Attachment 3

Development of an Integrated Energy and Communications Systems Architecture (IECSA): A White Paper

INTRODUCTION

Society has entered into a new era of economics and social experience, driven by digitally-based technologies. Our world is more interconnected than at any time in history, utterly dependent on the integrity of complex, interactive networks, including the Internet, telecommunications, and electric power systems.

In many ways, the electricity network is the foundation of this interconnection. The National Academy of Engineering has hailed the U.S. electrical system as the supreme engineering achievement of the twentieth century because of its ubiquitous impact in improving quality of life down to the household level. In the twenty first century, its role as a key enabler of the digital society promises equally significant implications.

However, the electricity system – generation, transmission, distribution, and end use – is in serious need of upgrading towards an appropriate twenty-first century architecture if the benefits of interconnection are to be fully realized at both commercial and individual consumer levels.

Lack of critical infrastructure investment and surging demand for high quality, digital-grade electricity has taxed the electrical infrastructure beyond its limit. Put simply, our current system cannot meet demand. EPRI research shows that U.S. electricity demand has exceeded transmission capacity by more than 15% for the last ten years. Most credible forecasts predict that this inequity will continue. Additionally, microprocessor-based technologies have radically altered the nature of the electrical load, resulting in electricity demand that is incompatible with a power system created to meet the needs of an analog economy. This has led to unprecedented electricity reliability problems, as well as low service quality responsible for tens of billions of dollars in losses to industry and society annually.

EPRI and the Electricity Innovation Institute (E2I) have formed the Consortium for Electric Infrastructure to Support a Digital Society (CEIDS) to provide the strategic framework for this serious commitment to upgrading the electric system.

Strategic in nature, CEIDS is a collaborative research initiative, supporting recommendations made in EPRI's *Electricity Technology Roadmap*—EPRI's long-term strategic vision, forecasting society's electrical needs on a 25-year basis. Fittingly, the Technology Roadmap's three primary "destinations"— advanced electrotechnologies for increased economic productivity, a power supply system hardened against disaster, and an engaged customer in control of their energy use—support a new mega-infrastructure caused by the convergence of energy, telecommunications, transportation, the Internet, and electronic commerce.

Two Infrastructures - Not Just One

The future of the power industry will require the continued development of two infrastructures - not just one. The existing power delivery infrastructure that delivers energy to millions of homes and businesses has been formed by over a century of advancements in electrical engineering. The discipline of electrical engineering has advanced as the power delivery system has become increasingly more complex. To manage this complexity, the power delivery system will rely increasingly on data network communications combined with intelligent equipment that will enable a variety of improved energy delivery and consumer service applications. The required data networks and intelligent equipment, collectively known as "distributed computing", must be recognized as a significant infrastructure in their own right. Power system engineers, operators, planners and many other "stakeholders" will increasingly rely upon the distributed computing infrastructure to operate the power delivery system. However, the industry must recognize that the distributed computing infrastructure must be engineered and designed with as much technical discipline as the power system. The "Development of a systems architecture for the self-healing grid and for connecting energy consumers with markets" project is focused on designing the distributed computing infrastructure(s) necessary to support the future of the power industry. However, unlike the electrical engineering discipline that built the existing power delivery system, the distributed computing world does not have the benefit of a mature underlying engineering discipline. This project will follow an industry best practices approach to capture and document the distributed computing infrastructure that will be necessary to support the future of the power industry.

The scope of the architecture proposed in this project spans advancements in existing energy systems as well as future scenarios of energy system operations. The project will, in effect, begin to architect the future of energy system operations. This future includes advancements in power system automation as well as an expanded role that includes more dynamic interaction with consumers. Concepts such as "self healing" power delivery systems that are self aware and better able to respond to fault conditions will be included among other scenarios of how grid operations can be improved through distributed computing technologies. This architecture includes communications with consumer systems as well. The future of the power delivery system will include more dynamic operation with building and automation systems that can effectively respond to real-time pricing and other power system dynamics necessary to ensure a high level of power service reliability. This architecture should be independent of and compatible with different corporate structures of the industry. For example, the architecture should be equally applicable to a Regional Transmission Organization, a for-profit transmission company and a rural electrical coop.

The thrust of the work on the architecture is to contribute to the development of relevant open system standards and create a shared infrastructure that can enable the envisioned future(s). In this sense the project is not just codifying the past but inventing the future. For, while there has been no shortage of vision in the past, there is an ongoing need for a stable open systems based shared infrastructure to enable the integration of equipment into an enterprise and industry wide managed distributed computing system. This infrastructure will enable a free market to supply the interoperable intelligent equipment necessary to manifest the visions of the future power system.

