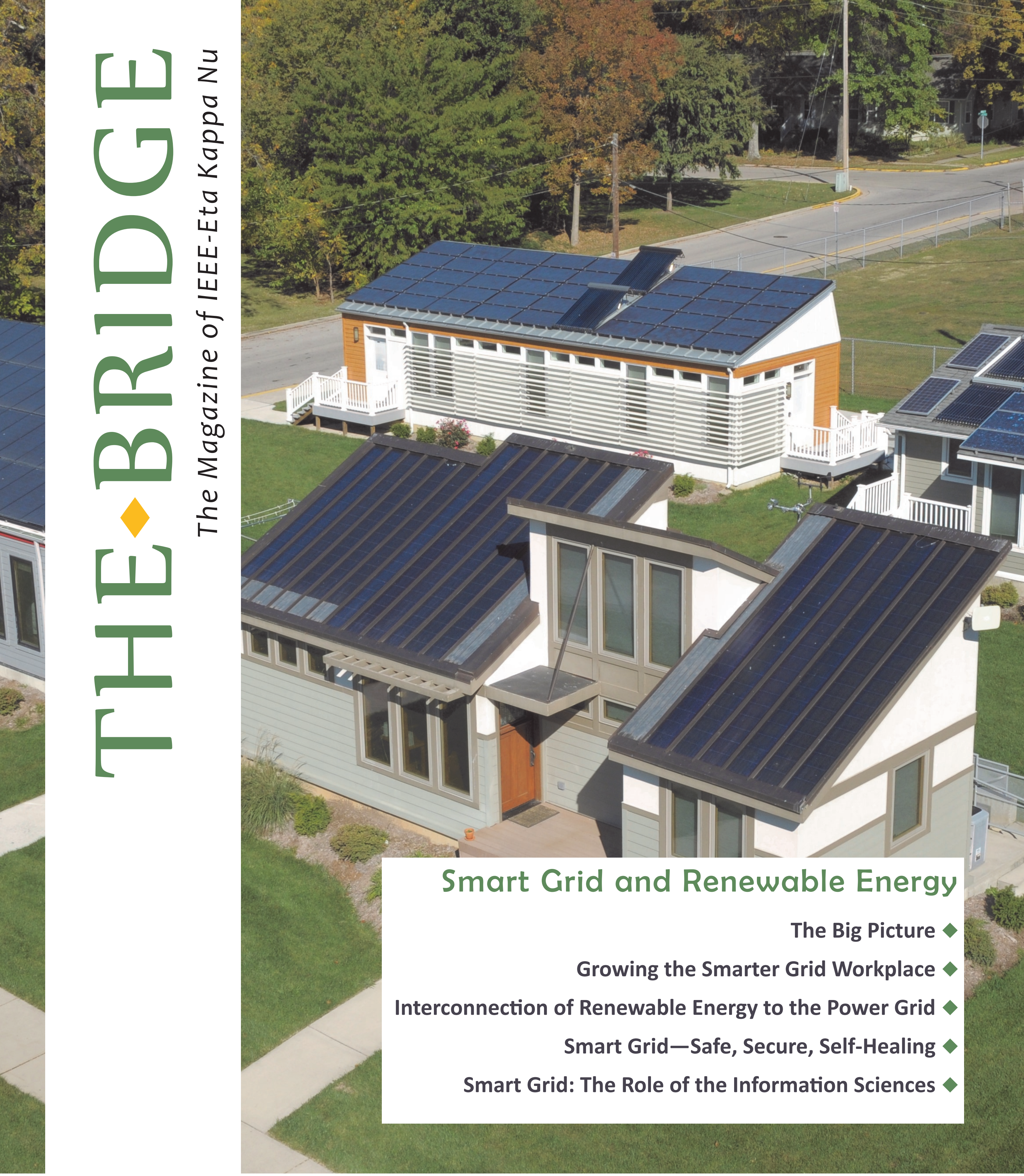

THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

Smart Grid and Renewable Energy

February 2015 Vol. 111 / No. 1

HKN IEEE

IEEE-HKN AWARD NOMINATIONS

As an honor society, IEEE-Eta Kappa Nu has plenty of opportunities designed to promote and encourage outstanding students, educators and members.

