

Needed: A Grid Operating System to Facilitate Grid Transformation

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Executive Summary

Energy management systems (EMS) are computer-based systems used today to operate the complex electric power systems around the world. These systems assure that the power system or “grid” operates properly and that consumers enjoy reliable electricity supply at the lowest possible cost. These systems operate by balancing the demand for electricity with generation resources (see sidebar). However, the rapid growth of renewable power generation, the increased use of electric vehicles, and increased need to integrate customers with the power system are rendering the current generation of EMS systems obsolete. This paper examines the evolution of today’s grid operating system and outlines the development of a new grid operating system which will facilitate the transformation of the grid. Without the development of an advanced grid operating system, the full value of a variety of individual technologies like electric vehicles, electric energy storage, demand response, distributed resources, and large central station renewables such as wind and solar will not be fully realized.

Background

Grid Operating System 1.0

One of the first challenges which both Edison and Westinghouse faced in the operation of either the first direct current (DC) power systems or alternating current (AC) power systems was to enable reliable operation through control such that in any instant the total generation in a power system was “balanced against” total load. Balancing ensures the generation which is running at any point in time be equal to the total load or demand for electricity at that same moment (see sidebar). When generation is not balanced with load, the system becomes unstable and can collapse. In the 1800s when the first of the Pearl Street Generators was placed in service, this balancing act was a relatively simple endeavor primarily done through control systems in generators. This was a primitive form of a grid operating system which can be labeled as Version 1.0 or Grid Operating System 1.0.

Grid Operating System 2.0

As power systems evolved, they became larger, more complex, and increasingly more difficult to control. Balancing multiple generators with a network of loads located throughout a city or across town and into the countryside could not be facilitated by generation control alone. By the mid 1950s, some of the first Supervisory Control and Data Acquisition (SCADA) systems were being deployed within

power delivery systems. Grid Operating System 2.0 grew out of the understanding of these SCADA systems.

The first SCADA systems utilized data acquisition by means of panels of meters, indicator lights, and strip chart recorders. The power system operator manually controlled the power system by turning various knobs or activating switches which in turn sent signals to open or close circuit breakers or to start up generators. These SCADA systems are still used today to do supervisory control and data acquisition in some small utilities, older power plants, and industrial facilities. These primitive SCADA systems were technically simple; they did not require computers or digital sensors. However, the quantity and type of data were minimal and rudimentary. SCADA systems became popular for two principal reasons: they minimized blackouts, and they could significantly increase the utility bottom line through effective dispatch of generation and the marketing of excess generating capacity.

By 1962, there were several large interconnected power grids in the Midwestern, southern, and eastern portions of the U.S. These were the largest synchronized systems in the world. A large blackout in 1965 prompted the U.S. Federal Power Commission to recommend coordination between these systems. As a result, the Electric Power Reliability Act of 1967 was passed, and subsequently, the National Electric Reliability Council was formed.

Late in the last century, the Federal Energy Regulatory Commission (FERC) passed a series of laws which enabled wholesale electricity markets (for example, FERC Order 888 in 1996). Accordingly, many of the grid operating systems in the nation were modified so

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as to incorporate connection to an increased number of market participants. For some systems, this meant increasing from a few dozen transactions per day to hundreds.

These actions, coupled with an overall concern within the industry that more needed to be done to assure reliable electricity supply, led to the invention of Grid Operating System 2.0. This system was a computer-based operating system and, although enhanced repeatedly since then, is the basic system in use today. During this period, the grid operating system came to be called energy management system or EMS. The major difference between Grid Operating System 1.0 and 2.0 is the capability to balance supply and demand between many market participants, multiple bulk power central generation resources, and a wide ranging control with numerous interconnections area using today's high-voltage grid. In addition, Grid Operating System 2.0 used a much more sophisticated mathematical technique to estimate the condition of the system.

System 2.0 allowed the system operator to estimate the condition of the system at any point in time. Often referred to as real-time monitoring and control, the grid operating system operates in near-real time using data coupled with input from sensors to estimate the condition of the grid 20 to 30 seconds after the fact. A unique development in Version 2.0 was the ability to "fill in" or estimate data from missing sensory inputs. System 2.0 is complex, uses rather sophisticated applications software, and has a large number of input/output (I/O) points and a substantial number of remote terminal units (RTUs). The most prevalent type of intelligent electronic devices (IEDs) which communicate with System 2.0 are reclosers, protective relays, substation controllers, and phasor measurement units.

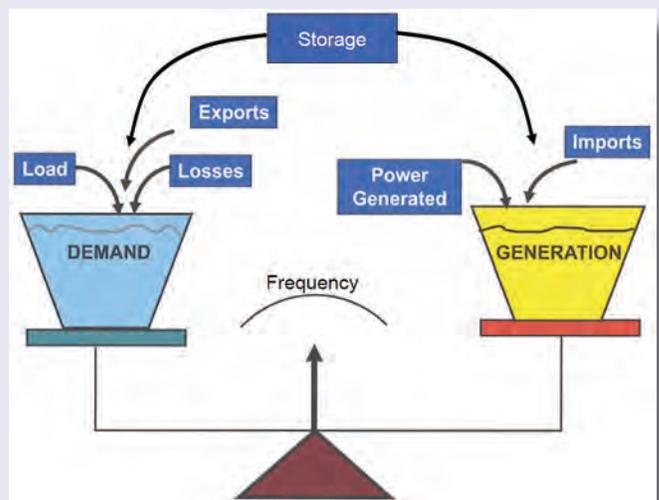
Tectonic Changes in the Electricity Grid

The power system is revolutionizing at an exponential pace into a highly interconnected, complex, and interactive network of power systems, telecommunications, the Internet, and electronic com-

What does a Grid Operating System do?

What does a Grid Operating System do? – The basic function which a grid operating system performs (see illustration) has not changed since Thomas Edison operated the first power system at Pearl Street in New York City, which is to balance the demand for electricity with the energy available as supplied by generation. The demand for electricity is comprised of the demand from consumers plus exports to other systems and system losses. The components of generation available consist of power generated plus discharge from storage and imports. As alternating current (AC) systems proliferated, a type of generator called synchronous was used. Synchronous generators operate synchronously with each other. The grid operating system's job is to facilitate balancing demand with supply by keeping the frequency of the U.S. grids at or very close to 60 Hertz. If the system deviates from 60 Hertz, it becomes unstable and can collapse. Synchronous generators need to be controlled to stabilize that frequency. When there is too much generation on the system, the generators speed up

raising the frequency above 60 Hertz. Conversely, where there is inadequate generation on the system, generators slow down and the frequency falls below 60 Hertz. In some countries, 50 Hertz is the standard.



Energy Balance



merce applications. Virtually every element of the power system will incorporate sensors, communications and computational ability. No longer will society depend primarily on central station power and what is essentially one-way flow on the grid, since the use of distributed generation and distributed energy storage will proliferate. At the same time, the move towards more competitive electricity markets requires a much more sophisticated infrastructure for supporting myriad informational, financial, and physical transactions between the several members of the electricity value chain that supplements or replaces the vertically integrated utility. Although reliability is now and will remain critical, this complexity will naturally create more opportunities for nodes of failure and potentially allow for increased risk from cyber attacks and coordinated physical and cyber attacks.

