipment, but are deal-makers who operate on commissions paid by the actual producers and users.

The concept behind this arrangement is that electricity, much like oil and natural gas, is a *commodity* that can be sold in the cash or spot market. As a commodity, it is possible to buy and sell future options and more complex derivative contracts based on electricity prices. However, it is not clear that electricity meets all the necessary criteria for commodity trading. The original assumptions of NYMEX and its traders were based on the model of natural gas, which, unlike electricity, can be stored economically. Once a unit of electricity is produced it must be consumed almost immediately; however, a true commodity can be stored for some length of time and consumed when and how desired. Electricity storage devices are capable of handling only a small percentage of an area's electricity requirements. Storage limitations and capacity constraints on inter-regional transfer prevent all available suppliers across the continent from head-to-head competition.

An alternative, and more entrepreneurial, view is that furnishing electricity is a *service* to the end user. Electric service may be segmented into more specific markets such as heating, cooling, lighting, building security, etc., or combined with other consumer services such as telephone, cable TV, Internet connections, etc. Both views may be reconcilable by separating the *product*, handled by generation and transmission companies, from the *service*, performed by distribution companies.

3) That's an interesting analogy in your SciAm article in which you say "to remain reliable, the grid will have to function more like a fighter plane" – How do you mean this?

Answer: Please see the answer to question 1 above; in addition, here are more nuggets for your consideration:

My earlier work with NASA-Ames and McDonnell Douglas during 1993-1997 on control and stabilization of a damaged F-15 aircraft in part provided background for the creation, successful launch, and management of research programs for the electric power industry, including the EPRI/DOD CIN/SI mentioned above, which involved six university research consortia, along with two energy companies, to address challenges posed by our critical infrastructures. This work was done during the period of 1998 to early 2002.

A grid operator is similar to a pilot flying an aircraft, monitoring how the system is being affected, how the "environment" is affecting it, and having a solid sense of how to steer it in a stable fashion.

A small-scale, yet complex, example of what may be done is illustrated by a successful program undertaken to enable a pilot to safely land a jet fighter that has suffered damage to its control surfaces that would render it "unflyable." In the case of an F-15 fighter, the team I was on, developed and implemented a self-repairing flight control system that would allow the pilot to fly and land the fighter even in the case that it lost over 90% of its wing:

In the late 1980s, an Israeli pilot of an F-15 aircraft had a mid-air collision with his wingman. As a result, the F-15 aircraft lost over 90% of the right wing, not only losing control surfaces but also a loss of symmetry which would typically mean flipping over and crashing.

Fortunately, in this case, the F-15 pilot managed to successfully land the aircraft using the remaining control surfaces combined with judicious use of engine thrust. There are no rear-view mirrors in an F-15, and thus while in flight the pilot didn't know the extent of the extreme damage before he landed the aircraft and looked to his right!

In the aftermath of this event, the aircraft was put through extensive wind-tunnel flight dynamics and control tests in McDonnell Douglas (now Boeing) in St. Louis, Missouri. The tests revealed that the pilot had only an angle of 2 degrees around the Angle-of-Attack (AOA) of the aircraft; AOA is the axis that runs thought the airframe. Not only luck was on the pilot's side, but also he was an outstandingly capable pilot who accurately sensed the stability manifolds of the aircraft and continually steered the plane back into stability region quickly and repeatedly via effective use of the remaining control surfaces and the engine thrust.

During the period of 1985-1998 I was with a research center and team at Washington University involved with several pertinent optimization and control projects. During the period 1994-1997 at

Washington University my graduate students and I worked as a sub-contractor with McDonnell Douglas (now called Boeing Phantom Works), NASA-Ames Research Center, and NASA Dryden Flight Research Center to develop a damage adaptive Intelligent Flight Control System (IFCS). This work utilized neural network technology to predict the aircraft parameters and to continuously optimize the control system response. The IFCS was designed to provide consistent handling response to the pilot under normal conditions *and during unforeseen damage or failure conditions to the aircraft (Figure 1).*

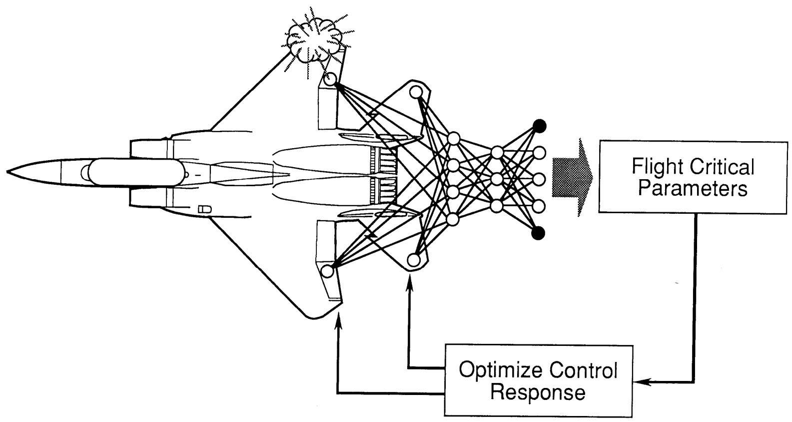


Figure 1. The IFCS Design goal is to optimize controls to compensate for damage or failure conditions of the aircraft (picture courtesy of Boeing and NASA)

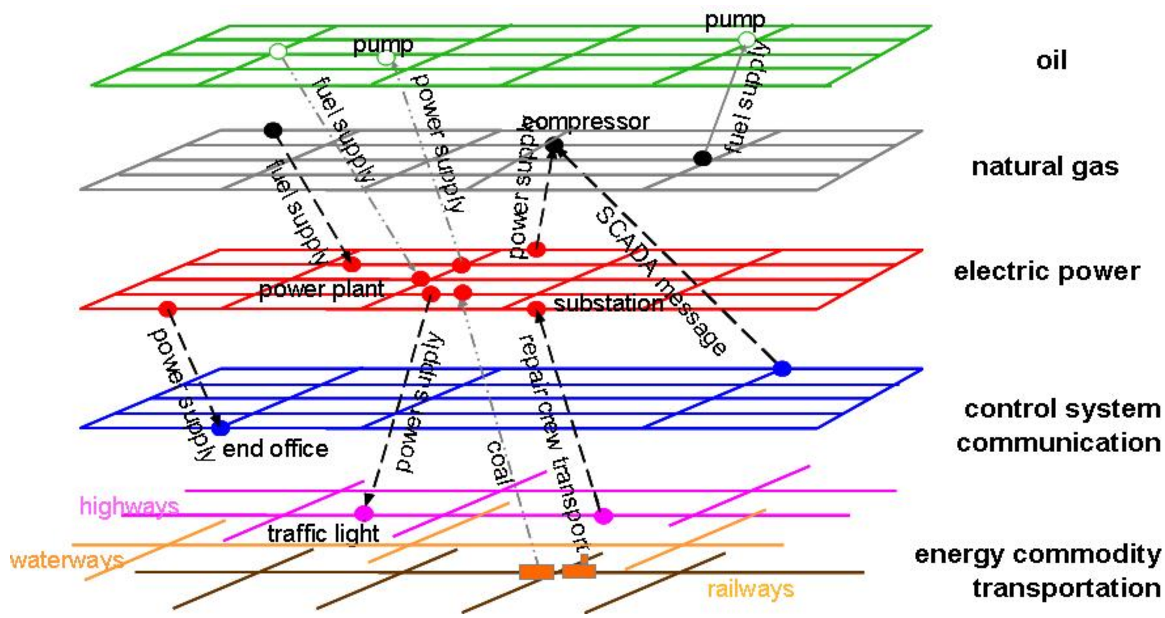
The work on the F-15 in part provided background for the creation, successful launch, and management of research programs for the electric power industry, including the EPRI/DOD Complex Interactive Networks/Systems Initiative (CIN/SI) which involved six university research consortia, along with two energy companies, to address challenges posed by our critical infrastructures. This work was done during the period of 1998 to early 2002.

The IFCS laid the conceptual foundation of a self-healing power system, where analogously a squadron of aircraft can be viewed in the same manner as components of a larger interconnected power delivery infrastructure, where system stability and reliability must be maintained under all conditions, even when one (N-1 contingency) or more (N-k contingencies) of parts are disabled.

The self-healing, or autonomic, system created for the F-15 is based on a modeling, estimation and control framework that scales to manage risk for a large scale and complex interactive networks, such as a Fortune 100 company or a regional power grid. In the case of developing a self-healing power grid, the key conceptual components and tools included:

- Anticipation of disruptive events;
- Look-ahead simulation capability;
- Fast isolation and sectionalization; and,
- Adaptive islanding.

As in the case of corporate IT management, critical system components and potential error or fault propagation pathways need to be mapped, with degrees of coupling measured.



With knowledge of how failures occur, then by assessing vulnerabilities and working out self-healing strategies, a holistic risk management, monitoring and control system can be designed and deployed. The resulting self-optimizing and self-healing system would operate on three conceptual levels:

- Sensing;
- Reasoning; and,
- Deciding.

Because the system would be utilized by classes of user with differing needs and requirements -- including top executives, business line leaders, and operations managers – it would provide multiple levels of resolution: macro (entire system); meso (e.g., individual operation): and micro (e.g., subsystem, asset).

Given that in recent decades in light of increased demand we have reduced the generation and transmission capacity margins of the electric power grid, we are indeed flying closer to the edge of the stability envelope. Ongoing programs at EPRI, DOE are further pursuing these objectives.