Visit www.hkn.org/awards to view the awards programs, awards committees, list of past winners, nomination criteria and deadlines.

Outstanding Young Professional Award

Presented annually to an exceptional young professional who has demonstrated significant contributions early in his or her professional career. (Deadline: 30 April)

Vladimir Karapetoff Outstanding Technical Achievement Award

Recognizes an individual who has distinguished him or herself through an invention, development, or discovery in the field of electrical or computer technology. (Deadline: 30 April)

Outstanding Student Award

Annually identifies a senior who has proven outstanding scholastic excellence, high moral character, and exemplary service to classmates, university, community and country. (Deadline: 30 June)

Outstanding Chapter Award

Singles out chapters that have shown excellence in their activities and service at the department, university and community levels. Winners are determined by their required Annual Chapter Reports for the preceding academic year. (Deadline: 15 October)

C. Holmes MacDonald Outstanding Teaching Award

Presented annually to a dedicated young professor who has proven exceptional dedication to education and has found the balance between pressure for research and publications and enthusiasm and classroom enthusiasm and creativity. (Deadline: 30 April)

Distinguished Service Award

Presented annually to recognize those members who have devoted years of service to the society, resulting in significant benefits to all of the society's members. (Deadline: 30 April)

IEEE-Eta Kappa Nu (IEEE-HKN) was founded by Maurice L. Carr at the University of Illinois at Urbana-Champaign on 28 October 1904, to encourage excellence in education for the benefit of the public. IEEE-HKN fosters excellence by recognizing those students and professionals who have conferred honor upon engineering education through distinguished scholarship, activities, leadership, and exemplary character as students in electrical or computer engineering, or by their professional attainments. THE BRIDGE is the official publication of IEEE-HKN. Ideas and opinions expressed in THE BRIDGE are those of the individuals and do not necessarily represent the views of IEEE-HKN, the Board of Governors, or the magazine staff.

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Smart Grid and Renewable Energy

Departments

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LETTER FROM THE PRESIDENT

EVELYN H. HIRT
Beta Sigma Chapter

Dear IEEE-HKN Members and Colleagues:

As I embark on my year as IEEE-HKN President I am reminded of why I accepted the invitation to induction into Eta Kappa Nu at the University of Detroit (now University of Detroit Mercy, UDM). For me, induction was not just something for my resume; it was my milestone accomplishment of overcoming challenges that were even greater than I realized at the time.

You see, if it had not been for a quirk of fate that the Archdiocese of Detroit decided to reorganize their pre-university schools into elementary, middle, and high schools I would not have spent my final high school years in the nurturing environment that enabled me to not only be eligible for university but encouraged me to the real possibility of pursuing engineering. As an inner-city Detroit youth whose father did not complete elementary school, and mother did not complete high school, this alone would have resulted in a significant family milestone. At university there were other challenges including the rarity of being a female engineering student (before my graduation year, as I understand it, only 5 women had graduated before me from UDM). However with the support of fellow students (especially HKN members) and Dr. Wayne Panyan, my faculty advisor, I was able to gain confidence in my abilities and to perform at a level worthy of induction into HKN. There is one more aspect of that invitation to induction that sealed the deal for me; it was the call to leadership and service in addition to demonstrated academic excellence.

Part of my preparation for induction into Beta Sigma Chapter was to demonstrate service by working with my fellow inductees on our chosen service project. In addition, we all finished our rough brass casting of the Bridge so it would be suitable for display on a desk. Specific Chapter induction activities are not the real focus here though. What is important is that each IEEE-HKN Chapter creates its own memorable traditions and level of comradery that will unite each of their HKN inductees to the Chapter while at university and when they become alumni.