Why Focus on an Architecture?

The concept of an enterprise or industry-wide architecture is appropriate for the power industry because of the massive scope and scale of what is envisioned for the industry. The future for the supporting data communication networks is envisioned to be as extensive as the existing power delivery system. The intelligent devices supporting the future vision will number in the millions. An architecture development effort enables a view from a height that can be useful for identifying potential synergies such as data and applications sharing among multiple stakeholders and multi-vendor equipment integration. Architectural perspectives can identify system management issues that would otherwise go unnoticed until they were implemented. Emerging industry policies in critical infrastructure protection and security will require a systematic approach to appropriately implement security policies in data networks and intelligent equipment. Architecture analysis can also provide an understanding of the strengths and limitations of potential system designs. The architectural perspective can head off problems that can arise from under specified component and subsystem buildouts. Many apparently successful “tactical” implementations of intelligent equipment can run into “brick walls” when it comes to integration between vendors, sharing data, scaling up to large numbers and attempts to “retrofit” security. Architecture analyses can also be useful in identifying life cycle equipment management and robustness issues that will arise when the systems need to be maintained and expanded to meet a steady stream of future needs.

This project will apply the latest methods coming from the systems engineering community, but it is not an academic exercise. This project reflects a serious effort to address looming industry issues related to the design, deployment and management of intelligent equipment for the existing and emerging power/energy industry. For all the potential benefits that can come from distributed computing technologies there is also a “dark side” that must be addressed upfront. The lack of a concerted deliberate technical approach to the deployment of distributed computing by the energy industry risks not only misspent capital and poor systems integration but potentially more serious consequences from security threats to the power delivery system infrastructure.

The Architecture Project Will Seek To Identify What New Applications Are Desired As Well As Identify How They Should Be Implemented.

This project anticipates surfacing requirements that will require the development of new applications using the "new" architecture. In addition the project will surface improvements to existing applications as well. The architecture effort is equally interested in capturing new system requirements that will define "What" the future power system will be able to do, as well as helping to define "How" that future would be implemented with open systems. The identification of new and improved applications anticipated by this project will require gathering input from wide variety of stakeholders.

Building on Prior Infrastructure Work

This project recognizes that there are significant efforts by the power industry to develop new applications and the standards for specific application domains. The most significant work is taking place within several committees under the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE). There are also a steady stream of new requirements emerging from a variety of ad hoc and industry restructuring groups. Some of these requirements are coming from the regulatory community such as FERC and State Public Service Commissions. While there are pockets of coherence within this work there is also the potential for fragmentation and disparate solutions to the same problem. This project will recognize the work that is taking place, build upon it and seek to contribute and accelerate its refinement and adoption by the industry.

Pathways to Commercial Products and Industry Implementation

The architecture development represents initial steps in a new generation of intelligent equipment development. A rich set of requirements based on potential operating scenarios will help to ensure a robust approach to intelligent equipment development and strategically planned deployments. One of the goals of the architecture project is to effectively contribute to the development of a robust open distributed computing infrastructure for the industry and accelerate and complete key standards initiatives. These open standards will, in turn, provide the basis for real products.

SCENARIOS OF FUTURE ENERGY INDUSTRY OPERATIONS:

The following sections illustrate a few of the application visions to provide context to the overall architecture. The first, "Consumer Communications", illustrates potential future consumer-energy system dynamic interactions. The second, the "self-healing" grid, illustrates improvements on the power delivery system. These concepts are not orthogonal but will increasingly become more tightly integrated in the future. Consumer dynamics will become increasingly relied upon for improved operations and improved industry economics in the future.

1. Integrated Consumer Communications: Enabling Dynamic Consumer Interaction

The vision of the electric infrastructure of the future extends beyond the traditional utility environment to include internetworking with consumers. Consumer loads drives the entire process of power generation and delivery. In simple terms the energy flows "downhill" toward end-use loads. Influencing consumer loads is seen as a strategically viable option for improving power system operation and overall economics for all parties. The emphasis in the architecture work is also driven by the need to connect consumers to market dynamics. Present pricing mechanisms are based on rate structures that have no dynamic character. Future rate structures will more accurately reflect the cost to provide power at any given time. The vision includes the ability to influence loads through pricing, incentive based load reduction signals, emergency load reduction signals and other methods to dynamically impact the characteristics of consumer loads. The vision of the integrated consumer includes the ability to not only communicate with remote consumer-sited equipment but to develop the infrastructure to support sophisticated levels of consumer energy management. This vision includes the customer taking a very active part in deciding how and when they use energy and from what sources. This vision will be enabled through a combination of wide area access network communications that can securely and appropriately inter-network with in-building networks and intelligent end-use loads. The networking infrastructures that need to be addressed by the architecture also include improving the energy management and energy efficiency application capabilities of in-building networks and communications with end-use loads.