CIN/SI laid the foundation for several on-going initiatives on the self-healing infrastructure and subsets focusing on smart reconfigurable electrical networks. These have now been under development for some time at several organizations, including programs sponsored by the NSF, DOD, DOE, and EPRI, including EPRI's "Intelligrid" program and the US Department of Energy's "Gridwise" and "Modern Grid" initiative.

"Wind tunnel" testing of technologies, designs and policies: Over the last fifteen years, our efforts in this area have developed, among other things, a new vision for the integrated sensing, communications, protection and control of the power grid. Some of the pertinent issues are why/how to develop protection and control devices for centralized versus decentralized control and issues involving adaptive operation and robustness to various destabilizers. However, instead of performing in Vivo societal tests which can be disruptive, we have performed extensive "wind-tunnel" simulation testing (in Silico) of devices and policies in the context of the whole system along with prediction of unintended consequences of designs and policies to provide a greater understanding of how policies, economic designs and technology might fit into the continental grid, as well as guidance for their effective deployment and operation.

If organized in coordination with the internal structure existing in a complex infrastructure and with the physics specific to the components they control, these agents promise to provide effective local oversight and control without need of excessive communications, supervision, or initial programming. Indeed, they can be used even if human understanding of the complex system in question is incomplete. These agents exist in every local subsystem-from "horseshoe nail" up to "kingdom"-and perform preprogrammed self-healing actions that require an immediate response. Such simple agents already are embedded in many systems today, such as circuit breakers and fuses as well as diagnostic routines. The observation is that we can definitely account for lose nails and to save the kingdom.

Another key insight came out of analysis of forest fires, which researchers in the one of the six funded consortia which I led found to have similar "failure-cascade" behavior to electric power grids. In a forest fire the spread of a spark into a conflagration depends on how close together are the trees. If there is just one tree in a barren field and it is hit by lightning, it burns but no big blaze results. But if there are many trees and they are close enough together-which is the usual case with trees because Nature is prolific and efficient in using resources-the single lightning strike can result in a forest fire that burns until it reaches a natural barrier such as a rocky ridge, river, or road. If the barrier is narrow enough that a burning tree can fall across it or it includes a burnable flaw such as a wooden bridge, the fire jumps the barrier and burns on. It is the role of first-response wild-land firefighters such as smokejumpers to contain a small fire before it spreads by reinforcing an existing barrier or scraping out a defensible fire line barrier around the original blaze.

Similar results hold for failures in electric power grids. For power grids, the "one-tree" situation is a case in which every single electric socket had a dedicated wire connecting it to a dedicated generator. A lightning strike on any wire would take out that one circuit and no more. But like trees in Nature, electrical systems are designed for efficient use of resources, which means numerous sockets served by a single circuit and multiple circuits for each generator. A failure anywhere on the system causes additional failures until a barrier-a surge protector or circuit breaker, say-is reached. If the barrier does not function properly or is insufficiently large, the failure bypasses it and continues cascading across the system.

These preliminary findings suggest approaches by which the natural barriers in power grids may be made more robust by simple design changes in the configuration of the system, and eventually how small failures might be contained by active smokejumper-like controllers before they grow into large problems. Other research into fundamental theory of complex interactive systems is exploring means of quickly identifying weak links and failures within a system.

CIN/SI has developed, among other things, a new vision for the integrated sensing, communications, and control of the power grid. Some of the pertinent issues are why/how to develop controllers for centralized vs. decentralized control and issues involving adaptive operation and robustness to disturbances that include various types of failures. As expressed in the July 2001 issue of *Wired* magazine: “The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming—and interconnected with everything else.” The technologies included, for example, the concept of self-healing electricity infrastructure, Intelligrid as part of CEIDS, and the methodologies for fast look-ahead simulation and modeling, adaptive intelligent islanding and strategic power infrastructure protection systems are of special interest for improving grid security from terrorist attack.

4) **Describe to me how SCADA works:**

Answer: The operation of a modern power system depends on complex systems of sensors and automated and manual controls, all of which are tied together through communication systems. The technologies that support the operational control of electrical networks range from energy-management systems (EMSs) to remote field devices. Critical systems include:

Energy-Management System (EMS): The objective of the EMS is to manage the production, purchasing, transmission, distribution, and sale of electrical energy in the power system at a minimal cost with respect to safety and reliability. Management of the real-time operation of an electric power system is a complex task requiring interaction of human operators, computer systems, communications networks, and real-time data-gathering devices in power plants and substations. An EMS consists of computers, display devices, software, communication channels, and remote terminal units (RTUs) that are connected to other remote terminal units, control actuators, and transducers in power plants and substations. The main tasks that an EMS performs have to do with generator control and scheduling, network analysis, and operator training. Control of generation requires that the EMS maintain system frequency and tie line flows while economically dispatching each generating unit. Management of the transmission network requires that the EMS monitor up to thousands of telemetered values, estimate the electrical state of the network, and inform the operator of the best strategy to handle potential outages that could result in an overload or voltage-limit violation. EMSs can have real-time two-way communication links between substations, power plants, independent system operators, and other utility EMSs. More details on sensors, EMSs and their use in systems monitoring and control are provided in Chapter 6 of this report.

Supervisory Control and Data Acquisition (SCADA) System: A SCADA system supports operator control of remote (or local) equipment, such as opening or closing a breaker. A SCADA system provides three critical functions in the operation of an electric power system: data acquisition, supervisory control, and alarm display. It consists of one or more computers with appropriate applications software connected by a communications system to a number of RTUs placed at various locations to collect data, perform intelligent control of electrical system devices, and report results back to an EMS. SCADAs can also be used for similar applications in natural gas pipeline transmission and distribution applications. A SCADA can have real-time communication links with one or EMSs and hundreds of substations.

Remote Terminal Unit: RTUs are special-purpose microprocessor-based computers that contain analog-to-digital converters (ADCs) and digital-to-analog converters (DACs), digital inputs for status, and digital output for control. There are transmission substation RTUs and distribution automation (DA) RTUs. Transmission substation RTUs are deployed at substation and generation facilities, where a large number of status and control points are required. DA RTUs are used:

- To control air switches and Var-compensation capacitor banks on utility poles
- To control pad-mounted switches
- To monitor and automate feeders
- To monitor and control underground networks
- To monitor, control, and automate smaller distribution substations

RTUs are also used as indicated above in natural gas transmission and distribution. RTUs can be configured and interrogated using telecommunication technologies. They can have hundreds of real-time communication links with other substations, EMSs, and power plants. The SCADA and EMS systems are in a central control center. The data acquisition system in the SCADA-EMS gathers data periodically from the RTU at each substation through communication channels – mostly microwave, sometimes leased telephone lines and increasingly optical fiber – that connect the EMS to remote terminal units (RTU) at the substations. The RTU at each substation gathers the local data (analog measurements like voltage and power as well as digital states of switchgear) and uploads the latest set when polled by the EMS every few seconds. These communication channels by themselves are dedicated and are not interconnected with other communication systems.

Programmable Logic Controller (PLC): PLCs have been used extensively in manufacturing and process industries for many years and are now being used to implement relay and control systems in substations. PLCs have extended I/O systems similar to transmission substation RTUs. The control outputs can be controlled by software residing in the PLC and via remote commands from a SCADA system. The PLC user can make changes in the software stored in EEPROM without making any major hardware or software changes. In some applications, PLCs with RTU-reporting capability may have advantages over conventional RTUs. PLCs are also used in many power plant and refinery applications. They were originally designed for use in discrete applications like coal handling. They are now being used in continuous control applications such as feedwater control. PLCs can have many real-time communication links inside and outside substations or plants. More of general embedded controllers can be “soft PLCs” including software packages such as Labview. In addition to traditional binary logic, these include more advanced logic including for example fuzzy logic or general PID (proportional, integral derivative) algorithms.

Protective Relays: Protective relays are designed to respond to system faults and short circuits. When faults occur, the relays must signal the appropriate circuit breakers to trip and isolate the faulted equipment. Distribution system relaying must be coordinated with fuses and reclosures for faults while ignoring cold-load pickup, capacitor-bank switching, and transformer energization. Transmission-line relaying must locate and isolate a fault with sufficient speed to preserve stability, reduce fault damage, and minimize the impact on the power system. Certain types of “smart” microprocessor based protective relays can be configured and interrogated using telecommunication technologies. Chapter 6 of this report will next discuss applications and functional reliability of the control and protection systems.

Automated Metering: Automated metering is designed to upload residential and/or commercial gas and/or electric meter data. These data can then be automatically downloaded to a PC or other device and transmitted to a central collection point. With this technology, real-time communication links exist outside the utility infrastructure.

Plant Distributed Control Systems (DCSs): DCSs are plant-wide control systems that can be used for control and/or data acquisition. The I/O count can be higher than 20,000 data points. Often, the DCS is used as the plant data highway for communication to and from intelligent field devices, other control systems (such as PLCs), RTUs, and even the corporate data network for Enterprise Resource Planning (ERP) applications. The DCS traditionally has used a proprietary operating system. Newer versions are moving toward open systems such as Windows NT, Sun Solaris, and so on. DCS technology has been developed with operating efficiency and user configurability as drivers, rather than system security. Additionally, technologies have been developed that allow remote access, usually via PC, to view and potentially reconfigure the operating parameters.

Field Devices: Examples of field devices are process instrumentation such as pressure and temperature sensors and chemical analyzers. Other standard types of field devices include electric actuators. Intelligent field devices include electronics to enable field configuration, upload of calibration data, and so on. These devices can be configured off-line. They also can have real-time communication links between plant control systems, maintenance management systems, stand-alone PCs, and other devices inside and outside the facility.