So in the spirit of my sharing of my induction experience I invite all Chapters and alumni of Chapters to share your memorable or current induction traditions with us at IEEE-HKN. I'll work with the Bridge Editor-in-Chief and the 2015 IEEE-HKN Student Conference Committee to share as many of your contributions as possible. Please send yours to info@hkn.org.

In a future issue of the Bridge I plan to outline the 2015 IEEE-HKN strategy to resolve any remaining open items associated with the merger into IEEE, and fostering thriving IEEE-HKN Chapters around the globe.

Warmest regards,

Evelyn H. Hirt

Phone: 800-406-2590
Email: info@hkn.org

DR. STEVE E. WATKINS

Gamma Theta Chapter

Dear IEEE-Eta Kappa Nu Members and Friends:

This issue of THE BRIDGE magazine has a theme of "Smart Grid and Renewable Energy." Smart grid technologies offer flexible management tools and more customer options, while allowing the integration of distributed energy technologies. We have features that describe developments in our electric power infrastructure, the role of information technology, and new workforce needs. The availability of electric power has transformed modern life. Electrification was selected as one of the Greatest Engineering Achievements of the Twentieth Century through a project of the U.S. National Academy of Engineering (http://www.greatachievements.org/). The smart grid may be a similar achievement for the twenty-first century. Electrical and computer engineers will play a central role.

The acceptance of new technologies is sometimes slow and various means have been used to attract users. Electrification was and is promoted with branding mascots or characters just as numerous other products are promoted through advertising. For early private utilities, Reddy Kilowatt was created in 1926 as a cartoon mascot for branding. Electric cooperatives, which helped to electrify rural America, adopted Willie Wiredhand in 1950 as their advertising mascot (see figure). These mascots were used to promote electrical services and products and they were taken very seriously. Reddy Kilowatt even has its own collection in the Smithsonian and Reddy Kilowatt and Willie Wiredhand were on opposing sides in litigation regarding trademarks in a 1957 U.S. Court of Appeals case (Willie won).

Willie Wiredhand, the cartoon mascot of electric power cooperatives. Image courtesy of RE Magazine, National Rural Electric Cooperatives Association (NRECA).

I am especially looking forward to our planned October 2015 issue of THE BRIDGE magazine. The selected theme is

"Focus on HKN."

If you have any interesting historical material or early HKN-related photographs, please share them with us.

Regards,

Steve E. Watkins

Phone + 1 573-341-6321

Email: steve.e.watkins@ieee.org

LETTER FROM THE DIRECTOR

NANCY M. OSTIN, CAE

Dear IEEE-Eta Kappa Nu (IEEE-HKN) Member and Friends:

IEEE-HKN 2015 – What a year it will be! Get set for a program-packed, high-engagement and energy-filled year.

On March 20-22, we hope to see you at the Mu Chapter of UC Berkeley for the 2015 Student Leadership Conference. The Mu Chapter is celebrating their 100th anniversary, and this event is FREE for the first 200 IEEE-HKN students registered. REGISTER NOW at http://fs25.formsite.com/ieeevcep/form63/. Key Chapter recognition will be awarded at this meeting.

Our Virtual Conference is available on the IEEE-HKN Virtual Campus. Content is available "on demand". The Resource Library contains the 2013-2014 Chapter Reports which are a great source to learn about program ideas, and community service projects from other chapters. Alumni Hall contains a photo gallery of thousands of photos, including your induction ceremonies, installations, award programs, student conferences, historical photos and Founders Day. Find your chapter and tag your photos! To access the Virtual Campus visit http://bit.ly/188Sup5. First time users, please create a registration. (Your IEEE credentials will not work on the Virtual Campus, access requires a registration.)

In the spring, be sure to submit your nominations by 30 April for the Karapatoff Technical Achievement, Outstanding Young Professional, and Outstanding Teacher awards. Nominations for the Outstanding Student awards will be due on June 30. Annual Chapter Reports will be due on June 30.