The grid has matured steadily since the first high-voltage transmission line was built on overhead wood pole structures to bring hydroelectric power from Niagara Falls to New York City. Today's system is highly interconnected and has benefited from a steady evolution of technologies. Central station coal and nuclear power coupled with the use of gas in combustion turbines have been integrated throughout the nation and evolved in a way that has made the grid what it is today.

Figure 1 illustrates today's power system. It is largely comprised of large central station power generation connected by a high-voltage network or grid-to-local distributions systems which serve homes, businesses and industry. Electricity flows predominantly in one di-

rection using mechanical controls. The Grid Operating System 2.0 supports this power system.

Figure 2 (on the following page) illustrates the elements which will be part of tomorrow's power system. Tomorrow's power system will still depend on the support of large central station generation, but it will increasingly include renewable generation and electric energy storage both at the bulk power system level and in the local distribution system. In addition, tomorrow's power system will have greatly enhanced sensory and control capability configured to accommodate electric vehicles and allow direct engagement with consumers and their appliances and devices. Tomorrow's power system will require a grid operating system which is secure against cyber intrusion and can assure reliable long-term operation of an extremely complex systems comprised of an array of distributed components.

These changes include profound impacts on the generation, delivery, and use of electricity that require engineers to rethink the way the grid is currently operated. For example:

1. Variable Generation – The North American Electric Reliability Corporation (NERC) predicts that 200 gigawatts of variable generation will be added by 2020. These variable sources, primarily wind turbine generators and photovoltaic systems, present unique challenges to operators.
2. Demand Response – Capacity markets in the Northeast are now opened to demand response bids. In a recent auction, PJM

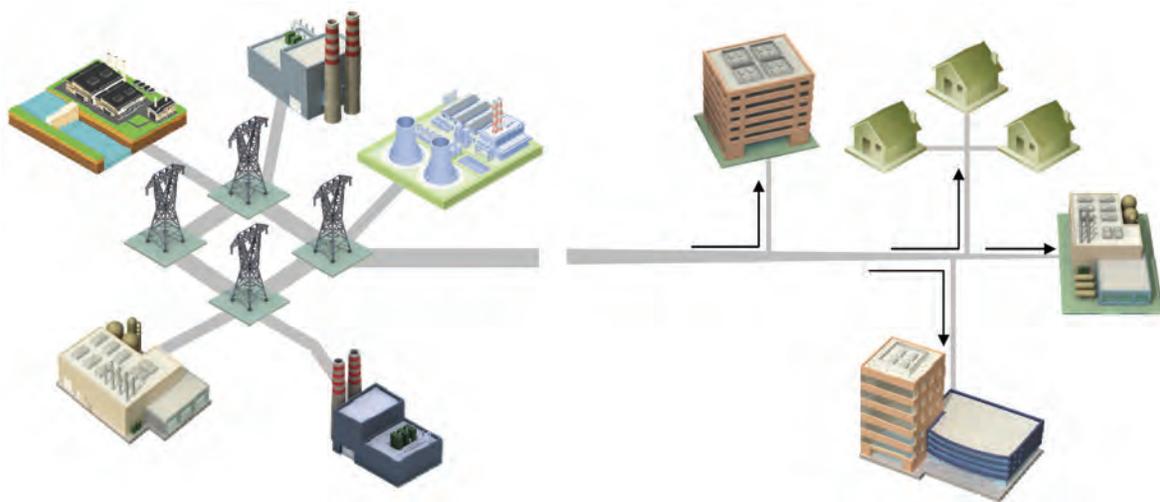


Figure 1 – Today's Power System

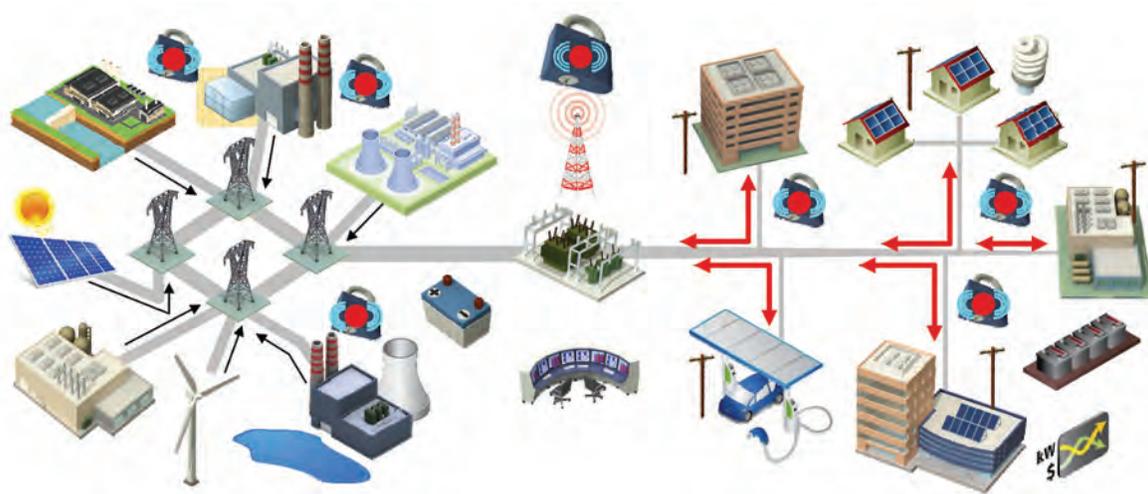


Figure 2 – Tomorrow's Power System

received 17% of their requested capacity in the form of demand response and energy efficiency. Managing demand response in conjunction with generation provides additional challenges.

3. Electric Vehicles – By 2030, it is anticipated that there will be more than 20 million electric vehicles connected to the grid at various times. These vehicles all have battery capacity on board which may enable their use as a fast-acting balancing resource.
4. Smart Meters – There are currently more than 20 million communicating nodes within smart meters. There is a potential for as many as 80% of the approximately 140 million meters in the U.S. to be converted by 2030. Each of these nodes provides opportunities for enhanced energy management and condition monitoring.
5. Distributed Generation – Photovoltaic power generation systems are now in place on over 70,000 roof tops in the U.S., and those installations are growing at over 10% per year. Those distributed sources must be monitored and controlled effectively.
6. PMUs – The increasing deployment of phasor measurement units (PMUs) and the growth in the use of smart substations and sensors will require much faster processing and intelligence to act upon than is present in today's grid operating systems.
7. Communications – The phenomenal proliferation of electronic communications and information technology in all spheres of

life and sectors of industry are extending into the electric power system. Sensors, communication and computational ability will transform the power system.

Grid Operating System 3.0

The present grid operating system was not designed to meet the increasing demands of a digital society or the increased use of renewable power production. There is a national imperative to modernize and enhance the power delivery system. That modernization must include a new grid operating system. Tomorrow's grid operating system must facilitate high levels of security, quality, reliability, and availability (SQRA) of electric power; improve economic productivity and quality of life; and minimize environmental impact while maximizing safety.

The grid operating system must monitor, protect and automatically optimize the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations, and to end-use consumers including their thermostats, electric vehicles, appliances, and other household devices.

Tomorrow's grid operating system must manage a two-way flow of electricity and information to create an automated, widely distributed energy delivery network. It must incorporate into the grid the benefits of distributed computing and communications to deliver



real-time information and to enable the near-instantaneous balance of supply and demand at the device level.