As power systems rely more heavily on computerized communications and control, system security has become increasingly dependent on protecting the integrity of the associated information systems. Part of the problem is that existing control systems, which were originally designed for use with proprietary, standalone communication networks, were later connected to the Internet (because of its productivity advantages and lower costs), but without adding the technology needed to make them secure. Communication of critical business information and controlled sharing of that information are essential parts of all business operations and processes.

5) You say in the article "as soon as power flows were restored, the system would again start to self-optimize." What do you mean?

Answer: The concept of the self-healing grid includes automated capabilities to recognize problems, find solutions and optimize the performance of the system. The basic building blocks include advanced sensors, enhanced computational ability and pattern-recognition software, and solid-state power flow controllers, such as flexible AC transmission systems (FACTS) to reduce congestion, react in real time to disturbances, and redirect the flow of power as needed. There are three primary objectives:

- **Optimize the overall performance and resilience of the power delivery.** Sensors will monitor the electrical characteristics of the system (voltage, current, frequency, harmonics, etc.) as well as the condition of critical components, such as transformers, feeders, circuit breakers, etc. The system will self-diagnose and reconfigure to achieve an optimal state. When a potential problem is detected and identified, its severity and the resulting consequences will be assessed and corrective actions taken. Examples of such potential problems would be a transformer with unusual gassing activity or a cable termination with higher than normal partial discharge.
- **Instantly respond to disturbances to minimize impact.** When an unanticipated disturbance does take place on the system, it can be quickly detected and its location identified. An intelligent islanding or sectionalizing scheme, for example, can be activated to separate the system into self-sustaining parts to maintain electricity supply for consumers according to specified priorities, and to prevent blackouts from propagating.
- **Restore the system after a disturbance.** Following system reaction to a major disturbance, actions will be taken to restrict the spread of the disturbance and to move the system towards a stable operating regime. To do so, the state and topology of the system need to be monitored and assessed in real time, allowing alternative corrective actions to be identified and the effectiveness of each determined by look-ahead fast simulation and modeling computer simulations. The most effective actions would then be implemented. When a stable operating state is achieved, the system will again self-optimize.

6) **What is a "digital energy portal?" Explain, please, the process of replacing the power switches and upping the voltage capacity.**

Answer: Digital Energy Port is a consumer gateway that allows price signals, decisions, communications, and network intelligence to flow (EnergyPort is a service mark of EPRI). EnergyPort is one of the six enabling advanced technologies (discussed below) now under development or under consideration holds the promise of meeting the electricity needs of a robust digital economy. The architecture for this new technology framework is evolving through early research on concepts and the necessary enabling platforms. This architectural framework envisions an integrated, self-healing, electronically controlled electricity supply system of extreme resiliency and responsiveness—one that is fully capable of responding in real time to the billions of decisions made by consumers and their increasingly sophisticated agents. The potential exists to create an electricity system that provides the same efficiency, precision and interconnectivity as the billions of microprocessors that it will power.

The institutional and economic framework envisioned for the 21st Century Power System ultimately depends upon building new types and levels of functionality into today's power system. These needed capabilities will be "enabled" by several breakthrough innovations, including but not limited to the following:

- **Digitally controlling the power delivery network** by replacing today's electro-mechanical switching with real-time, power-electronic controls. This will become the foundation of a new "smart, self-healing power delivery system" that will enable innovative productivity advances throughout the economy. Digital control, coupled with communications and computational ability is the essential step needed to most cost-effectively address the combined reliability, capacity, security, and market-service vulnerabilities of today's power delivery system.
- **Integrating communications** to create a dynamic, interactive power system for real-time information and power exchange. This capability is needed to enable retail energy markets; power interactive, microprocessor-based service networks; and fundamentally raise the value proposition for electricity. Through advanced information technology coupled with sensors, the system would be "self healing" in the sense that it is constantly self-monitoring and self-correcting to keep high-quality, reliable power flowing. It can sense disturbances and instantaneously counteract them, or reconfigure the flow of power to cordon off any damage before it can propagate.

- **Automating the distribution** system to meet evolving consumer needs. The value of a fully automated distribution system integrated with communication—derives from four basic functionality advantages:

  1. Reduced number and duration of consumer interruptions, fault anticipation, and rapid restoration.
  2. Increased ability to deliver varying levels of reliable, digital-grade power.
  3. Increased functional value for all consumers in terms of metering, billing, energy management, demand control, and security monitoring, among others.
  4. Access to selective consumer services including energy-smart appliances, electricity-market participation, security monitoring, and distributed generation.

5. The value of these advantages to consumers, suppliers, and society alike more than justify the needed public/private investment commitment. This transformation will enable additional innovations in electricity service that are bounded only by our imagination.

- **Transforming the meter** into an EnergyPort (Energy Port is a service mark of EPRI). EnergyPort is a consumer gateway that allows price signals, decisions, communications, and network intelligence to flow back and forth through the two-way energy/information portal. This will be the linchpin technology that leads to a fully functioning marketplace with consumers responding (through microprocessor agents) to service offerings and price signals. This offers a tool for moving beyond the commodity paradigm of 20th Century electricity service, and quite possibly ushering in a set of new energy/information services as diverse as those in today's telecommunications.
- **Integrating distributed energy resources.** The new power delivery system would also be able to seamlessly integrate an array of locally installed, distributed power generation as power system assets. Distributed power sources under could be deployed on both the supply and consumer side of the energy/information portal as essential assets dispatching reliability, capacity and efficiency.
- **Accelerating end-use efficiency**. The growing trend toward digital control can enable sustained improvements in efficiency and productivity for nearly all industrial and commercial operations. Similarly, the growth in end-use energy consuming devices and appliances, networked with system controls, will afford <u>continuous</u> improvements in productivity and efficiency.

7) If the "self-healing grid" is as good as it sounds, why isn't it in place yet?

Answer: Developing the self-healing grid will be costly, but not prohibitively expensive in light of historic investments patterns. The incremental cost of both transmission and distribution transformation is about $13 billion/year, or 65% over and above current business-as-usual investment of about $20 billion annually.

Several reports and studies have estimated that for existing technologies to evolve and for the innovative technologies to be realized, a sustained annual R&D investment of $10-$13 billion is required. However, the current level of R&D funding in the electric industry is at an all-time low. The investment rates for the electricity sector are the lowest rates of any major industrial sector with the exception of the pulp and paper industry. The electricity sector invests at most only a few tenths of a percent of sales in research. This is in contrast to fields such as electronics and pharmaceuticals, in which R&D investment rates have been running between 8 and 12 percent of net sales.

Funding and sustaining innovations, such as the self-healing grid, remain a challenge as utilities must meet many competing demands on precious resources while trying to be responsive to their stakeholders. That tends to limit R&D investments to immediate applications. In addition, utilities have little incentive to invest in the longer term. For investor–owned utilities, there is added pressure caused by Wall Street to increase dividends.

As I write this, consolidation of the industry seems to be proceeding; it is important to note that achieving the grid performance, security and reliability are a national profitable investment, not a cost burden on the taxpayer. The economic pay-back is three to seven times and in some cases an order of magnitude greater than the money invested. Further, the payback starts with the completion of each sequence of grid improvement. The issue is not merely who invests money because that is ultimately the public, whether through taxes or kWh rates.

Whether or not the power industry renews its traditional levels of investment in research and in new transmission lines and the government clarifies its regulatory role in the making and dispatching of electricity, the grid will have to go on functioning. Fortunately, several recent innovations promise to make better use of the existing electrical network.

At the core of the power infrastructure investment problem lie two paradoxes of restructuring, one technical and one economic. Technically, the fact that electricity supply and demand must be in instantaneous balance at all times must be resolved with the fact that new power infrastructure is extraordinarily complex, time-consuming, and expensive to construct. Economically, the theory of deregulation to achieve the lowest price must be resolved with the market reality of deregulation to achieve the highest profit. Both the technical and economic paradoxes could be resolved by knowledge and technology.

A balanced, cost-effective approach to investments and use of technology can make a sizable difference in mitigating the risk.

Similarly, revolutionary developments in both information technology and material science and engineering promise significant improvement in the security, reliability, efficiency, and cost-effectiveness of all critical infrastructures. Steps taken now can ensure that critical infrastructures continue to support population growth and economic growth without environmental harm.

Considering the impact of regulatory agencies, they should be able to induce the electricity producers to plan and fund the process. That may be the most efficient way to get it in operation. The current absence of a coordinated national decision making is a major obstacle. State's rights, and State PUC regulated have removed the individual State's utility motivation for a national plan. Investor utilities face either collaboration on a national level, or a forced nationalization of the industry.

Simply replicating the existing system through expansion or replacement will not only be technically inadequate to meet the changing demands for power, but will produce a significantly higher price tag. Through the transformative technologies outlined here, the nation can put in place a 21st Century power system capable of eliminating critical vulnerabilities while meeting intensified consumer demands, and in the process, save society considerable expense. A few observations:

- Annual business losses in the US from electrical failures might be $100 billion or more. Much of this arises from short power interruptions. On any day, typically a half million people will be without power for two hours.

- The US power grid operates under ever more stress from increasing electrical traffic and from a changing economic climate. Here are four notable grid issues:
    1. the regulatory problem: federal and state grid guidelines often conflict;
    2. the investment problem: demand for power is increasing faster than new grid construction;

3. the reliability problem: operating rules should keep the grid up and running more of the time;
4. the marketplace problem: in many instances, the production, transmission, and distribution of power is subject to unfair competition.

- Operating the grid will increasingly come to resemble the flight of combat aircraft, including the use of complex adaptive software.

A phased approach to system implementation will allow the utility to capture many cost synergies. Equipment purchased, for example, should emphasize switchgear, regulators, transformers, controls, and monitoring equipment that can be easily integrated with automated transmission and distribution systems. Long-term plans for equipment upgrades should also address system integration considerations.