Over the past year, IEEE-HKN has had great success in attracting new chapters, re-instating dormant chapters, inductions, chapters reporting, chapters voting, chapters participating in programs – encompassing all areas of engagement and activity that indicate a healthy, growing, and successful organization. Thank you to all of our Faculty Advisors, Chapter Officers, members, and to our Board of Governors for their support and dedication to the success and growth of IEEE-HKN.

I am looking forward to a great 2015 for IEEE-HKN, and we hope to see you at many of these events.

Nancy M. Ostin

Phone + 1 732-465-6611

Email: n.ostin@ieee.org

Join us

March 20-22, 2015

Registration and more information:
http://slc2015.hkn.mu

At the IEEE-HKN Student Leadership Conference, immerse yourself and your chapter members in the best that Silicon Valley has to offer:

Keynotes from leaders in industry and academia

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The Big Picture

Smart Research for Large-Scale Integrated Smart Grid Solutions

By Mladen Kezunovic, Vijay Vittal, Sakis Meliopoulos, and Tim Mount

The evolutionary path of the U.S. electricity grid is at a historical crossroads. Decisions must soon be made about the direction of grid development so that it can meet extraordinary economic challenges, critical needs for energy security, and essential requirements for a sustainable way of life. This is a defining moment in terms of our nation's commitment to providing an electric energy system, including a bulk transmission network, that can meet the societal needs of the 21st century and beyond. A major evolutionary step in the grid's design, planning, and operation is needed, one that adopts new design concepts and innovative technologies that can be integrated into a modern infrastructure. The American Recovery and Reinvestment Act of 2009 (ARRA) provided a number of opportunities to achieve these far-reaching objectives.

This article describes a vision of—and the steps needed to reach—the national objective of having a smart grid infrastructure. Our focus is on new concepts and related technological considerations in developing smart grid solutions that will meet the seven objectives of the smart grid, as identified by the U.S. Department of Energy (DOE):

1) enabling informed participation by customers

2) accommodating all generation and storage options

3) enabling new products, services, and markets

4) providing the level of power quality required to meet the full range of needs in the 21st century economy

5) optimizing asset utilization and operating efficiently

6) addressing disturbances through automated prevention, containment, and restoration

7) operating resiliently against all hazards.

To achieve these goals, smart research and development efforts must harmonize four principal aspects of the future grid:

- **Expansion of the electricity grid infrastructure:** This includes building new infrastructure to replace aging infrastructure while expanding grid capacity, improving the operation and efficiency of the existing infrastructure, and developing novel concepts, technologies, and applications. The smart grid will integrate renewable generation and distributed energy sources. It will also enable creative options for customers to participate in system operations by offering their loads and storage capability (e.g., from plugin hybrid electric vehicles) as resources. Customers also want options for making their own usage more energy and cost efficient (such as through building energy management systems).

- **Introduction of information technology, communications infrastructure, and modern sensors at large scales for both online and back-office services to facilitate the operation and management of assets:** Smart grid innovations will expand the use of computers and communications. They will also add new sensor technologies, database management systems, data-processing capabilities, computer-networking facilities, cybersecurity technologies, and visualization tools for asset operators and managers.

- **Incorporation of new monitoring, control, and protection applications that are integrated and operate seamlessly:** The smart grid will bring technological advances in monitoring, data-to-information conversion and visualization technologies, and advanced control and protection schemes. These advances will serve to integrate renewable resources and distributed generation, support customer choices, facilitate risk-based asset management and control strategies, and improve efficiency and protection of the grid.

- **Enactment of a new regulatory environment for operating the smart grid that provides the correct economic signals for all participants and all market products:** The basic economic principle for the smart grid should be that all participants should pay for the services they use and be paid for the services they provide. Traditionally, the regulatory environment treated the levels of demand for energy on the grid as exogenous sinks. Regulation was directed to the suppliers of energy and ancillary services, and customers expected to have reliable sources of energy available wherever and whenever they wanted. The main change for the smart grid will be to recognize that customers can also supply services to the grid and modify the timing of their demand for energy in response to incentives. Allowing new demand response products to participate in capacity markets is only the first step in developing new demand response capabilities for the smart grid.