Energy Consumers Influence System Operations at All Levels

Consumer loads are foreseen to become more integrated with utility distribution and transmission operations as well as having an influence on the need and placement of generation. Consumers may participate in providing ancillary services and transmission level support as well as influencing distribution operations. Communications with consumers will increasingly rely on an industry architecture if these visions of dynamic interaction are to be manifest. Intermediary firms may spring up to help customers aggregate and/or maximize their energy value.

More than reading a meter or Traditional Load Management

The ability to communicate with consumer in-building networks enables a variety of energy services that may be offered to improve efficiency, provide premium power services at individual sensitive loads and provide energy services such as equipment diagnostics at individual loads. Communications with consumer equipment opens opportunities for improved end-use efficiencies through equipment monitoring and opens up new paradigms for load management. Sophisticated space conditioning equipment may be able to receive a “day ahead” Real-Time Price (RTP) signal and implement control algorithms that can use the thermal mass of the building in combination with cool storage to effectively reduce peak loads and maintain comfort. The vision is that new rate structures will be a stimulus for a variety of new communicating equipment that can assist consumer response to RTP and other operation signals from energy providers.

A Robust architecture and implementation approach is necessary

Several challenges loom in the consumer communications environment. The rules are still being written for the future. It is unclear how this environment will be regulated. The architecture must take into account that the policies will remain uncertain in the near-term and plan for a robust approach to the development and implementation of the technology. RTP for instance may be implemented in a dozen different ways. The architecture must prepare for any reasonable eventuality and avoid the “forklift” upgrade approaches of the past. The infrastructure must be appropriately secure and must be managed on a massive scale. The architecture should not preclude residential consumers from scenarios such as RTP and consumer sited generation. This means securely managing networks with millions of nodes.

Consumer-Sited Generation

Stimulus from RTP or other signals from system operators can invoke power injection from consumer-sited generation. Consumer generation (or storage) may be connected to the grid through the development of standardized interfaces for both power electrons and communications systems. Consumer power injection however must be carefully integrated with the operation of the distribution (or Transmission) system to avoid interfering with power delivery protection and operations. The expansion of consumer-sited generation further emphasizes the need for a common open communications architecture that encompasses a variety of future operating scenarios and enables new power delivery operation/coordination paradigms

Consumer Communications in a Direct Access Environment

The prospect of implementing consumer participation in a retail choice environment raises the technical challenge bar even higher. The need to interoperate with potentially hundreds of market participant entities opens the need for a communication infrastructure that is unprecedented. The consumer communication portion of the architecture will include the following ten categories of technology:

1) Business to Business Information Systems
2) Metering and Measurement of Consumer Energy and Power
3) Wide Area Access Networking Technology
4) Consumer Access "Gateway" Technologies
5) Consumer energy management and control systems
6) In-building Networking Technologies
7) Intelligent Networked Consumer End-Use Equipment and Subsystems
8) Integrated Distributed Generation and Storage
9) Integrated Utility-Consumer Field Operations
10) An overall technical Architecture for a consumer communications infrastructure

A future strategic vision of consumer communication technology is one that extends integration across all of these categories and overlays the communications and applications with a management framework that is robust, secure and extensible. Today only portions of the infrastructure and associated technologies to support this vision have been developed. The architecture work will more fully develop the vision, the technical requirements and the architectural framework to complete the development of the necessary infrastructures.

2. The "Self-Healing" Transmission and Distribution System:

Development of a self-healing transmission and distribution system – capable of automatically anticipating and responding to disturbances, while continually optimizing its own performance – will be critical for meeting the future electricity needs of an increasingly digital society. According to EPRI's *Electricity Technology Roadmap*, "By 2020, the demand for premium power – now just developing – will be pervasive throughout every sector of the economy." Preliminary EPRI estimates indicate that the proportion of U.S. electricity requiring 9-nines reliability (available 99.9999999% of the time) will grow from 0.6% of current consumption to nearly 10% by 2020, and that the proportion requiring 6-nines reliability will grow from about 8-10% to nearly 60%. In contrast, the average reliability of today's power "at the plug" is only about 3-nines.