Energy policy and technology development and innovation require long-term commitments as well as sustained and patient investments in innovation, technology creation and development of human capital. Given economic, societal, and quality-of-life issues and the pivotal role of the electricity infrastructure, a self-healing grid is essential.

8) Approximately how old is the technology we're using in our electric grid infrastructure?

Many parts of the infrastructure are over 25-30 years old. For example, the key elements and principles of operation for power grids were established in the 1960s or 1970s prior to the emergence of extensive computer and communication networks. Today, computer simulations support all the planning and most of the operational control that goes into assuring the success of its primary function: to deliver bulk electric power from generation sources to load areas reliably and economically. In the past, the assurance of reliability has been the overwhelming goal in performing this function.

Computation is now heavily used in all levels of the power network-for planning and optimization, fast local control of equipment, processing of field data. But coordination across the network happens on a slower time-scale. Some coordination occurs under computer control, but much of it is still based on telephone calls between system operators at the utility control centers, even-or especially! - during emergencies.

From a historical perspective the electric power system in the U.S. evolved in the first half of the 20th century without a clear awareness and analysis of the system-wide implications of its evolution. Once "loosely" interconnected networks of largely local systems, electric power grids increasingly host large-scale, long-distance wheeling (movement of wholesale power) from one region or company to another. Likewise, the connection of distributed resources, primarily small generators at the moment, is growing rapidly. The extent of interconnectedness, like the number of sources, controls, and loads, has grown with time. In terms of the sheer number of nodes, as well as the variety of sources, controls, and loads, electric power grids are among the most complex networks made.

9) **Currently, if there is an outage or other problem with service within an electric grid, how easy/difficult is it to detect the problem and respond?**

Depending on the instrumentation, it takes over 30 seconds to gather and process all the filed data in the control centers; so it is as if you are driving the car by looking at the rear-view mirror instead of look-ahead foresight. While some of the operations of the system are automatic, ultimately human operators in the system control center make decisions and take actions to control the operation of the system.

One of the most important of enabling technology has been the proposal to "fly" the grid more like the way an advanced jet fighter is actually flown. Modern warplanes are now so packed with sophisticated gear as to be nearly impossible to operate by human skill alone. Instead they rely on a battery of sensors and automatic control agents that quickly gather information and act accordingly. While working at the Electric Power Research Institute (EPRI), I proposed just such a complex adaptive system for operating large regional power grids.

Revolutionary developments in both information technology and material science and engineering promise significant improvement in the security, reliability, efficiency, and cost-effectiveness of this transformation:

- What is "self healing"?
    - A system that uses information, sensing, control and communication technologies to allow it to deal with unforeseen events and minimize their adverse impact …
- Why is self healing concept important to the Energy Infrastructure?
    - A secure "architected" sensing, communications, automation (control), and energy overlaid infrastructure as an integrated, reconfigurable, and electronically controlled system that will offer unprecedented flexibility and functionality, and improve system availability, security, quality, resilience and robustness.

Steps taken now can ensure that critical infrastructures continue to support population growth and economic growth without environmental harm.

10) **How vulnerable is our current system to environmental damage?**

The existing power-delivery system is vulnerable to natural disasters and intentional attack. Regarding the latter, a successful terrorist attempt to disrupt the power-delivery system could have adverse effects on national security, the economy, and the lives of every citizen. Secure and reliable operation of the system is fundamental to national and international economy, security and quality of life. Their very interconnectedness makes them more vulnerable to global disruption, initiated locally by material failure, natural calamities, intentional attack, or human error.

This is not new-- both the importance and difficulty of protecting power systems have long been recognized. In 1990, the Office of Technology Assessment (OTA) of the U.S. Congress issued a detailed report, *Physical Vulnerability of the Electric System to Natural Disasters and Sabotage*, concluding: "Terrorists could emulate acts of sabotage in several other countries and destroy critical [power system] components, incapacitating large segments of a transmission network for months. Some of these components are vulnerable to saboteurs with explosives or just high-powered rifles." The report also documented the potential cost of widespread outages, estimating them to be in the range of $1 to $5/kWh of disrupted service, depending on the length of outage, the types of customers affected, and a variety of other factors. In the New York City outage of 1977, for example, damage from looting and arson alone totaled about $155 million—roughly half of the total cost.

During the twenty years since the OTA report, the situation has become even more complex. Accounting for all critical assets includes thousand of transformer, line reactors, series capacitors, and transmission lines. Protection of ALL the widely diverse and dispersed assets is impractical because there are so many assets involved. In addition, cyber, communication, and control layers add new benefits only *if architected correctly and securely*, and new challenges.

11) How secure is our current system? Is it vulnerable to cyber attacks?

The articles and media reports on our nation's electric power grid "penetrated by spies"[1] bring back memories of the last seven years: In the aftermath of the tragic events of 9/11, when I became responsible for security R&D at EPRI, I received seemingly contradictory piles of reports/files that either claimed that "we are bullet proof" or "the sky is falling."

Without going through sensitive information in this email, it was neither extreme as the broad brush on the whole sector. The truth critically depended on the specifics of the organization's preparedness and security measures that had been put in place.

Electric power utilities typically own and operate at least parts of their own telecommunications systems which often consist of backbone fiber optic or microwave connecting major substations, with spurs to smaller sites. Increased use of electronic automation raises significant issues regarding the adequacy of operational security, if security provisions are not built in

Security of cyber and communication networks is fundamental to the reliable operation of the grid. As power systems rely more heavily on computerized communications and control, system security has become increasingly dependent on protecting the integrity of the associated information systems. Part of the problem is that existing control systems, which were originally designed for use with proprietary, standalone communication networks, were later connected to the Internet (because of its productivity advantages and lower costs), but without adding the technology needed to make them secure. Communication of critical business information and controlled sharing of that information are essential parts of all business operations and processes.

In addition, some trends show that worldwide cyber attacks are on the rise; the number of documented attacks and intrusions has been rising very rapidly in recent years. Due to the increasingly sophisticated nature and speed of some malicious code, intrusions, and denial-of-service attacks, human response may be inadequate.

Any telecommunication link that is even partially outside the control of the organization that owns and operates power plants, SCADA systems, or EMSs represents a potentially insecure pathway into the business operations of the company as well as a threat to the grid itself. The interdependency analyses done by most companies in the last 10 years (starting with preparations for Y2K, and after the tragic events of 9/11) have identified these links and the system's vulnerability to their failures. Thus they provide an excellent reference point for a cyber-vulnerability analysis.

Like any complex dynamic infrastructure system, the electricity grid has many layers and is vulnerable to many different types of disturbances. While strong centralized control is essential to reliable operations, this requires multiple, high-data-rate, two-way communication links, a powerful central computing facility, and an elaborate operation-control center, all of which are especially vulnerable when they are needed most—during serious system stresses or power disruptions. For deeper protection, intelligent distributed secure control is also required, which would enable parts of the network to remain operational and even automatically reconfigure in the event of local failures or threats of failure.

I have presented and published non-sensitive material on this key issue for over a decade. Most recently on Thursday, 26 March 2009, I spoke at the U.S. Congressional Research and Development [R&D] Caucus, on the Smart Grid briefing that ASME and IEEE-USA convened. I highlighted cyber security as one of the key challenges, and asked for the design of a smart grid would include "security built-in as part of its design and NOT glued on as afterthought," to solving the cyber security question (www.researchcaucus.org).

Regarding today's cyber threat reports, it is fundamental to separate "hype" from the truth; what concerns me about such reports is mainly one piece in an earlier article: "The response to the alert was mixed. An audit of 30 utility companies that received the alert showed only seven were in full compliance, although all of the audited companies had taken some precautions."

That is the reality that needs to be addressed.

12) Is the regional structure of the United States electric grid a problem? Would it be better to have a unified national system?

The existing grid has served the country well and its development has been recognized as the greatest engineering achievement of the 20th century, but the needs of the nation in the 21st century require that the grid be reinforced. Key factors driving the need to upgrade the grid include expected expansion in the use of renewable generation resources, introduction of new end use technologies such as Plug-In Hybrid Vehicles, and advances in information technologies that create the opportunity to improve grid operation and efficiency.

However, currently only 0.2 percent of net sales in the electricity and gas sector have been put into R & D. The dog food industry spends more on research and development. In fact, investment in energy R&D has been at a 30-year low. The result of this is increased outages and the impact on society has been enormous. Power outages and power quality disruptions in the United States have been causing over $75 billion lost annually (in a slow economy) on up to $188 billion lost in a good economy.

At the core of the power infrastructure investment problem lie two paradoxes of restructuring, one technical and one economic. Technically, the fact that electricity supply and demand must be in instantaneous balance at all times must be resolved with the fact that new power infrastructure is extraordinarily complex, time-consuming, and expensive to construct. Economically, the theory of deregulation aims to achieve the lowest price through increased competition. However, the market reality of electricity deregulation has often resulted in business-focused drive for maximum efficiency to achieve the highest profit from existing assets and not resulting in lower prices or improved reliability. Both the technical and economic paradoxes could be resolved by knowledge and technology.

Electricity shall prevail at the quality, efficiency and reliability that customers demand and are willing to pay for. On the one hand the question is who provides it; on the other hand it is important to note that achieving the grid performance, security and reliability are a national profitable investment, not a cost burden on the taxpayer. The economic pay-back is three to seven times and in some cases an order of magnitude greater than the money invested. Further, the payback starts with the completion of each sequence of grid improvement. The issue is not merely who invests money because that is ultimately the public, whether through taxes or kWh rates. Considering the impact of regulatory agencies, they should be able to induce the electricity producers to plan and fund the process. That may be the most efficient way to get it in operation.