Next we discuss a systematic approach to identifying the challenges of integrating a mix of energy generation, storage, and customer resources and to developing an integrated operations framework across the electric energy enterprise.

Defining a Vision for the Operations of Integrated Systems

To satisfy these objectives, there needs to be a novel mapping of smart grid applications to the proposed infrastructure. Figure 1 illustrates how infrastructure and application solutions may be mapped to objectives. The vision needs to establish categories of new applications that are more effective than the existing ones in achieving the goals of the smart grid. The core of the new applications is integration of massive sources of data measured from the grid and extraction of information that can serve the needs of the stakeholders: market operators, generator owners, wires companies, and, most of all, customers.

The integration of smart grid solutions requires a versatile communications infrastructure that is much more flexible

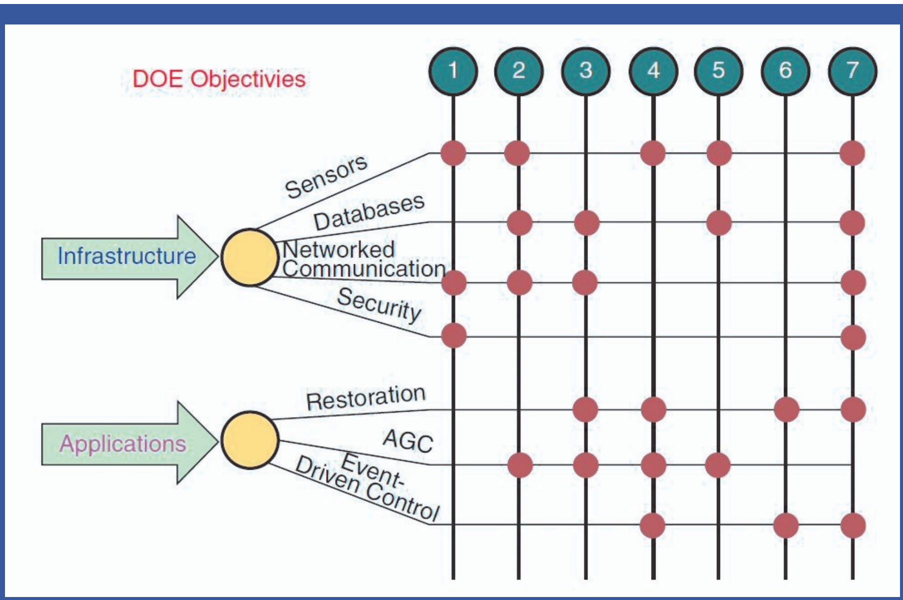

Figure 1. Mapping solutions to objectives.

than the existing one. Figure 2 illustrates a communication system that will provide the needed integration. The communication requirements of the smart grid are much more demanding than those of the legacy grid. The real-time requirements for exchange of data and information require low latency and redundancy in communication paths. The back-office data processing and storage require communication support for distributed databases and processing facilities. The communication infrastructure also has to enable the special protection schemes critical to reliable system operation and control. Recent developments of modern communication architectures, such as the North American SynchroPhasor Initiative network, are a step forward, but more work is needed to fully understand the communication requirements of new applications in a smart grid.