The overall benefits from the self-healing grid will include not only enhanced reliability, but also will enable innovative customer services, reduced O&M costs and increased throughput on existing lines via more effective power flow control. The self-healing grid will increase grid security in response to the threat of terrorism.

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

Typical objectives of the self-healing grid would include the following:

- **Dynamically optimize the performance and robustness of the system.** Under normal operating conditions, an array of 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. State and topology estimation will be based on these real-time measurements. The system will constantly be tuning itself to achieve an optimal state based on predetermined optimality criteria, while constantly monitoring for potential problems that could lead to disturbances. Examples of such potential problems would be a transformer with unusual gassing activity or a cable termination with higher than normal partial discharge. When a potential problem is detected and identified, its severity and the resulting consequences will be assessed. Various corrective actions can then be identified, and computer simulations run to study the effectiveness of each action. When the most effective response is determined, a situational analysis will be presented to the operator, who can then implement the corrective action very efficiently by taking advantage of the grid's many automated control features, such as dispatch control of distributed resources, parameter tuning of solid-state power flow controllers, etc.

- **Quickly react to disturbances in such a way as to minimize impact.** When an unanticipated disturbance does occur on the system, it will be quickly detected and identified. An intelligent islanding or sectionalizing scheme, for example, can be activated automatically to separate the system into self-sustaining parts to maintain electricity supply for customers according to specified priorities, and to prevent blackouts from spreading.

- **Effectively restore the system to a stable operating region after a disturbance.** Following the system's reaction to a disturbance, actions will be taken to move the system towards a stable, operating region. To do so, the state and topology of the system need to be assessed in real time, allowing corrective actions to be identified and their effectiveness to be determined by look-ahead computer simulations. The most effective actions can then be implemented automatically. When a stable operating state is achieved, the system will again start to self-optimize.

The "Self-Healing" Transmission and Distribution System: Program Plan

The following program plan outlines the technological development work envision for the self-healing grid. In this plan, the transmission and distribution systems are considered as one "grid". This approach is valid at a conceptual level; however, it is understood that there are substantial differences in deploying technologies on the transmission and distribution systems. For example, compared to transmission, a key concern for distribution is how to reduce the cost of self-healing technologies – including communications equipment and sensors – enough to justify their use on a much larger number of much smaller system components.

The highest priority in launching the self-healing grid initiative is to develop ***a system architecture*** for the communications, data networking and robust control infrastructure required to support the integration of the self-healing grid**.** This architecture will define the capabilities and the functional requirements for the system. It will convey several views of the overall system to identified stakeholders. This architecture will be built on open systems specifications and will build upon past work as appropriate. The self-healing grid will ultimately be constructed by a wide variety of stakeholders. This architecture will provide a series of open systems-based specifications that can enable the independent construction of intelligent equipment that interoperates.

The system architecture will:

- Assess the current state of power delivery infrastructure development,
- Engage stakeholders to define the desired capabilities of the self-healing grid,
- Develop the blueprints for building the actual data networks and connected equipment including all the necessary specification details for interoperable and inter-workable equipment.
- Contribute results as appropriate to relevant Standards Development Organizations to assist in the development of key open standards that will enable the deployment of the self-healing grid.

Other areas of development in this plan are organized according to three primary functions that must be conducted in real-time, either to enhance power system performance on an ongoing basis, react to disturbances or to restore the system after a disruption:

- **Assessment.** Self-healing begins by assessing the current status of the system by processing pertinent data
- **Simulation/Modeling.** The most effective way to optimize or reconfigure the system can be determined by using look-ahead simulations that examine various control actions and determine effectiveness.
- **Control.** Based on simulation results, the grid can be remotely reconfigured for optimal performance.

Figure 1 shows how these functions map to the objectives of the self-healing grid.