The current absence of a coordinated national decision making is a major obstacle. State's rights, and State PUC regulated have removed the individual State's utility motivation for a national plan. Investor utilities face either collaboration on a national level, or a forced nationalization of the industry.

Simply replicating the existing system through expansion or replacement will not only be technically inadequate to meet the changing demands for power, but will produce a significantly higher price tag. Through the transformative technologies we have developed, the nation can put in place a 21st Century power system capable of eliminating critical vulnerabilities while meeting intensified consumer demands, and in the process, save society considerable expense.

The key is to make this a national priority. We need to create a public/private partnership in order to make it happen, because 80 percent of the infrastructure when it comes to electricity, oil and gas is privately owned. The government cannot do it alone and the industry cannot do it alone either.

13) **How much human supervision is required in our current system? How much would be necessary in a smart grid format?**

While some of the operations of the system are automatic, ultimately human operators in the system control center make decisions and take actions to control the operation of the system. My hat is off to the grid operators who keep the lights on, even though they are managing an increasingly stressed system with diminished shock absorbers and closer to the edge.

In this and many complex networks, the human participants themselves are both the most susceptible to failure and the most adaptable in the management of recovery.

14) **How easy/difficult is it to feed electricity back into the grid right now?**

In addition to being dispatchable by the grid operators, having the appropriate permits, and ability to sell back to the grid…, from an engineering perspective: For DC networks it is easy, for AC networks it requires power electronics to be installed. The electric power industry is similar in many ways to the telecommunications and transportation industries, but it has important differences which cannot be ignored in its practical operations, whether regulated or market driven, integrated or unbundled. While electricity also "flows" (from high voltage to low voltage locations), its transmission is inherently different from that of gas or water:

- Power flows through the grid in inverse relation to the impedance on each line.
- Electric power systems use phase shifters rather than valves.
- Providing the required flow on one line often results in "loop flows" on several other lines.
- Despite batteries and capacitors, and in contrast to "line packing" of gas or the use of reservoirs for water, there is no practical way to store large amounts of electricity for any significant length of time.
- Reliable electric service is critically dependent on the <u>whole grid's</u> ability to respond to changed conditions instantaneously.
- Global stability is essential for local efficiency, but every local change has some effect on global stability.

For an electric power network, there are three basic operating requirements:

- all components within their thermal ratings
- all voltages within upper and lower limits
- all generators synchronized

Electricity has the shortest shelf-life of any product that we manufacture. Its perishability is partly compensated by the ability to transport it at almost the speed of light. But the infrastructure required for that transportation is made up of local parts that have limited capacities, and the viability of the whole system depends in an extremely complex way on the performance of each of those parts.

15) **Because of the regional nature of the U.S. grid, is information about the grid distributed across regions or does it exist in silos?**

Please see the responses above; in addition: On a limited basis, several utilities are beginning to employ remote control, distributed sensing, and communications methods to improve network performance. High-speed electronic power controllers such as FACTS (flexible AC transmission system) devices represent an especially promising technology. By replacing the slow mechanical switches now used to manage system operations, these controllers offer for the first time the potential to dynamically fine-tune transmission so that power delivery can respond instantly to changes in demand without the burden of maintaining large amounts of "spinning reserve" generation. However, these devices represent a two-edged sword. On the one hand, they are capable of controlling the system's inherent modal behavior and directing the flow of active power to where it is wanted by accepting changes in reactive power elsewhere. But, on the other hand, increased use of high-speed electronic controllers like FACTS presents more opportunities for large disturbances to occur. In addition, the use of economically beneficial, high voltage direct current (HVDC) interconnections also encourages dependence on geographically remote power sources, making the new controls associated with them essential for secure & stable operation.

16) **How prepared is our current grid to incorporate alternative sources of energy such as wind or solar power?**

The electric power grid's emerging issues include creating distributed management through using distributed intelligence and sensing; integration of renewable resources; use of active-control high-voltage devices; developing new business strategies for a deregulated energy market; and ensuring system stability, reliability, robustness, and efficiency in a competitive marketplace and carbon-constrained world.

In a truly smart grid, the analogous programs would run in processors attached to the various key components of the grid, and would be fed by a rich stream of real-time data flowing in from sensors all over the grid. In principle such a smart grid could be not only self-managing, but self-healing. In my vision, the processors in the future grid will be able to localize and anticipate the consequences of disturbances, whether they are natural disturbances, such as lightning or hurricanes, or intentional disturbances.

Electricity travels almost at the speed of light, so we have a few milliseconds to take this action before it becomes widespread. During the past 12 years, I have estimated that such a grid in the United States would take ten years to roll out and cost between $10 billion and $13 billion per year to install (above what the electric power utilities spent annually), shouldered by a public–private partnership. That's no budget operation but, it would cost just a seventh or an eighth of the current annual cost to society of power interruptions.

17) **Is it expensive to maintain the grid in its current form? Would a smart grid be less expensive to maintain once it's in place?**

The North American power network may realistically be considered to be the largest machine in the world since its transmission lines connect all the electric generation and distribution on the continent.

This network represents an enormous investment, including over 15,000 generators in 10,000 power plants, and hundreds of thousands of miles of transmission lines and distribution networks, whose estimated worth is over US$800 billion. In 2000, transmission and distribution was valued at US$358 billion (EIA 2003; EPRI 1999-2003).

In the coming decades, electricity's share of total energy is expected to continue to grow, as more efficient and intelligent processes are introduced into this network. Electric power is expected to be the fastest-growing source of end-use energy supply throughout the world. To meet global power projections, it is estimated by the U.S. DOE/EIA that over $1 trillion will have to be spent during the next 10 years.

18) Why the US uses a 120v power system as opposed to Europe's 240v system?

The system of three-phase alternating current (AC) electrical generation and distribution was invented by Nikola Tesla in the nineteenth century, and the technology was mass produced by Westinghouse in the late 1880s. Tesla considered that 60 Hz was the best frequency for alternating current (AC) power generating at 240 Volts, which was considered less lossy for long transmission lines.

On the other hand, Thomas Edison developed direct current (DC) systems at 110 V and this was claimed to be safer, and DC worked well with incandescent lamps that were the principal load of the day, and with motors.

Originally Europe was also at 110 Volts, just like the U.S. and Japan today. It was necessary to increase voltage to draw more power with reduced loss and voltage drop from the same copper wires used in transmission lines. At the time the US also wanted to change, but it was deemed too costly to change all of the existing infrastructure.

In America we are still confronted with the problems of the lower voltages for our AC circuits. A device at 120 Volts draws twice as much current as a device with the same power draw at 240 Volts. A 3000 Watt domestic clothes dryer requires 12.5 A at 240 V or 25 A at 120 V. The end result is that wiring must be larger, and each outlet supplies less power. This may have been a factor in the use of circuit breakers in America long before they became common in Europe.

Smaller buildings in North America get 240 Volts split in two 120 Volt supplies between neutral and hot wire. Larger buildings often have 3-phase with 208 Volts. Major appliances, such as dryers and ovens, are now connected to 240 Volt or 208 Volt supply.

Transmitting electric power over large distances can result in losses up to 7.5%. The major loss is heat, and this can be reduced by increasing the voltage and decreasing the current. Most of the power in the United States is alternating current (ac), and this allows the power from the generator to be stepped up. This is done using transformers; the unit in which this is done is called a step-up transmission substation. Long distance transmission is typically done with overhead lines of voltages of 110 to 765 kV. The capacity of an overhead line varies with the voltage and the distance: thus, a 765 kV line for a 100 mile length has a maximum capacity of 3.8 GW; for a 400 mile length the capacity is 2.0 GW. To avoid system failures, the amount of power flowing over each transmission line must remain below the line's capacity.

The principal limitation on the capacity of a line is its temperature. As a line gets warmer, it sags; and in the worst cases it may touch trees or the ground. Another factor is mechanical strength of the support structure. Conductors with higher strength-to-weight ratios for a given current-carrying capacity may increase the overall capacity of the right-of-way. Typically, the right-of-way for a 230 kV transmission line is 75–150 feet or more.

For more information about the early battles between proponents of AC and DC supply systems, please see the movie War of Currents (or the website at http://en.wikipedia.org/wiki/War_of_Currents).

19) Does operating at a lower voltage cuts carbon emissions. I'm hoping someone can explain a little about the differences between the US and European systems as well as speak basically about where (or if) there is a carbon footprint at the power plants, in the power transmission, or in the consumption of power. If the question is incorrect, then maybe you can explain what would be a measure of energy efficiency and whether that would be affected by operating on a higher or lower voltage.

Answer: Energy consumption is proportional to the voltage supplied. Running equipment at higher than optimum voltages results in higher energy consumption. For example, things like lighting and motors consume more power at higher voltages. The higher voltage also puts extra stress on components, and reduces their operating life.

In the developed parts of the World, we ca n improve our overall system efficiency. In the U.S. our total Energy system efficiency is about 43%, meaning that over 55% is wasted. Much can be and must be done in this area.

As a related example, in January 2006, analyses of performance of North Yorkshire County Hall headquarters in England showed that savings of about 14% were being achieved by optimizing/tailoring voltages for device-specific needs. In February 2007 the savings for all of 2006 added to about €27,000 (£18,500) from the annual baseline electricity bill and CO2 emissions reductions of 114 tons for the city hall– this is equivalent to the emissions of around 20 households.