The next-generation power delivery operating system, referred to here as Grid Operating System 3.0 or Grid 3.0 must be developed to provide for seamless integration and interoperability of the many disparate systems and components, as well as enable the ability to manage competitive transactions resulting from competitive service offerings that emerge in the restructured and distributed utility environment. Figure 3 illustrates the challenges Grid Operating System 3.0 faces.

Realizing Grid 3.0 depends on developing the architecture – namely the functional requirements and the design requirements based on an open-source design, which can facilitate the informational, financial, and physical transactions necessary to assure adequate security, quality, reliability and availability of power systems operating in complex and continually evolving electricity markets. In addition, the architectural requirements will be designed to support multiple operational criteria including analysis and response to electrical grid contingencies, pricing, and other market and system conditions. The goals of the architecture are to allow for interoperability and flexibility of the power system operations while at the same time facilitate and enable competitive transactions to occur. Interoperability can be enabled by the use of open communication protocols

developed in EPRI’s IntelliGrid Program. Flexibility can be provided by the specification of user-defined business rules which capture the unique needs of various service offerings.

The concept of Grid 3.0 provides a new perspective on how to manage transactions given the nature of the existing and emerging distributed, heterogeneous communications and control network combined with the extensive use of new innovations on the power system. What is needed is an architecture that allows future developers to access this framework as a resource or design pattern for developing distributed software applications, taking into account the core concepts of interoperability and support for multiple operational criteria including business rules.

Grid 3.0 must increase the independence, flexibility and intelligence for optimization of energy use and energy management within local energy networks at the building level, at the local level, at the distribution level, and then integrate local level devices to the Smart Grid. As such, energy sources and a power distribution infrastructure can be integrated at the local level. This could be an industrial facility, a commercial building, a campus of buildings, or a residential neighborhood. Using Grid 3.0, these “local energy networks” are interconnected with different localized systems to take advantage of power generation and storage through the Smart Grid enabling complete integration of the power system across wide areas. This

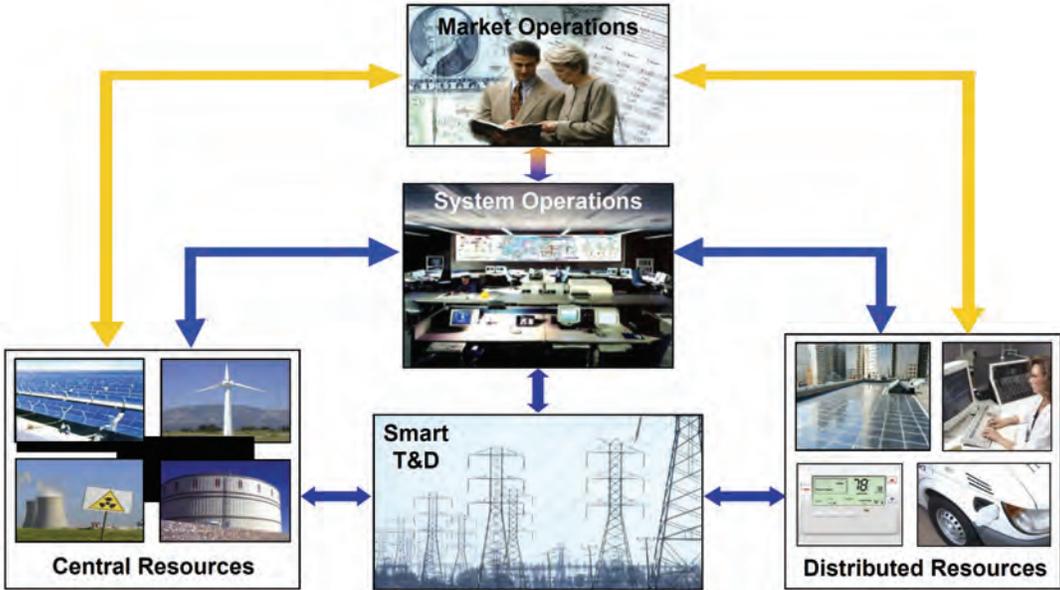


Figure 3 – Grid Operating System 3.0 Challenges: Integrate Systems and Components



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includes control of building energy and thermal storage systems. Localized energy networks can accommodate increasing consumer demands for independence, convenience, appearance, environmentally friendly service, and cost control.

While some of these local energy networks can operate in a stand-alone mode, integration into the distribution system using Grid 3.0 allows interconnection and integration with technologies that ultimately enable the next generation of the Smart Grid.

Fundamentally, tomorrow's grid operating system will need to handle millions of intelligent electronic devices located through the power system from the generation switchyard through to end-use energy consuming devices and appliances on the consumer's premises. In addition, tomorrow's grid operating system must have the following functionality:

- Geospatial Power System Model Database – Tomorrow's grid operating system must have a hierarchical geospatial data acquisition and maintenance architecture. Geospatial power system model database feeding would allow the power system models to be derived directly from detailed geospatially correct computer-aided design (CAD) models. Increasingly, transmission utilities are analyzing their transmission lines using an optically remote sensing technology known as light detection and ranging (LIDAR) technology in order to measure the dimensions of, and the physical features of, a transmission corridor and its lines. With over 400,000 miles of lines greater than 100 kV in North America, some many decades old, there are discrepancies between design and actual field conditions. Also, many of these lines are in hard-to-reach places. LIDAR permits easy assessment of these lines. This data can be post-processed into CAD models like power-line systems – computer-aided design and drafting (PLS-CADD) tools (see www.powline.com.) These models use the LIDAR data to accurately model lines. These CAD files can then be used as input into line constants computer programs which give accurate transmission line ratings and loading. Geospatial feeding would integrate all of these steps and seamlessly calculate a more precise set of line parameters eliminating many of the assumptions used today. The output would be put into common information model (CIM) formats easily interchanged between systems. These physically precise models could also be used to develop screen interfaces much like those that have been made popular by Google Earth and other geospatial systems.

- Integration of Traditional and Non-Traditional Data – Integration of traditional utility operating data along with non-operating data such as smart meters and distributed sensors can be “mashed up” with readily available internet features such as Google Earth. It can provide very useful visual displays of information within geospatial context. Figure 4 illustrates an analysis of an actual outage and the response of the Smart Grid meters to loss of power and restore events shown on the multiple screen Google Earth video wall. Figure 5 is a Google Earth illustration of 1,000,000 meter voltages on a hot summer day.