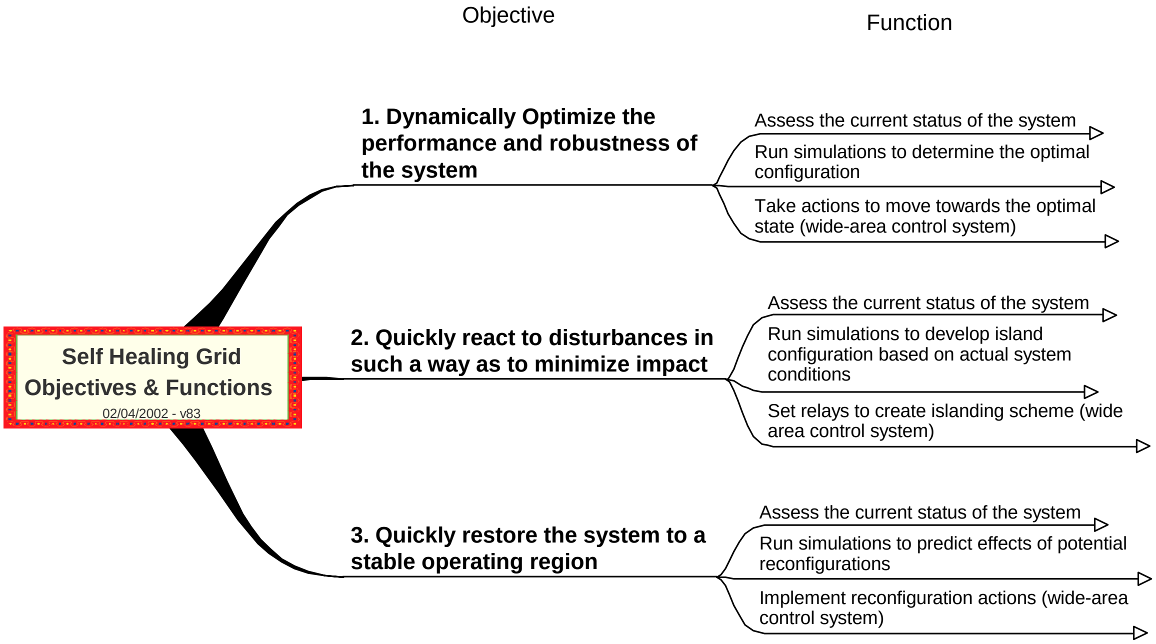

Figure 1 – Three Primary Objectives of a Self-Healing Grid Each Supported by Three Functions That Require Technology Development

Assessment

The first step of the self-healing process is to assess the current state of the grid – either to anticipate problems by recognizing early symptoms or to respond to disturbances already underway. For both transmission and distribution systems, the availability of numerous condition-monitoring sensors connected to a secure communications network will be crucial for achieving a rapid assessment. Figure 2 shows simplified functional requirements necessary to assess the current status of the system.