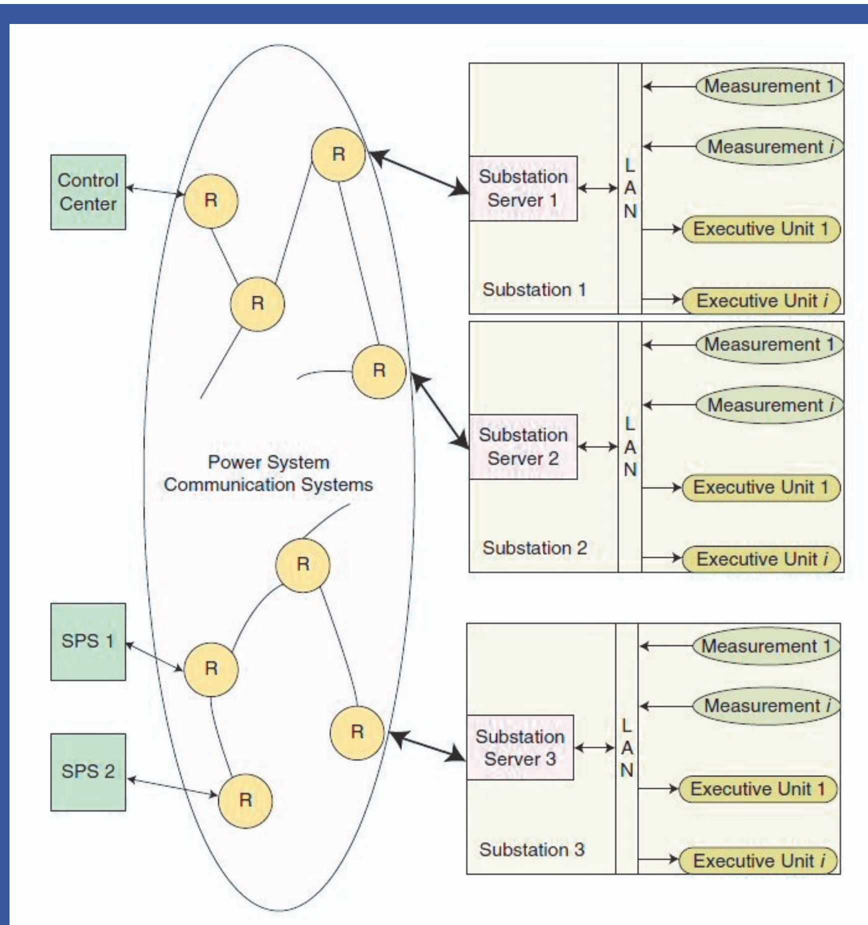

Figure 2. Communication among system elements.

Conceptualizing the Smart Grid Architecture

A conceptual architecture for the smart grid is depicted in Figure 3. The proposed architecture advocates a synergy of computing and physical resources and envisions a trustworthy middleware providing services to grid applications through message passing and transactions. The architecture also accounts for a power system infrastructure operating on multiple spatial and temporal scales. That infrastructure must support growing penetration of distributed energy resources. There will also be thousands of sensors and actuators that will be connected to the grid and to its supporting information network. Energy generation, transmission, and distribution will be controlled by a new generation of cyber-enabled and cybersecure energy management systems (EMSs) with a high-fidelity supervisory control and data acquisition (SCADA) front end. A notable change from the previous architectures is the two-way communication between customers or service aggregators with all electricity market stakeholders: distribution, transmission, and the market operator. This is shown in Figure 3, as a link through the information network. To reduce complexity, the market operator connection is not shown in Figure 3.

The information network of the future will merge the capabilities of traditional EMSs and SCADA with the next generation of substation automation solutions. It will enable multiscale networked sensing and processing, allow timely information exchange across the grid, and facilitate the closing of a large number of control loops in real time. This will ensure the responsiveness of the command and control infrastructure in achieving overall system reliability and performance objectives.

The key to the success of the smart grid infrastructure is an underlying system of data acquisition, data validation, and data processing that will provide accurate and reliable data as well as extracted information to all the applications implied in Figure 3. Two concepts, namely data validation and data processing, are elaborated next.