Figure 4 – Illustrates an Actual Outage

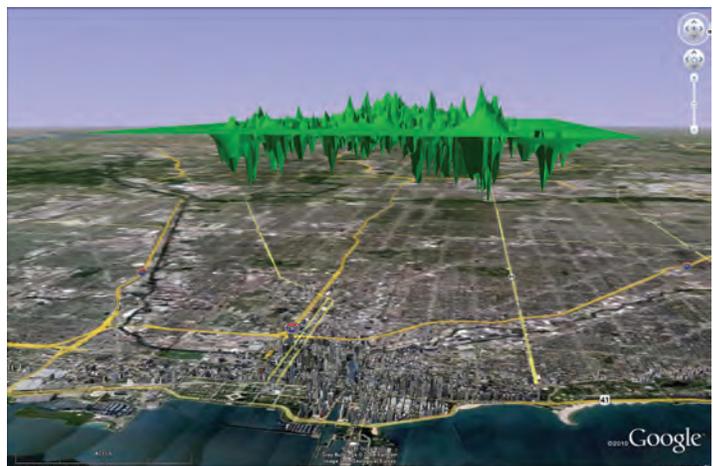


Figure 5 – Illustrates 100,000 Meter Voltages



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- **Advanced Protection and Control Functions** – Tomorrow’s grid operating system must have advanced protection and control functions which shall include coordination, execution, and confirmation of all necessary actions required to prevent the power grid from entering into an irreversible degradation in performance. The process of advanced protection and control used today is becoming unmanageable and will not support many of the smart-grid concepts. Grid Operating System 3.0 migrates protection properties further down into the hardware and software on the power system and greatly simplifies the technical skills needed by protection engineers. The existing system of using many, greatly distributed intelligent agents are unmanageable for the long term. Hardware is obsolete by the time normal upgrade cycles of 10 to 15 years are completed on large systems. Protection schemes in Grid 3.0 need to be aligned with the current NERC philosophy regarding special protection schemes.
- **State Measurement with Look-Ahead Capability** – Tomorrow’s grid operating system must have a forward-looking state measurement and a decision support tool that can help grid operators manage severe operating condition with future situational awareness. As technology enables synchronized measurements to be collected, power systems shall lead to a linear, non-iterative state measurement – as opposed to the conventional non-linear and iterative– state estimator which will be free of convergence problems. The state measurement is also expected to eliminate or minimize the effects of missing measurements, erroneous measurements, errors in network topology, etc. Furthermore, since synchronized measurements can be obtained much more frequently than conventional measurements, state measurement must have the capability of capturing slow dynamics associated with the states and predict state trajectory which possibly indicates some instability scenarios.
- **Cyber Security** – Cyber security will be an essential element of Grid 3.0. The North American Electric Reliability Corporation (NERC) has created eight Critical Infrastructure (CIP) Standards. These include standards for Critical Cyber Asset Identification (CIP002) and Security Management Controls (CIP003) as well as others. Meeting these standards will be part of Grid 3.0 including emerging security standards like NIST’s Smart Grid Interoperability Standards Framework and AMI-SEC System Security Requirements, for end-to-end security of the Smart Grid. Grid 3.0 will likely use a system of systems approach to cyber security by deploying International Organization for Standardization and International Electrotechnical Commission (ISO/IEC), National Security Agency InfoSec Assessment Methodology (NSA IAM), Information Systems Audit and Control Association (ISACA), and International Information Systems Security Certification Consortium (ISC2). Cyber security will be part of every input/output (I/O) function for interfaces with IEDS and systems as part of Grid 3.0 including:
 - Market Participants including third party Demand Response providers
 - Central station generation resources
 - Advanced metering infrastructures
 - Plug-in electric vehicle (PEV) management systems
 - Distributed generation and storage
 - Distribution operating systems including distribution automation and Local Energy Network Controllers
 - Substations which are automated and fully instrumented
 - Fully instrumented transmission lines and corridors
 - Detection and prevention services (IDS/IPS) as well as security information event management (SIEM).
- **Enable Active Participation by Consumers** – The grid operating system must facilitate interaction with and include customers who are an integral part of the electric power system. Tomorrow’s consumer must be informed, modifying the way they use and purchase electricity. They have choices, incentives, and disincentives to modify their purchasing patterns and behavior facilitated by the grid operating system.
- **Accommodate All Generation and Storage Options** – The grid operating system must accommodate all generation and storage options. It must support large, centralized power plants as well as distributed energy resources (DER). DER may include system aggregators with an array of generation or storage systems or individual consumers with a windmill and solar panels.
- **Enable New Products, Services, and Markets** – The grid operating system must enable a market system that provides cost-benefit tradeoffs to consumers by creating opportunities to bid for competing services. As much as possible, regulators, aggregators and operators,



and consumers can modify the rules of business to create opportunity against market conditions. A flexible, rugged market infrastructure exists to ensure continuous electric service and reliability, while also providing revenue or cost reduction opportunities for market participants. Innovative products and services provide third-party vendors opportunities to create market penetration opportunities and consumers with choices and clever tools for managing their electricity costs and usage.

- Optimize Asset Utilization and Operate Efficiently – The grid operating system optimizes assets and operates efficiently. It dispatches an array of generation, storage and load technologies to ensure the best use of assets. Assets operate and integrate well with other assets to maximize operational efficiency and reduce costs.
- Anticipate and Respond to System Disturbances (Self-Heal) – Tomorrow’s grid operating system independently identifies and reacts to system disturbances and performs mitigation efforts to correct them. It incorporates software designed to enable problems to be isolated, analyzed, and restored with little or no human interaction. It performs continuous predictive analysis to detect existing and

future problems and initiates corrective actions. It will react quickly to disruptions in service and optimizes restoration exercises.

- Operate Resiliently Against Attack and Natural Disaster – The grid operating system must resist attacks on the cyber-structure (markets, systems, software, and communications). Constant monitoring and self-testing are conducted against the system to mitigate malware and hackers.
- Effectively Integrate Local Energy Networks – The grid operating system must effectively integrate local energy networks with central station power generation and the Smart Grid.

Local Energy Networks

Local Energy Networks are combinations of distributed technologies at the building, community, or distribution level which will increase the independence, flexibility, and intelligence for optimization of energy use and energy management at the local level; and then integrate Local Energy Networks with the bulk power system. Figure 6 illustrates the bulk power system of tomorrow with gen-