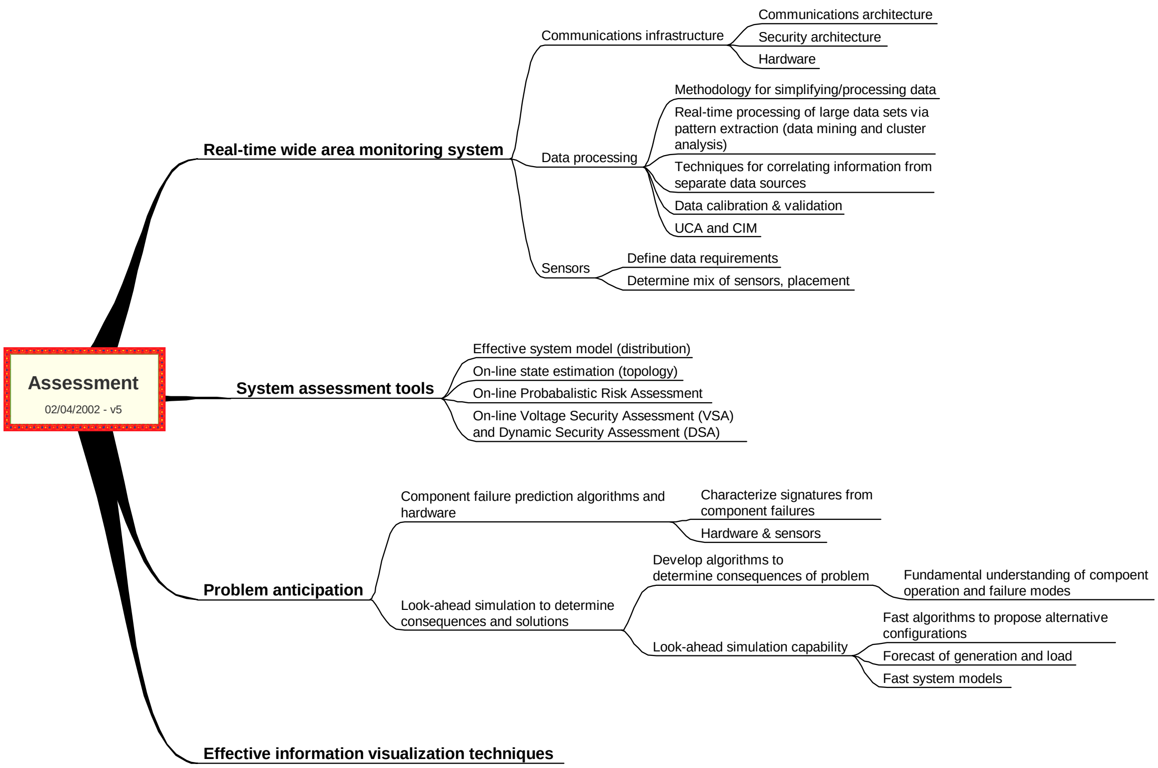

Figure 2 – Technology Development Areas Required for Assessment Function

Technology development areas include:

- **Real-time wide-area monitoring system**. Elements of the real-time wide-area monitoring system are already in operation on both the transmission and distribution system. For example, Wide Area Measurement System (WAMS), originally developed by Bonneville Power Administration (BPA), is a system based on high speed monitoring of a set of measurement points by means of Phasor Measurement Units (PMUs), "concentration" of these measurements by means of Phasor Data Concentrators (PDCs) and generation of displays based on these measurements. WAMS provides a strong foundation on which to build the real-time wide-area monitoring system required for the self-healing grid. The system architecture will define the data, communications and control requirements for the self-healing grid. Next development steps include:
  - Define data requirements, including what data needs to be measured and how quickly, in order to enable development of a self-healing grid
  - Determine the mix of sensors and placement required to offer the necessary data, including the phasor measurement units, sensors to monitor key components and permit dynamic ratings and sensors for market data
  - Establish requirements for data management, calibration, and validation (to identify erroneous, missing, or malicious data)

- Develop methodology and tools for processing/simplifying wide area measurement data, including real time processing of large data sets via pattern extraction (data mining and cluster analysis), and techniques for correlating information from separate data sources
- Develop specifications for a secure, real-time communications system that will enable wide-area visualization and robust control

- **On-line system assessment tools.** Improved state estimation is required for real-time topology monitoring and validation that could enable operations closer to the system limits, savings in asset utilization and improved security. Real-time data provided by a wide-area monitoring system would help improve the quality and speed of state (and topology and parameter) estimation. On-line system assessment tools, such as EPRI’s Dynamic Security Assessment (DSA), Voltage Security Assessment (VSA) and Probabilistic Risk Assessment (PRA) programs will also be required.

- **Anticipation of failures and disruptions.** Substantial work has been done by EPRI and others in determining the root-cause of failures in critical components such as transformers, cables, surge arresters, etc., and in developing monitoring and diagnostics systems for these components. The next step is to develop fault anticipation technology that will provide early warning and failure forecasting. Work on fault anticipation for overhead distribution systems is currently underway. Some failure prediction work was also done under the CIN/SI initiative. Development tasks include:
  - Characterize signatures from component failures on the transmission system
  - In addition to analyzing real-time data, begin simulating failures and capture the resulting signatures for future reference
  - Develop algorithms to determine the consequences of an impending fault on utility equipment and on customers
  - Develop look-ahead simulation capabilities that assess the effectiveness of various corrective actions.
  - Determine type and placement of sensors necessary
  - Ensure common approach for communicating sensor data within and between both transmission and distribution systems
  - Integrate databases to provide historical information on component performance, maintenance, inspection, etc.

- **Effective information visualization.** In order to keep system operators from being overwhelmed by all the new data, improvements are also needed in data visualization, analysis, and modeling. These will help operators recognize and manage the full spectrum of static and dynamic vulnerabilities of the grid, its protection systems, and associated computer and communication networks

Simulation/Modeling

Look-ahead simulation capability will require development of fast algorithms to propose alternative reconfigurations of the system – either in response to disturbances or as a step toward optimizing long-term system performance. These algorithms would propose alternative configurations of the grid, and then look-ahead simulation would be used to assess the effectiveness of each configuration. This task would also investigate different methods of generating alternative ways of reconnecting the grid from an existing state of partial or complete blackout, with multiple small islands and blacked-out pockets. It would develop fast simulation methods for determining the power flow solutions, voltage stability, transient stability, and dynamic stability of the connected islands. On a continuing basis, look-ahead simulation would identify customer criticality and use this information to assess the adequacy of current system configuration. Figure 3 shows simplified functional requirements necessary to perform simulation and modeling.