As another example, a review of manufacturing in China has shown that without system optimization about 10% of China's emissions (2% of global emissions) in 2020 will come from China's motor systems alone and to improve industrial efficiency even by 10% would deliver up to 200 million tons (Mt) CO2e savings.
(http://www.theclimategroup.org/assets/resources/publications/Smart2020Report.pdf)

Transmission and distribution losses in the U.S. were about 5% in 1970, and grew to 9.5% in 2001, due to heavier utilization and more frequent congestion.33 In addition, it is estimated that power outages and power quality disturbances cost the economy from $75 to $180 billion annually

Smart grids: Reducing electricity transmission & distribution losses in India's power sector by 30% is possible through better monitoring and management of their electricity Power grids, first with smart meters and then by integrating more advanced information and communication technologies into the so-called energy Internet.

Smart grid technologies have been the largest opportunity found not just to reduce outages and economic losses (over $75 billion per year in the U.S.), but also could globally reduce 2.03 GtCO2e, worth $124.6 billion.

- For details as well as the big picture of the smart grid, please see my presentation on 26 March, 2009, at the U.S. Congressional Research and Development [R&D] Caucus, on the Smart Grid at www.researchcaucus.org

- Please also see my kickoff presentation on the "Smart Grid" at the annual MIT Energy Conference: http://160.94.126.215/amin/MIT%20Energy%202009_SNL_Massoud_Amin_expanded.pdf

- Additional material, presentations and publications are available from the sidebar at the left-hand column of http://umn.edu/~amin

A related recent article: http://news.medill.northwestern.edu/chicago/news.aspx?id=133055

Funding a brighter future: Paying for the smart grid

***by* Kellen M. Henry**
June 03, 2009

We can rebuild it. We have the technology. The U.S. electricity grid can be made better, stronger and faster, according to energy and security experts.

With increasing concern over cyber attacks and the push for greater energy independence, revolutionizing how electricity reaches consumers through smart grid technology is no longer the stuff of science fiction.

However, the challenges lie in financing unproven technology for an overhaul of one of the most complex transmission systems in the world.

“Ultimately everything comes down to who pays,” said Ray Dotter, spokesman for PJM Interconnection LLC, the organization that operates the electrical grid in thirteen states, including the Chicago area of Illinois.

“We can accomplish revolutionary things with the existing technology. It’s just a matter of bringing it together and helping it talk to each other,” he said.

The term ‘smart grid’ refers to a diverse pool of technologies that would modernize the transmission of electricity to consumers using digital technology to reduce costs, increase reliability and protect the grid from hostile invasion. This type of electrical system would allow operators to more accurately monitor and correct problems quickly.

Several studies have indicated that a sustained annual investment of $10 billion would be necessary for the existing technology to evolve, but research and development investment is at an all-time low and utility companies have little incentive to invest long term, said Massoud Amin, director of the Center for the Development of Technological Leadership at the University of Minnesota. Amin, a professor of electrical and computer engineering, directed all security-related research and development for the Electric Power Research Institute after Sept. 11, 2001.

Government appropriations for energy research and development declined nearly 60 percent to $2.75 billion from 1978 to 2004, according to the Department of Energy. Data on private sector research and development is less complete but also show a decline in funding and capital investment as a percentage of revenue.

“We are at a historical low,” Amin said. “The dog food industry spends more in research and development than does the electricity industry.”

At the same time, power outages are becoming more frequent and more costly. The aging of transmission facilities and the increasing reliance on devices that use electricity mean outages and disturbances now cost the U.S. economy more than $100 billion per year, according to Amin. This is equivalent to a 50-cent surcharge on every dollar consumers spend on electricity.

With a growing emphasis on bringing renewable energy sources to the grid, the Obama administration’s stimulus funding in February’s American Recovery and Reinvestment Act in included $4.5 billion to be used in upgrading and modernizing the nation’s electricity grid.

However, states are the primary regulators of energy transmission and smart-grid proponents are looking to the federal government to further incentivize states to reform rate structures to encourage utilities to invest in the grid.

A smart grid with efficient communication and information processes could save $15 billion to $35 billion in energy and fuel costs, according to a November 2008 report by the Global e-Sustainability Initiative, formed by information and telecommunications companies with the goal of promoting United Nations energy and sustainability goals.

In addition to the money-saving benefits, a smarter grid would also have intangible benefits, including reduction of carbon dioxide emissions by between 40 million and 100 million metric tons by the year 2020, according to the GeSI report.

The Illinois Institute of Technology is developing a “Perfect Power” system with the Galvin Electricity Initiative that both entities say would fulfill many of the same environmental and reliability goals that leaders are seeking in smart technology.

The “Perfect Power” system would work through a microgrid, allowing operators to isolate problem areas and prevent massive blackouts. It would also incorporate security measures in the design, rather than add them as an afterthought.

“There’s no plug and play capability in the current design,” said Kurt Yeager, executive director of the Galvin Electricity Initiative. “The smart grid with digital control can see [outages] coming and correct for it or reconnect the system. It’s localized and not spread over a whole state.”

PJM is also looking closely at the development of these self-healing grids, as developers and transmission utilities consider investments in these technologies. But the regulators’ utility members want to see actual benefits in investing in the technology that may not be immediately profitable.

“One of the challenges is, how do you monetize the value of certain things?” Dotter said. “Reducing the risk of an outage, alone, has value. Being able to squeeze more use out of the existing system has value. There is real potential that higher efficiencies make the investment worthwhile.”

Attached below please find a summary that I prepared on the stimulus plan (**American Recovery and Reinvestment Act of 2009**):

1) Summary of the numbers:

Energy efficiency and conservation block grants	$3,200,000,000
Weatherization Assistance Program (increases maximum income level and maximum assistance)	$5,000,000,000
State energy program	$3,100,000,000
Advanced batteries manufacturing, including lithium ion batteries, hybrid electrical systems, component manufactur and software designers	$2,000,000,000
Modernize electricity grid	$4,400,000,000
Electricity grid worker training	$100,000,000
Fossil energy research and development	$3,400,000,000
Uranium Enrichment Decontamination and Decommission Fund	$390,000,000
Department of Energy science programs	$1,600,000,000
Advanced Research Projects Agency	$400,000,000
Innovative technology loan guarantee program	$6,000,000,000
Western Area Power Administration construction and maintenance	$10,000,000
Bonneville Power Administration borrowing authority	$3,250,000,000
Western Area Power Administration borrowing authority	$3,250,000,000
Leading edge biofuel projects	$500,000,000
Federal building conversion to "high-performance green buildings"	$4,500,000,000
Energy efficiency federal vehicle fleet procurement	$300,000,000

FYI, this also includes $10m to fund Section 1305 of the EISA.

2) Summary of Renewable Energy Provisions:

Here's a summary of the renewable energy provisions in the recently passed Stimulus bill compiled by ACORE. The full text can be found at:
http://www.acore.org/files/images/email/acore_stimulus_overview.pdf

Most notable for some consumers is that the bill increases the tax credit for qualified plug-in electric drive vehicles for the first 200,000 placed in service. The base amount of the credit is $2500. Batteries with at least 5 kilowatt hours of capacity have a credit of $2917. The credit cannot exceed $5000

American Recovery and Reinvestment Act of 2009
The full text of the tax provisions in the stimulus package can be found here.
http://thomas.loc.gov/home/h1/Recovery_Bill_Div_B.pdf
The full text of the appropriation provisions in the stimulus package can be found here.
http://thomas.loc.gov/home/h1/Recovery_Bill_Div_A.pdf

Tax Incentives
Three-Year Extension of PTC: The bill provides a three-year extension of the Production Tax Credit (PTC) for electricity derived from wind facilities through December 31, 2012, as well as for geothermal, biomass, hydropower, landfill gas, waste-to-energy and marine facilities through December 31 2013.

Investment Tax Credit (ITC) Accessible to All Renewable Energy: The bill provides project developers of wind, geothermal, biomass and other technologies eligible for the PTC, the option of instead utilizing the 30% ITC that previously only applied to solar and other clean technology projects.

Repeals Subsidized Energy Financing Limitation on ITC: The bill would allow businesses and individuals to qualify for the full amount of the ITC, even if their property is financed with industrial development bonds or other subsidized energy financing.

Grant Program in Lieu of Tax Credits: The bill allows project developers to apply for a grant from the Treasury Department in lieu of the ITC. The grant will be equal to 30% of the cost of eligible projects that start construction in 2009 or 2010. It will be issued within sixty days of the facility being placed in service or, if later, within sixty days of receiving a grant application.
Increases Credit for Alternative Fuel Pumps: The bill increases the size of credits for installing alternative fuel pumps at gas stations from 30 to 50% ($30,000 to $50,000) for taxable years 2009-2010.

Advanced Energy Manufacturing Credits: The bill provides $2 billion worth of energy related manufacturing investment credits at a 30% rate. These credits apply to projects creating or retooling manufacturing facilities to make components used to generate renewable energy, storage systems for use in electric or hybrid-electric cars, power grid components supporting addition of renewable sources, and equipment for carbon capture and storage (CCS).

Plug-in Electric Drive Vehicle Credit: The bill increases the tax credit for qualified plug-in electric drive vehicles for the first 200,000 placed in service. The base amount of the credit is $2500. Batteries with at least 5 kilowatt hours of capacity have a credit of $2917. The credit is further increased by $417 for every kilowatt hour in excess of 5 kilowatt hours, but cannot exceed $5000.The credit is allowed to be taken against the alternative minimum tax (AMT).

Five Year Carry-Back Provision for Operating Losses of Small Businesses: The bill would extend the carry-back period for net operating losses (NOL) from two to five years for tax years 2008 and 2009. An eligible NOL includes the NOL for any taxable year ending in 2008 or if the taxpayer chooses, any taxable year beginning in 2008. An election under this provision may only be taken for one taxable year.