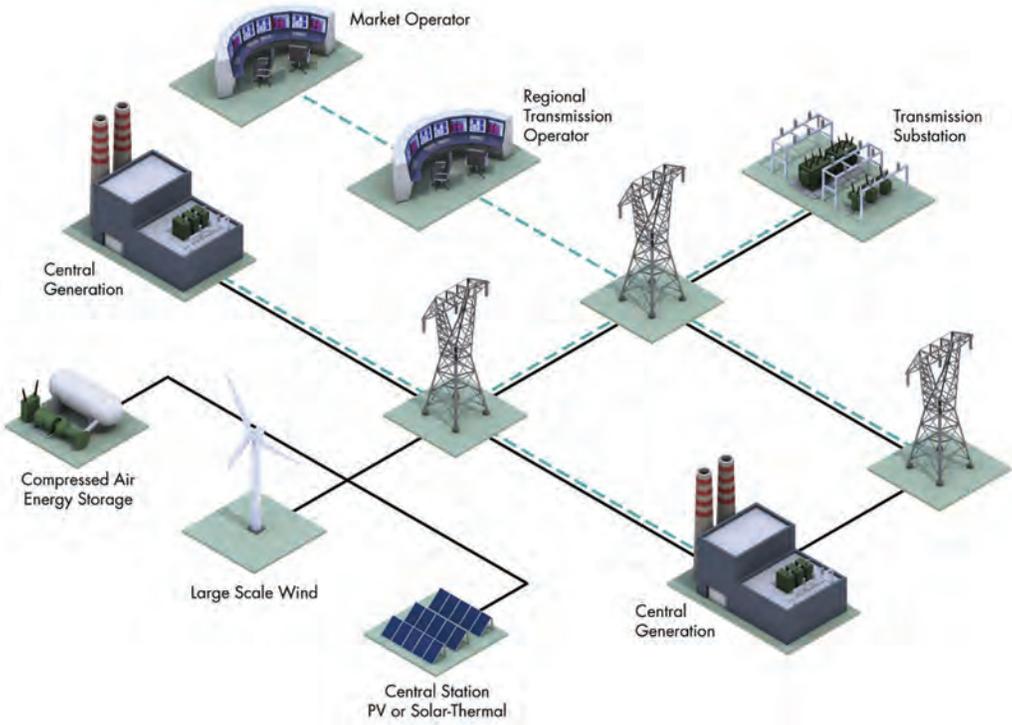


Figure 6 – Tomorrow’s Bulk Power System

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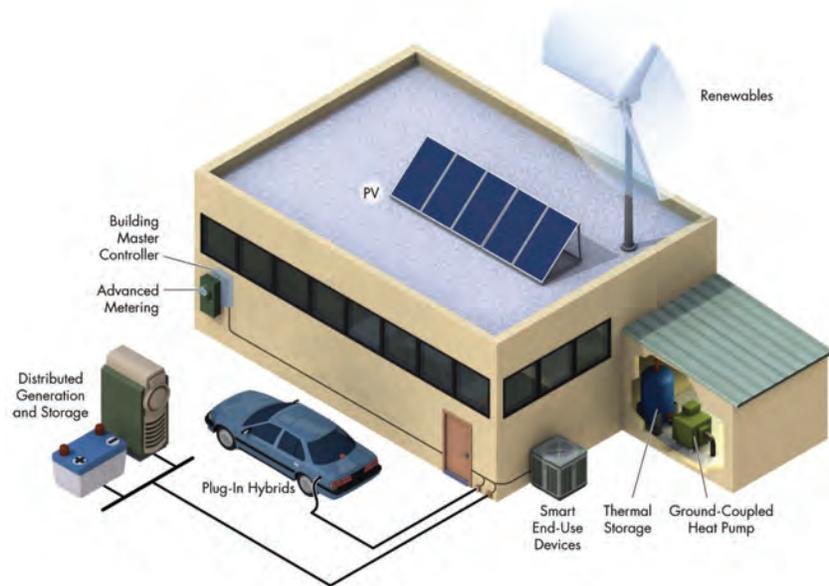


Figure 7 – Building-Level Local Energy Network

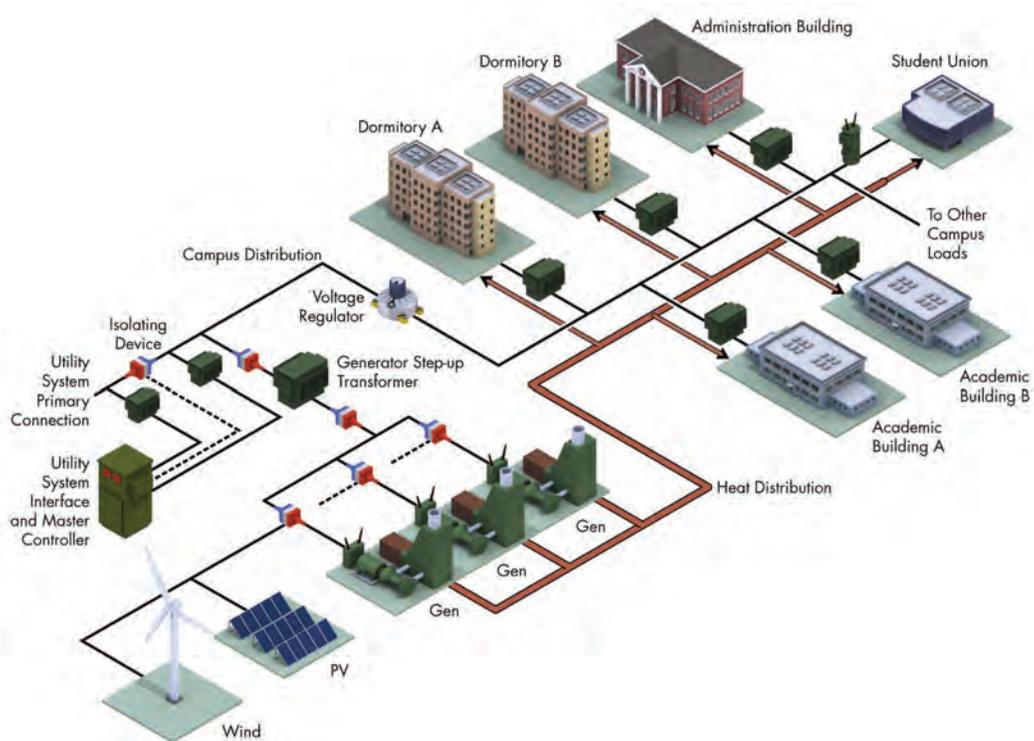


Figure 8 – Campus-Level Local Energy Network

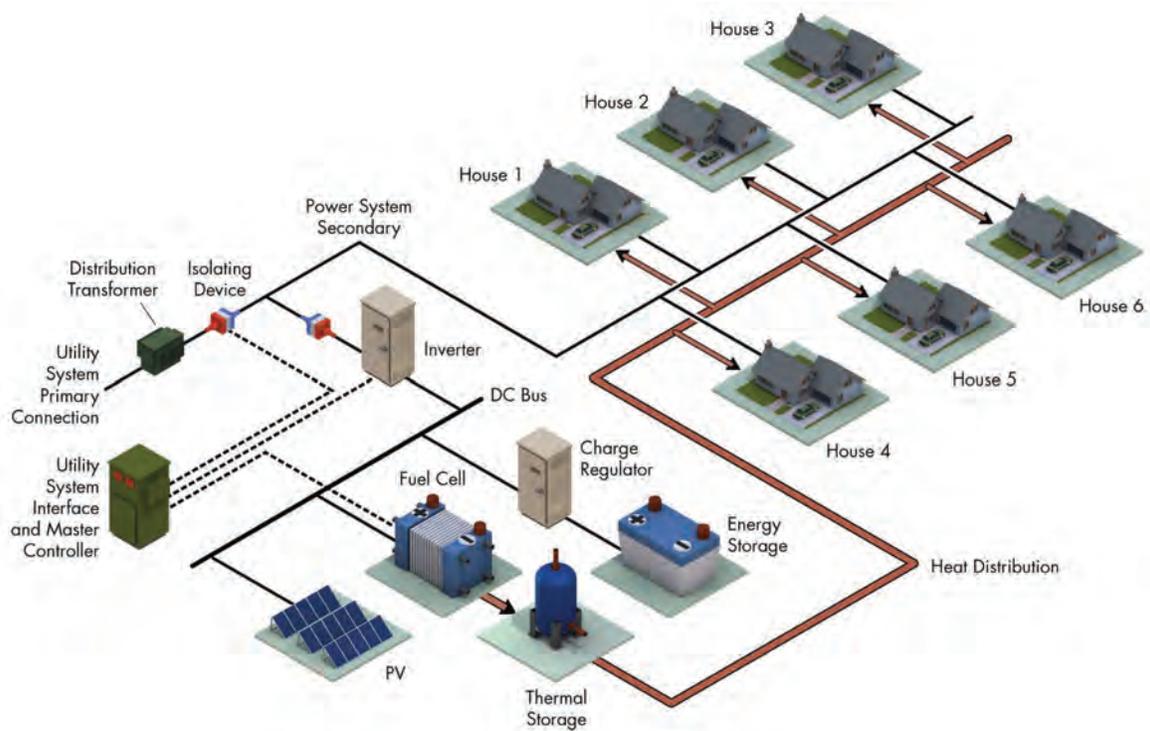


Figure 9 – Community-Level Local Energy Network

eration, storage and renewable power generation. The availability of comparatively inexpensive and clean Central Generation and storage (e.g., advanced coal, advanced nuclear, advanced hydro and advanced large wind systems) will occur in parallel with the development of more localized or distributed infrastructures.