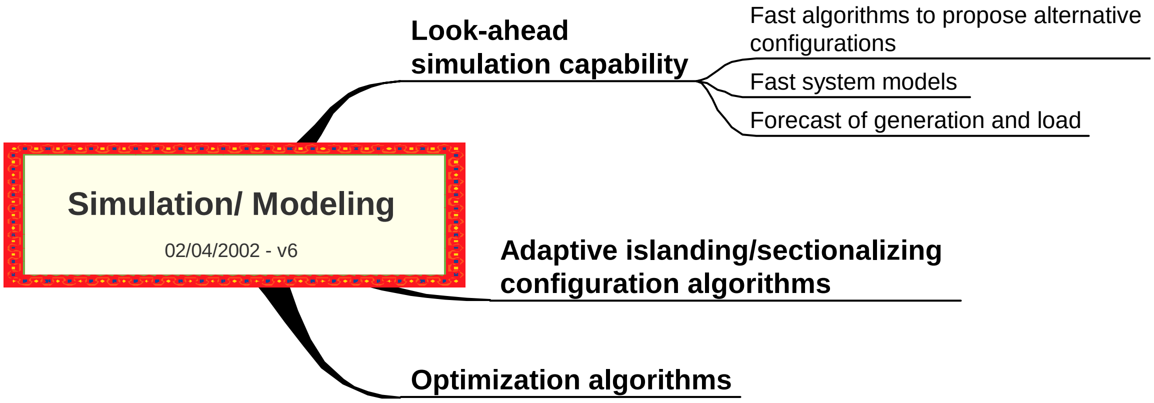

Figure 3 – Technology Development Areas Required for Simulation/Modeling Function

Technology development areas include:

- **Adaptive islanding.** Following a terrorist attack or major grid disruption from natural causes, initial reaction will focus on creating self-sufficient islands in the power grid, adapted to make best use of the network resources still available. To achieve this aim, new methods of intelligent screening and pattern extraction will be needed, which could rapidly identify the consequences of various island reconnections. Adaptive load forecasting will also be used to dispatch distributed resources and other resources in anticipation of section reconnection and to help stabilize the overall transmission-distribution system.

- **Look-ahead simulation and modeling**. Understanding the true dynamics of a system will require development of new modeling techniques that can be used to analyze the dynamics of transmission and distribution networks and to halt disturbances quickly (in the order of milliseconds or faster). Tasks for creating the necessary qualitative and quantitative models of complex interactive systems include development of:
  - Formal methods for modeling true dynamics and for real-time computation to cope with system uncertainties and establish provable performance bounds
  - Multi-resolution simulations, with the ability to go from the macro to the micro level and vice versa
  - Optimization and control theory along with decision analysis to model hybrid (discrete/continuos) systems
  - Techniques for on-line mathematical modeling and decision support with partial inputs and in the presence of errors.
  - Whole-system models that can speed restoration (e.g., be able to predict which lines might become overloaded if energized in a particular order), and embed these models in chips
  - Improved transmission-distribution interface, so as to predict the reciprocal impact of their individual restoration activities
  - Modeling and analysis of the couplings between power market dynamics and physical system control. The effects of market structures, distributed generation, and other new features must also be taken into account.
  - Develop accurate forecasting techniques for both generation and load.

- **Optimization algorithms**. Improved optimization and control theory will be needed, along with decision analysis to model hybrid (discrete/continuous) systems. Stability simulation capabilities should also be introduced as needed. Individual development tasks include:
  - Define new “optimality” criteria from multiple point of view
  - Create new optimization algorithms for power delivery as a whole, and implement them through an improved interface between transmission and distribution systems

Control (Wide Area Control System)

Once predictions have been made about the effectiveness of various potential control actions, the identified actions need to be carried out quickly and effectively. Achieving this goal will require automating many operations that will make human intervention on both transmission and distribution systems more efficient. Figure 4 shows simplified functional requirements necessary to control the system.