Extends Bonus Depreciation: The bill extends, through 2009, the temporary increase of bonus depreciation to 50% that Congress enacted last year. These write offs can be applied to capital expenditures ranging from $250,000 to a newly increased threshold of $800,000.

Direct Spending
Total Direct Spending for Renewable Energy and Energy Efficiency: The bill provides $16.8 billion in direct spending for renewable energy and energy efficiency programs over the next ten years.

Grid Development: The bill provides $4.5 billion to modernize the nation's electricity grid with smart grid technology. The bill increases federal matching grants for the Smart Grid Investment Program from 20% to 50%.

R&D, Demonstration Projects: The bill provides $2.5 billion for renewable energy and energy efficiency R&D, demonstration and deployment activities.

Federal Power Marketing Administrations: The bill provides $6.5 million for capital investments by certain federal power marketing administrations in electric power transmission systems.

Advanced Battery Grants: The bill provides $2 billion for grants for the manufacturing of advanced batteries and components. This includes the manufacturing of advanced lithium ion batteries, hybrid electrical systems, component manufacturers, and soft-ware designers.

Defense Energy and Efficiency Programs: The bill provides $300 million to the DOD for the purpose of research, testing and evaluation of projects to energy generation, transmission and efficiency. The bill provides an additional $100 million for Navy and Marine Corps facilities to fund energy efficiency and alternative energy projects.

Study of Electric Transmission Congestion: The bill requires the Secretary of Energy to include a study of the transmission issues facing renewable energy in the pending study of electric transmission congestion that is due to be issued in August 2009.

Bond and Loan Programs
Clean Energy Renewable Bonds (CREBs): The bill provides $1.6 billion of new clean energy renewable bonds to finance wind, closed-loop biomass, open-loop biomass, geothermal, small

irrigation, hydropower, landfill gas, marine renewable, and trash combustion facilities. One third of the authorized funding will be available for qualifying projects of state/local/tribal governments, one-third for public power providers and one-third for electric cooperatives.

Renewable Energy Loan Guarantee Program: The bill provides $6 billion for a temporary loan guarantee program for renewable energy power generation and transmission projects that begin construction by September 30, 2011.xxv Up to $500 million of the overall $6 billion can be used for the development of leading edge biofuels that have been demonstrated and have commercial promise to substantially reduce greenhouse gas emissions.

3) I've also cut and pasted related legislation, which contains targeted efforts in:

- Clean, Efficient, American Energy
- Transforming our Economy with Science and Technology
- Lowering Health Care Costs and Ensuring Broader Coverage
- Investing in Education for the 21st Century
- Modernizing Roads, Bridges, Transit and Waterways
- Tax Cuts for Middle-Class Families and American Businesses
- Helping Workers Hurt by the Recession
- Providing Strong Accountability Measures.

Following are highlights of some key provisions in each of these areas.
Clean, Efficient, American Energy: To put people back to work today and reduce our dependence on foreign oil tomorrow, we will increase renewable energy production and renovate public buildings to make them more energy efficient.

- Smart Grid/Advanced Battery Technology/Energy Efficiency
  - Provides a total of $30 billion for such initiatives as a new, smart power grid, advanced battery technology, and energy efficiency measures, which will create nearly 500,000 jobs.
  - Transforms the nation's electricity systems through the Smart Grid Investment Program to modernize the electricity grid to make it more efficient and reliable.
  - Supports U.S. development of advanced vehicle batteries and battery systems through loans and grants so that America can lead the world in transforming the way automobiles are powered.
  - Helps state and local governments make investments in innovative best practices to achieve greater energy efficiency and reduce energy usage.
  - Spurs energy efficiency and renewable energy R&D.

- Tax Incentives to Spur Energy Savings and Green Jobs
  - Provides $20 billion in tax incentives for renewable energy and energy efficiency over the next 10 years.
  - Includes a three-year extension of the production tax credit (PTC) for electricity derived from wind (through 2012) and for electricity derived from biomass, geothermal, hydropower, landfill gas, waste-to-energy, and marine facilities (through 2013).

- Provides grants of up to 30 percent of the cost of building a new renewable energy facility to address current renewable energy credit market concerns.
- Promotes energy-efficient investments in homes by extending and expanding tax credits through 2010 for purchases such as new furnaces, energy-efficient windows and doors, or insulation.
- Provides a tax credit for families that purchase plug-in hybrid vehicles of up to $7,500 to spur the next generation of American cars.
- Includes clean renewable energy bonds for State and local governments.
- Establishes a new manufacturing investment tax credit for investment in advanced energy facilities, such as facilities that manufacture components for the production of renewable energy, advanced battery technology, and other innovative next-generation green technologies.

- Landmark Energy Savings at Home
  - Provides $5 billion for landmark provisions to improve the energy efficiency of more than 1 million modest-income homes through weatherization.
  - This will save modest-income families on average $350 per year on their heating and air conditioning bills.
- Repairing Public Housing and Making Key Energy Efficiency Retrofits to HUD-Assisted Housing
  - Provides a total of $6.3 billion for increasing energy efficiency in federally-supported housing programs.
  - Specifically, establishes a new program to upgrade HUD-sponsored low-income housing (elderly, disabled, and Section 8) to increase energy efficiency, including new insulation, windows, and frames.
  - Also invests in energy efficiency upgrades in public housing, including new windows, furnaces, and insulation to improve living conditions for residents and lower the cost of operating these facilities.

Transform our Economy with Science and Technology: To secure America's role as a world leader in a competitive global economy, we are renewing America's investments in basic research and development, in training students for an innovation economy, and in deploying new technologies into the marketplace. This will help businesses in every community succeed in a global economy.

- Investing in Scientific Research (More than $15 Billion)
  - Provides $3 billion for the National Science Foundation, for basic research in fundamental science and engineering – which spurs discovery and innovation.
  - Provides $1.6 billion for the Department of Energy's Office of Science, which funds research in such areas as climate science, biofuels, high-energy physics, nuclear physics and fusion energy sciences – areas crucial to our energy future.
  - Provides $400 million for the Advanced Research Project Agency-Energy (ARPA-E) to support high-risk, high-payoff research into energy sources and energy efficiency in collaboration with industry.
  - Provides $580 million for the National Institute of Standards and Technology, including the Technology Innovation Program and the Manufacturing Extension Partnership.

  - Provides $8.5 billion for NIH, including expanding good jobs in biomedical research to study diseases such as Alzheimer's, Parkinson's, cancer, and heart disease.
  - Provides $1 billion for NASA, including $400 million to put more scientists to work doing climate change research.
  - Provides $1.5 billion for NIH to renovate university research facilities and help them compete for biomedical research grants.
- <u>Extending Broadband Services</u>
  - Provides $7 billion for extending broadband services to underserved communities across the country, so that rural and inner-city businesses can compete with any company in the world.
  - For every dollar invested in broadband, the economy sees a ten-fold return on that investment.

Lower Health Care Costs and Ensure Broader Coverage: Affordable and quality health care is key to strong economic growth. We are bringing our health care system into the 21st century with information technology, which will save billions of dollars, and are taking key steps to ensure broader coverage in this recession.

- <u>Modernizing Health Care System to Lower Costs and Save Lives</u>
  - Provides $19 billion to accelerate adoption of Health Information Technology (HIT) systems by doctors and hospitals, <u>in order to modernize the health care system, save billions of dollars, reduce medical errors and improve quality</u>.
  - Strengthens Federal privacy and security law to protect personally identifiable health information from misuse and abuse.
  - Creates hundreds of thousands of jobs – many in high-tech sectors – by promoting the adoption of HIT.
  - CBO estimates that this proposal will generate billions of dollars in "system-wide" savings.
- <u>Protecting Health Care Coverage for Millions through Medicaid</u>
  - Protects health care coverage for millions of Americans during this recession, by providing an estimated $87 billion over the next two years in additional federal matching funds to help states maintain their Medicaid programs in the face of massive state budget shortfalls.
  - Helps states avoid cutting eligibility for Medicaid and scaling back the health care services covered.
- <u>Providing Health Insurance for Unemployed Workers</u>
  - Currently, laid-off workers, under the COBRA program, can buy into their former employer's health insurance. But the premiums are often prohibitively expensive. In order to help people maintain their health coverage, the bill provides a 60% subsidy for COBRA premiums for up to 9 months.
- <u>Investing in Prevention & Comparative Effectiveness Research</u>
  - Provides $1 billion for a new Prevention and Wellness Fund. Studies have shown that investing in prevention can lower overall health care costs by billions of dollars.
  - Provides $1.1 billion for comparative effectiveness research, to help patients and doctors determine the effectiveness of different treatments. This research will improve the quality of care.

Education for the 21st Century: Economists tell us that strategic investments in education are one of the best ways to help America become more productive and competitive. This bill will make key investments to help states avoid teacher layoffs and other damaging education cuts in this recession, help make college more affordable, and make other key education investments.

- Preventing Teacher Layoffs and Education Cuts by the States
  - Prevents teacher layoffs and other cutbacks in education and other key services, by establishing a $53.6 billion State Fiscal Stabilization Fund, including $40.6 billion to local school districts using existing funding formulas, which can be used for preventing cutbacks, preventing layoffs, school modernization, or other purposes; $5 billion to states as bonus grants for meeting key performance measures in education; and $8 billion to states for other high priority needs such as public safety and other critical services, which may include education.
- Making College More Affordable
  - Increases the higher education tax credit to a maximum of $2,500. Also makes it available to nearly 4 million low-income students who had not had any access to the higher education tax credit in the past – by making it partially refundable.
  - Increases the maximum Pell Grant by $500, for a maximum of $5,350 in 2009 and $5,550 in 2010.
  - Adds $200 million to the vital College Work-Study program.