Local Energy Networks, energy sources, and a power distribution infrastructure are integrated at the local level. This could be an industrial facility, a commercial building, a campus of buildings, or a residential neighborhood (refer to Figures 7, 8 and 9). Local area networks are interconnected with different localized systems to take advantage of power generation and storage through the Smart Grid enabling complete integration of the power system across wide areas. Localized energy networks can accommodate increasing consumer demands for independence, convenience, appearance, environmentally friendly service, and cost control.

Components of Local Energy Networks

Local Energy Networks integrate energy sources and a power distribution infrastructure at the local level. This could be an industrial

facility, a commercial building, a campus of buildings, or a residential neighborhood. Local Energy Networks allow for:

- The optimization of energy availability across a larger variety of energy sources, resulting in improved economics.
- The creation of an infrastructure for more optimum management of overall energy requirements (heating, cooling, and power).
- The control and management of reliability at the local level.

Technologies needed to facilitate Local Energy Networks include:

- Energy-Efficiency Appliances and Devices – End-use equipment will have to become very efficient in order to optimize Local Energy Networks. Losses have dramatic impacts on the thermal design requirements of equipment and result in the need for larger electrical storage systems, as well as energy sources. Many energy-efficiency gains will be achieved through miniaturization of technologies (and associated reduced energy requirements for operation), as well as advancements in power electronics (see below).



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- **Energy Storage** – As with portable power systems, energy storage (including thermal storage) is a key to the success and reliability of localized power systems. In this case, the focus of energy storage can be larger systems that are part of the overall local energy system as opposed to the emphasis on energy storage in each device. Energy storage systems, sized for 1 to 15 kW and upwards to larger systems of MW capacity for industrial and large campus applications, are needed to enable the localized power systems. The single biggest obstacle for this application is the high cost of energy storage.
- **Distributed Generation** – Photovoltaics, microturbines, and fuel cells can become essential components of Local Energy Networks. Storage systems will provide the flexibility to utilize renewable energy sources as appropriate. Development of these technologies has been ongoing for many years, but there are still tremendous opportunities for advancement of the technologies.
- **Power Electronics** – Local Energy Networks will take advantage of local direct current (DC) distribution with inverters to provide alternating current (AC) as required by motors, etc. Power conversion technologies to achieve this will dramatically improve the energy efficiency and reliability of the local systems.
- **Sensors** – The integration of different energy systems and end-use devices will require development of low-cost, highly functional sensors to track performance and status of the different parameters and components. These will be embedded sensors in devices that provide information about status, energy requirements (present and future), and problems. The sensors must have integrated communications capability for interface with the overall facility energy management.
- **Building Systems** – Energy management moves from the requirements of individual devices to optimization at the local facility level. Energy management functions must optimize heating, cooling, and power requirements with available energy sources and storage systems. This optimization function (especially including the storage capability of individual loads and the overall system) can provide tremendous benefits in terms of using renewable energy sources in an optimum manner and improving the reliability of the overall system. Additionally, combined heat and power applications are important to the viability of localized power systems. Combined heat and power systems have significant benefits in that the fuel is used more effectively. For instance,

the car could be used to provide both, heat and power to a home, while parked in the garage. The heat could also be used to provide air conditioning in buildings using chillers that convert the waste heat to cooling.

While some of these Local Energy Networks can operate in a stand-alone mode, integration into the distribution system allows inter-connection and integration with technologies that ultimately enable tomorrow's power system. Figure 10 illustrates the components of tomorrow's distribution system.

Inherently, Local Energy Networks can operate somewhat independently, but their value is maximized when they are nested with each other and with the bulk power system. This nesting concept also allows for increased overall stability within the power system. In various configurations, storage (large and small) and power electronics (large and small) at all levels of the power system can be utilized to reduce interdependencies between system components and make the system immune to temporary disturbances. Nesting of Local Energy Networks is illustrated in Figure 11. In this figure, a "master controller" is embedded into each LEN. These controllers are not all the same – their complexity increases for the LENs which have more components. The master controllers and the Local Energy Networks they control will require local intelligence and infrastructure. In turn, integration of Local Energy Networks will require higher levels of integration involving more significant infrastructure transformation in communications and control, as well as in the overall power delivery infrastructure. Grid Operating System 3.0 must enable interaction between the bulk power system and these master controllers.

There are a number of research issues which will need to be addressed in order to enable the integration of these master controllers. For example: engineers need to determine what information is needed from each node; what sensors are needed; where does computation occur; and what controls are needed. For each stage of master controllers, optimization algorithms are needed for reliability, security, stability, economics, and environmental impacts of generations. In addition, forecasts of resources requirements, availability, power production, and demand control need to be exercised.

A building-integrated (localized) power system could also comprise technologies required for an industrial facility such as demonstrated in Figure 8 or even multiple buildings in a campus-type environment.

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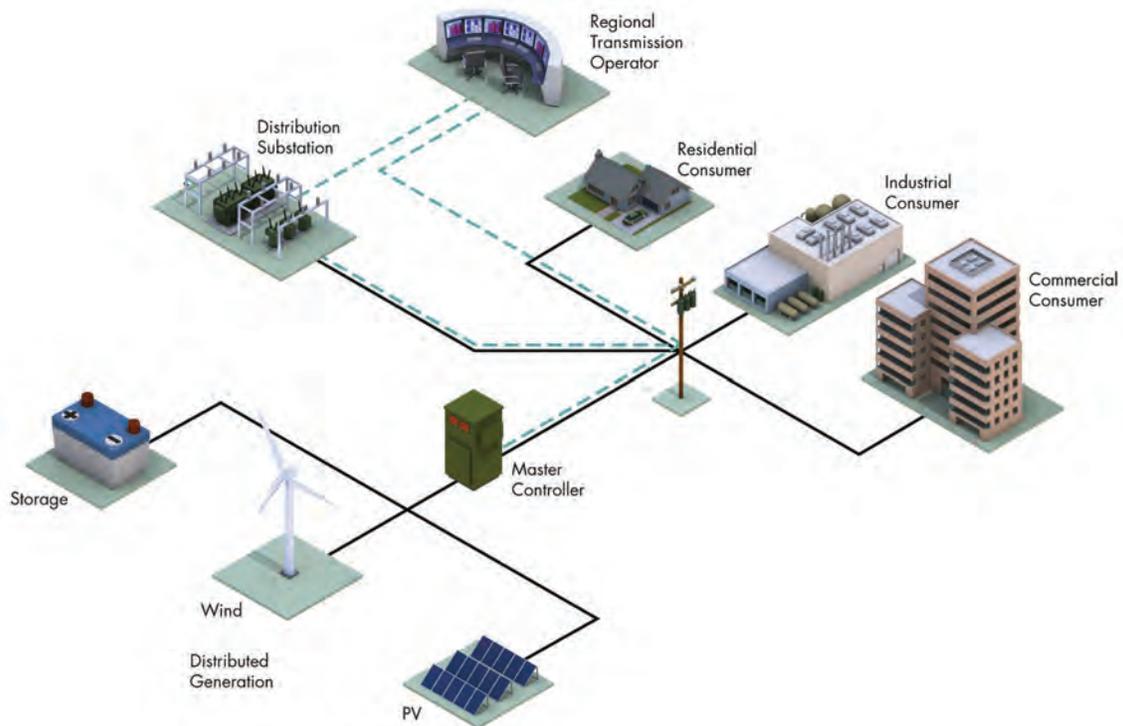