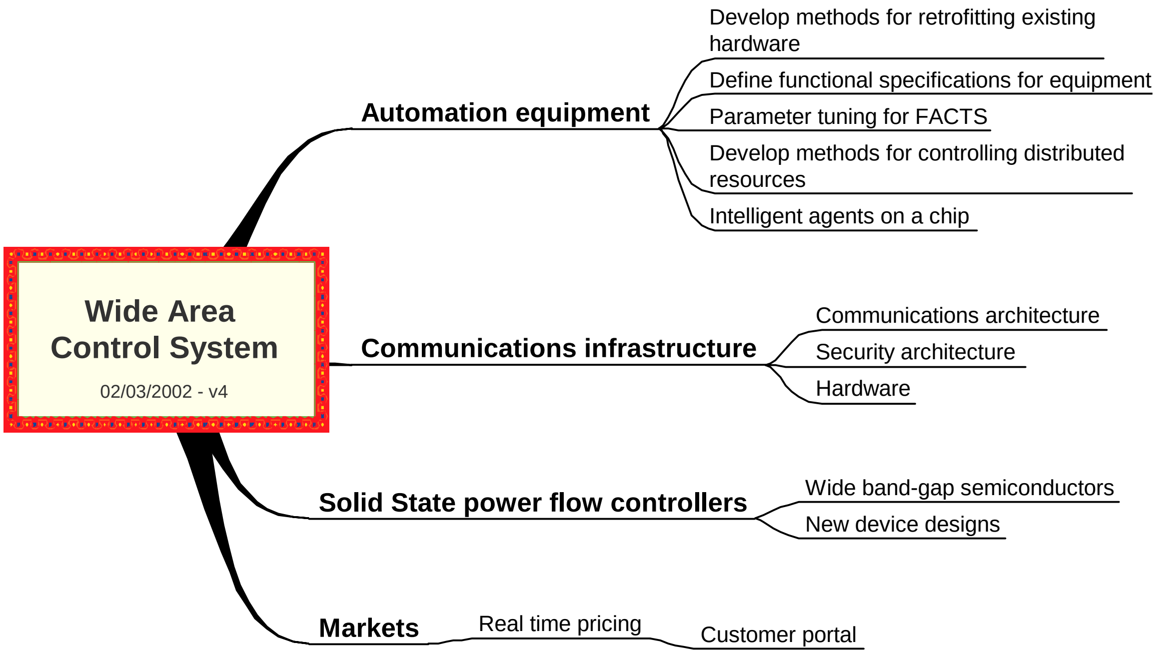

Figure 4 – Technology Development Areas Required for Wide Area Control Function

Technology development areas include:

- **Automation equipment.** The challenge will not only be to develop new equipment with the required intelligence, communications and control capabilities, but to also develop strategies for retrofitting existing equipment with these technologies. Individual development tasks include:
  - Implement INA-on-a-chip. Intelligent Network Agents (INA) now exist as software modules, which could be used in conjunction with current power system equipment, but reducing costs and increasing efficiency for widespread implementation will require that INAs be embedded into microprocessors. Related development tasks include:
    - Embed sensing, computing, and communicating functions of INA technology on microprocessors
    - Develop simple network models for INAs that would be capable of faster-than-real-time simulations with look-ahead “what if” contingency analysis
    - Establish open standards for INA chip design so that products from different vendors can be used together
  - Define functional specifications for distributed intelligent relays/switches
  - Develop methods for monitoring, communicating and controlling distributed resources and FACTS/Custom Power devices.
  - Determine how to retrofit existing relays/switches to make them “smarter” – ultimately becoming INAs
  - Determine how to minimize “hidden failure” of protection devices:

  - Failure modes that are locally correct but involve actions that adversely affect the larger system
  - Failure modes or faulty settings of protection devices that are incorrect but which have been previously unrecognized.

- **Solid-state power flow controllers.** By acting quickly enough to provide real-time control, solid-state power flow controllers, such as FACTS and Custom Power devices, can increase or decrease power flow on particular lines, alleviating system congestion. In addition, these controllers can enhance system reliability by counteracting transient disturbances almost instantaneously, allowing the system to be operated closer to its thermal limits. After nearly 25 years of R&D, FACTS and Custom Power controllers based on silicon power electronics are now entering utility service. The major developmental challenge now is to reduce the cost of these systems to achieve the needed widespread utility use. Development tasks include:
  – New wide-bandgap semiconductor material, such as silicon carbide, gallium nitride, and thin-film diamond, could dramatically lower the cost of FACTS and Custom Power devices.

- **Market-based pricing.** Market-based pricing provides an indirect method for controlling customer load. Market-based pricing provides a rational and efficient way for balancing the demand and supply of electricity. Market-based pricing enables customers to make the most of the price incentives by lowering usage during high price periods and increasing usage during low price periods.