- Investing in Early Childhood Development
  - Provides $1.1 billion for Early Head Start and $1 billion for Head Start, which provide comprehensive development services to low-income infants and preschool children – thereby providing services for 110,000 additional infants and children.
  - Provides $2 billion for the Child Care Development Block Grant to provide child care services to an additional 300,000 children in low-income families while their parents go to work.
- Providing Other Key Education Investments
  - Provides $13 billion for Title I grants to help disadvantaged kids reach high academic standards – ensuring that in this period of tight state and local budgets these vital services are maintained.
  - Provides $12.2 billion for grants for IDEA (Special Education) to increase the federal share of these costs, and prevent these mandatory costs from forcing states to cut other areas of education.

Modernize Roads, Bridges, Transit and Waterways: To build a 21st century economy, we must create jobs rebuilding our crumbling roads and bridges, modernizing public buildings, and putting people to work cleaning up our air, water and land.

- Modernizing Roads and Bridges
  - Provides $29 billion for modernizing roads and bridges, which will create 835,000 jobs. This investment creates jobs in the short term while saving commuters time and money in the long term.
  - Requires states to obligate at least half of the highway/bridge funding within 120 days.

- States have over 6,100 projects totaling over $64 billion that could be under contract within 180 days.

- Improving Public Transit and Rail
  - Provides $8.4 billion for investments in transit and $8 billion for investment in high-speed rail. These investments will reduce traffic congestion and our dependence on foreign oil.
  - Includes funds for new construction of commuter and light rail, modernizing existing transit systems, and purchasing buses and equipment to needed to increase public transportation and improve intermodal and transit facilities.
  - States have 787 ready-to-go transit projects totaling about $16 billion.
- Prioritizing Clean Water/Flood Control/Environmental Restoration
  - Provides $18 billion for clean water, flood control, and environmental restoration investments, which will create more than 375,000 jobs.
  - Experts note that $16 billion in water projects could be quickly obligated.
- Modernizing Public Infrastructure, Including To Achieve Major Energy Cost Savings
  - Provides billions to modernize federal and other public infrastructure with investments that lead to long-term energy cost savings, including about $5 billion to make improvements in DOD facilities, including housing for our troops and about $4.5 billion to make federal office buildings more energy-efficient in order to achieve long-term savings for taxpayers.

Tax Cuts to Make Work Pay and Create Jobs: More than 35 percent of the package will provide direct tax relief to 95 percent of American workers, as President-elect Obama pledged, and spur investment and job growth for American businesses. To gain the support of the needed Senate Republicans, the amount of Make Work Pay Tax credit has been scaled back, the AMT has been added, and several business tax incentives have been added (cancellation of debt income).

- Tax Relief for American Families
  - Provides immediate and sustained tax relief to 95 percent of American workers through the Making Work Pay Tax Cut, a refundable tax credit of up to $400 per worker ($800 per couple filing jointly), phasing out completely at $200,000 for couples filing jointly and $100,000 for single filers.
  - Cuts taxes for the families of millions of children through an expansion of the child tax credit (allowing families to begin qualifying for the child tax credit with every dollar earned over $3,000).
  - Expands the Earned Income Tax Credit by providing tax relief to families with three or more children and increasing marriage penalty relief.
  - Helps more than 4 million additional students attend college with a new, partially refundable $2,500 tax credit for families.
  - Protects 26 million middle-class families from being hit by the AMT.
  - Helps first-time homebuyers and strengthens the housing market by enhancing the current credit for first-time home purchases with the removal of the repayment requirement.
  - Provides incentives to buy new cars, including light trucks and SUVs, with a tax deduction for State and local sales taxes paid on the purchase.

    - Temporarily suspends the taxation of some unemployment benefits.
- Business Tax Incentives to Create Jobs and Spur Investment
    - Helps businesses quickly recover costs of new capital investments by extending the bonus depreciation and increased small business expensing for businesses making investments in plants and equipment in 2009.
    - Includes a variety of provisions to help small business, including small business expensing for investment in new plants and equipment, loss carry back for small businesses, a delay of the 3% withholding tax on payments to businesses that sell goods or services to governments, and a cut in the capital gains tax cut for investors in small businesses who hold stock for more than five years.
    - Provides assistance to companies looking to reduce their debt burdens by delaying the tax on businesses that have discharged indebtedness, which will help these companies strengthen their balance sheets and obtain resources to invest in job creation.
    - Provides incentives to create new jobs with tax credits for hiring recently discharged unemployed veterans and youth that have been out of work and out of school for the 6 months prior to hire.
- Tax Incentives to Spur Energy Savings and Green Jobs
    - Provides $20 billion in tax incentives for renewable energy and energy efficiency over the next 10 years.
    - Includes a three-year extension of the production tax credit (PTC) for electricity derived from wind (through 2012) and for electricity derived from biomass, geothermal, hydropower, landfill gas, waste-to-energy, and marine facilities (through 2013).
    - Provides grants of up to 30 percent of the cost of building a new renewable energy facility to address current renewable energy credit market concerns.
    - Promotes energy-efficient investments in homes by extending and expanding tax credits through 2010 for purchases such as new furnaces, energy-efficient windows and doors, or insulation.
    - Provides a tax credit for families that purchase plug-in hybrid vehicles of up to $7,500 to spur the next generation of American cars.
    - Includes clean renewable energy bonds for State and local governments.
    - Establishes a new manufacturing investment tax credit for investment in advanced energy facilities, such as facilities that manufacture components for the production of renewable energy, advanced battery technology, and other innovative next-generation green technologies.
- Tax Incentives for State and Local Economic Development
    - Includes provisions to enhance the marketability for state and local government bonds, which will reduce the costs they incur in financing state and local infrastructure projects.
    - Includes a new bond-financing program for school construction, rehabilitation, and repair.

Help Workers Hurt by the Recession: High unemployment and rising costs have outpaced Americans' paychecks. We will help workers train and find jobs, and help struggling families make ends meet. Every dollar in unemployment or food stamp creates at least $1.63 in economic activity, as these funds are spent quickly.

- Extending and Improving Unemployment Benefits

    - Continues through December 2009 the extended unemployment benefits program (which provides up to 33 weeks of extended benefits) that is otherwise scheduled to begin to phase out at the end of March 2009 – thereby helping an additional 3.5 million jobless workers.
    - Increases unemployment benefits for 20 million jobless workers by $25 per week, and encourages states to modernize their UI systems to keep up with the changing workforce with expanded coverage.
    - Temporarily suspends the taxation of some unemployment benefits.
    - Every dollar in unemployment benefits creates at least $1.63 in economic activity, according to chief economist Mark Zandi of Moody's Economy.com.
- <u>Increasing Food Stamp Benefits</u>
    - Increases food stamp benefits by over 13% to help offset rising food costs for more than 31 million Americans, half of whom are children.
    - Every dollar of food stamps creates at least $1.73 in economic activity, according to chief economist Mark Zandi of Moody's Economy.com.
- <u>Increasing Other Food Assistance</u>
    - Provides other food assistance, including $100 million for Emergency Food and Shelter to help local community organizations provide food and shelter; $100 million for formula grants to states for elderly nutrition services including Meals on Wheels; and $150 million for the Emergency Food Assistance Program to purchase commodities for food banks to refill emptying shelves.
- <u>Helping Workers Find Jobs</u>
    - Provides funding to help workers find jobs, including $4 billion for job training including formula grants for adult job training, dislocated worker job training, and youth services (including funding for summer jobs for young people); $500 million for Vocational Rehabilitation State Grants to help persons with disabilities prepare for gainful employment; $500 million to match unemployed individuals to job openings through state employment agencies; and $120 million to provide community service jobs to an additional 24,000 low-income older Americans.
- <u>Expanding Housing Assistance</u>
    - Increases support for several critical housing programs, including providing $2 billion for the Neighborhood Stabilization Program to help communities purchase and rehabilitate foreclosed, vacant properties and $1.5 billion for the Emergency Shelter Grant program to provide short-term rental assistance and other aid for families during the economic crisis.
- <u>Providing Aid to Seniors, Disabled Veterans, and SSI Recipients</u>
    - Provides a payment of $250 to Social Security beneficiaries, SSI recipients, and veterans receiving disability compensation and pension benefits from the VA.
- <u>Extending TAA</u>
    - Extends Trade Adjustment Assistance benefits for at least 160,000 new workers over the next two years who lose their jobs because of increased imports or factory shifts to certain foreign countries.

Unprecedented Accountability: An historic level of transparency, oversight and accountability will help guarantee taxpayer dollars are spent wisely and ensure that Americans can see the results of their investment.

- There are **no earmarks** or pet projects.
- In many cases, funds are distributed to existing initiatives with proven track records and with tough accountability measures already in place.
- How funds are spent, all announcements of contract and grant competitions and awards, and formula grant allocations must be posted on a special website created by the President. It must also include the names of agency personnel to contact with concerns about infrastructure projects.
- Public notice of funding must include a description of the investment funded, the purpose, the total cost, and why recovery dollars should be used. Governors, mayors, or others making funding decisions must personally certify that the investment has been fully vetted and is an appropriate use of taxpayer dollars. This information will also be placed on the internet.
- The Council of Economic Advisors must report quarterly on the results for the American economy.
- A Recovery Act Accountability and Transparency Board will be created to review management of recovery dollars and provide early warning of problems. The board is made up largely of Inspectors General.
- The Government Accountability Office and the Inspectors General are provided additional funding and access for special review of recovery funding.
- State whistleblowers who report fraud and abuse are protected.

I hope that this provides an adequate summary and is helpful.