Figure 10 – Tomorrow's Distribution System

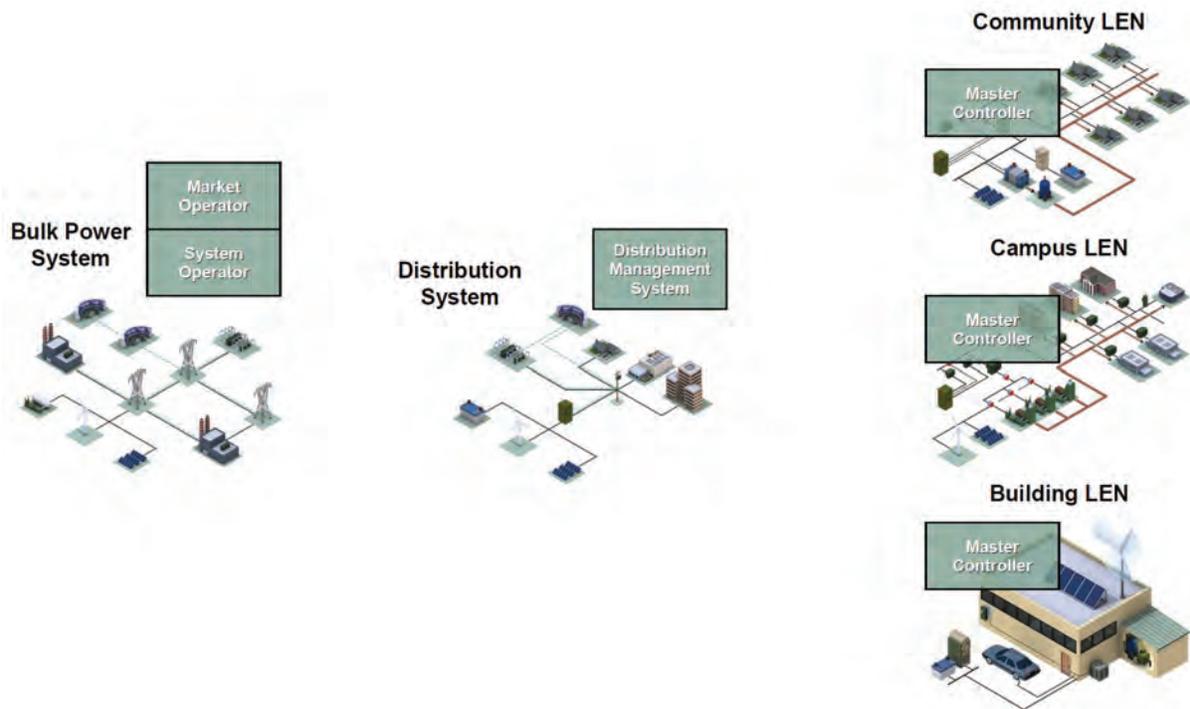


Figure 11 – Creating an Architecture with Multi-Level Controllers



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Distribution systems interconnect different localized energy networks with the Smart Grid to take advantage of power generation and storage that can support multiple Local Energy Networks. This allows sharing of generation and storage capabilities over wider areas for more efficient energy management. The structure also can result in improved reliability by allowing for energy supply alternatives.

Local Energy Networks will increasingly include electric transportation – particularly electric vehicles and, in the near term, plug-in hybrid electric vehicles (PHEVs). As PHEVs begin to proliferate, the availability of both a controllable load and controllable on-site electrical storage can have a profound impact on the electrical systems.

Background by Others

Several organizations have work underway which relates to Grid 3.0 which will be very helpful in the development of this system.

CIGRÉ has published a set of information technology (IT) requirements which will be useful in outlining some of the communications and IT requirements for Grid 3.0. CIGRÉ has outlined the real-time and near-real-time systems which will be part of future developments (CIGRÉ 2011).

The International Electrotechnology Commission (IEC) has a working group, TC-57, coincidentally working on standards which build off of several existing IEC Standards, several of which used foundational work by EPRI including: IEC 61970 – Common Information Model (CIM); IEC 60870-TASE.2 – Inter Control Center Protocols (ICCP); and IEC 61850 – Communications Networks and Systems in Substations.

The IRC (ISO/RTO Council) in North America has recently established an EAS project (Enterprise Architecture Standardization) with an objective of reducing IT costs of ISOs and RTOs.

Developing Grid Operating System 3.0

The industry has a unique opportunity in developing Grid Operating System 3.0. Rather than each control area operator, independent system operators, and regional transmission operators separately contracting with different EMS vendors, this development could begin with the collaborative engagement of stakeholders to develop the functional and design requirements on an open source basis. In this process, there is a need to engage

experts from all domains. Specifically, this entails characterizing what all types of input and output communications need to be and to identify all of the actors in the ultimate operation of the grid operating system. These actors are the suppliers of data and the users of data and information. Actors can include devices like individual sensors, smart meters, reclosers and PMUs. This process will identify “use cases” which clearly state the characteristics of data and information and its intended parameters. Once developed, individual vendors can offer bids which respond. By making these uniform requirements available, it is expected that innovative adaptation of new systems will result as well as economies in the cost of development. In particular, the ultimate developers will need a combination of traditional EMS and power system vendors coupled with those having expertise in networking, data management and security.

There are early signs of the development of some of the advanced attributes needed in Grid Operating System 3.0 in pilot projects underway in several U.S. states as well as a few European countries. These are early stages of Grid 3.0 in action in pilots and in distribution-level EMS systems. Examples include Hawaii, Illinois, and a series of demonstrations being coordinated by EPRI.

On the Hawaiian island of Maui, the General Electric Company, in cooperation with Hawaiian Electric Company and its subsidiary, Maui Electric Company, Ltd., are testing its smart-grid technology. This application involves development of renewable and distribution system technology integration. It includes an intermittency management system, demand response, wind turbines, and dynamic systems modeling. The distribution operating system under development will include the standard applications of network management, SCADA, outage management, and network analysis, but will also be enhanced with features which enable demand management, Volt/VAR control and transmission-level grid support while enabling two-way communication with Local Energy Networks and distribution IEDs including buildings, distributed energy resources, capacitor banks, load-tap changers (LTC), voltage regulators, and wind turbine generators.

At the campus of Illinois Institute of Technology (IIT) in Chicago, a Local Energy Network is being created which incorporates advanced (smart) metering and sub-metering, an intelligent “perfect power” controller, and an on-site gas-fired combustion turbine power generator, a demand-response controller, and an



uninterruptible power supply with electric energy storage. Perfect power is defined by IIT as always on, digital-grade power needed for its various laboratories. The features included in the perfect power controller will contain many of those needed by the master controllers needed to support Local Energy Networks operating as part of Grid 3.0.

EPRI is involved in a massive Smart Grid Demonstration Initiative involving a number of ongoing projects to demonstrate the potential for integrating distributed power generation, storage, and demand response technology into “virtual power plants.” Demonstrations include both utility-side and customer-side technologies and are intended to address the challenges of integrating distributed energy resources (DER) in grid and market operations, as well as in system planning. This includes aspects required for Grid 3.0, including:

- Demonstrating effective operational strategies for integrating different forms of distributed resources.
- Demonstrating multiple levels of integration and interoperability among various components.
- Exploring existing and emerging information and communication technologies required for tomorrow’s grid operating system.

The demonstrations are taking place at a number of U.S. locations and will include a variety of feeder constructions, climate zones, and technologies. Individual demonstrations are focused on the integration of specific feeder types used in residential neighborhoods, in a mixture of residential and commercial customers, and in areas with mostly commercial customers.

These developments are in their infancy in terms of how such distributed systems will become part of a hierarchical-based system by seamlessly integrate the different domains as highlighted in the Smart Grid Conceptual Model developed by EPRI for the National Institute of Science and Technology (NIST.)

The Smart Grid Conceptual Model

The Smart Grid Conceptual Model is a diagram and description that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements, and standards of the power delivery system of tomorrow, aka, the Smart Grid. This does not represent the final architecture of the Smart Grid; rather it is a tool for describing, discussing, and developing that architecture. The conceptual model provides a context for analysis of interoperation and standards, both for the rest of this document and for the development of the architectures of the Smart Grid. The top level of the conceptual model is shown in Figure 12.

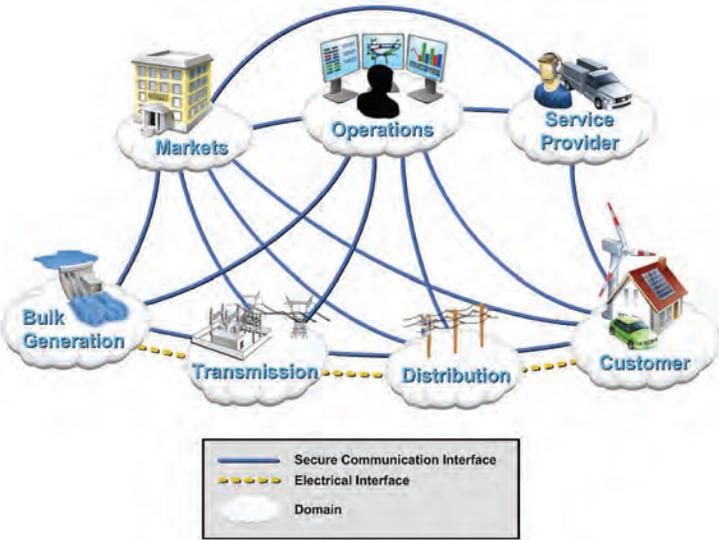


Figure 12 – Smart Grid Conceptual Model – Top Level (Source: EPRI Report to NIST, 2009)



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The conceptual model consists of several domains, each of which contains many applications and actors that are connected by associations, which have interfaces at each end:

- Actors may be devices, computer systems or software programs, and/or the organizations that own them. Actors have the capability to make decisions and exchange information with other actors through interfaces.
- Applications are the tasks performed by the actors within the domains. Some applications are performed by a single actor, others by several actors working together.
- Domains group actors to discover the commonalities that will define the interfaces. In general, actors in the same domain have similar objectives. Communications within the same domain may have similar characteristics and requirements. Domains may contain other domains.
- Associations are logical connections between actors that establish bilateral relationships. At each end of an association is an interface to an actor.
- Interfaces show either electrical connections or communications connections. In the diagram, electrical interfaces are shown as yellow lines and the communications interfaces are shown in blue. Each of these interfaces may be bi-directional. Communications interfaces represent an information exchange between two domains and the actors within; they do not represent physical connections. They represent logical connections in the Smart Grid Information Network interconnecting various domains (as shown in Figure 12).

The domains of the Smart Grid are listed briefly in Table 1. In Figure 12, domains are shown as clouds.

It is important to note that domains are NOT organizations. For instance, an ISO or RTO may have actors in both the Markets and Operations domains. Similarly, a distribution utility is not entirely contained within the Distribution Domain – it is likely to also contain actors in the Operations Domain, such as a Distribution Management System, and in the Customer Domain, such as meters.

A comprehensive architecture is needed embrace NIST’s conceptual model and enable the functional requirements highlighted in the previous sections in order to develop and specify the requirements

Table 1 – Domains in the Smart Grid Conceptual Model)

Domain	Actors in the Domain
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: home, commercial/building, and industrial.
Markets	The operators and participants in electricity markets.
Service Providers	The organizations providing services to electrical customers and utilities.
Operations	The managers of the movement of electricity.
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

for the Grid Operating System 3.0. To do so will require engagement of the entire stakeholder community: utilities, ISOs/RTOs, information technology suppliers, telecommunication providers, and others. Outlining the architecture and specifications for Grid Operating System 3.0 is an electricity sector innovation challenge for this decade. Without this development, the full value of a lot of individual technologies like electric vehicles, electric energy storage, demand response, distributed resources, and large central station renewables such as wind and solar will not be fully realized. The Grid Operating System Version 3.0 OS is the enabler that makes other technologies work seamlessly with the electricity grid.

Transitioning to Grid 3.0

Replacing the operating system in today’s increasingly complex grid is like replacing an engine on a jet plane while it is flying at 30,000 feet. Much like the plane, the grid needs to be “on” all of the time. There are two issues to look at regarding the power system being on all of the time. The first one relates to the inherent complexity and potential to disrupt the system during transitions from one operating version to a newer version. While many aspects of upgrading



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the power system have become routine, such as new line extensions and public improvement projects, other projects are more complex, such as upgrading a control system or its many parts that are critical to the minute-to-minute operation. The other issue is the ability to simulate or model the power system at a sufficient scale (e.g., in the eastern interconnection) and behavior (daily, weekly, seasonal modes) so that extensive recursion testing of system can be accomplished prior to actually putting a system in service in a real operating environment. This very issue has been one of the roadblocks to widespread phasor measurement unit deployment.

Collaboration to Develop Grid 3.0

EPRI can be a catalyst in the development of Grid 3.0 by becoming a facilitator among the stakeholders leading to development of the architecture and functional specifications. EPRI proposes initiating this effort with a design charade; preparing and organizing a multi-day workshop of the industry's best minds to put together a comprehensive plan. That plan will develop a 24-month vision of a full architecture and a requirement driven specification. This will be conducted in an open environment such that the implementation and ultimate innovative development of products and systems can be conducted by vendors. It is critical that the industry respond to this call for action to embrace this innovation challenge to develop Grid Operating System 3.0. EPRI will provide seed funding for the first phase of this effort from its Technology Innovation Program. Additional R&D funding resources and dedicated researchers from key institutions will ultimately be needed to make Grid 3.0 a reality.

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