A more detailed view of a system at the substation level that will assure more reliable data is provided in Figure 4. The proposed system for data acquisition and processing is based on substation automation technologies that are feasible

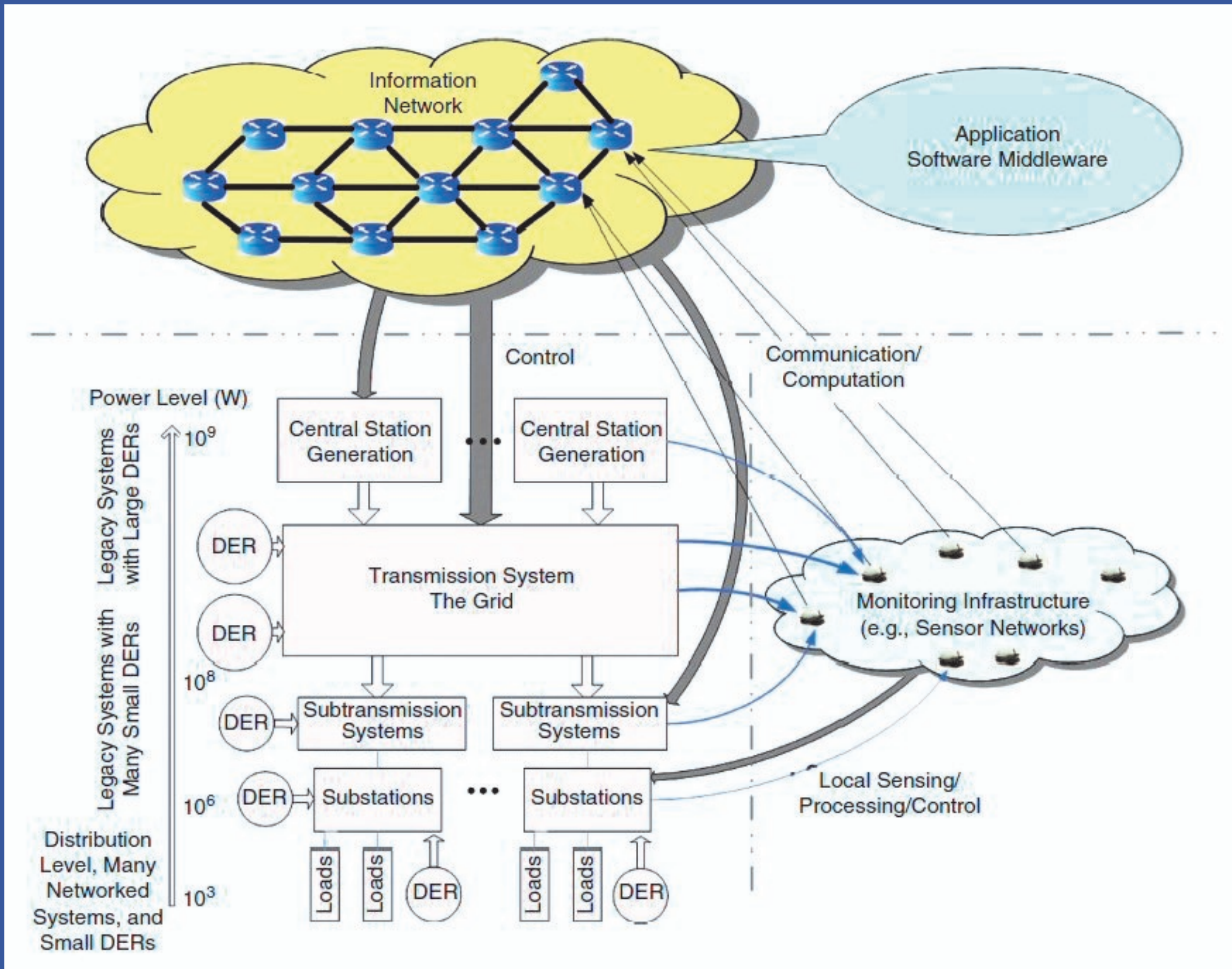

Figure 3. Architecture for a proposed integrated smart grid system.

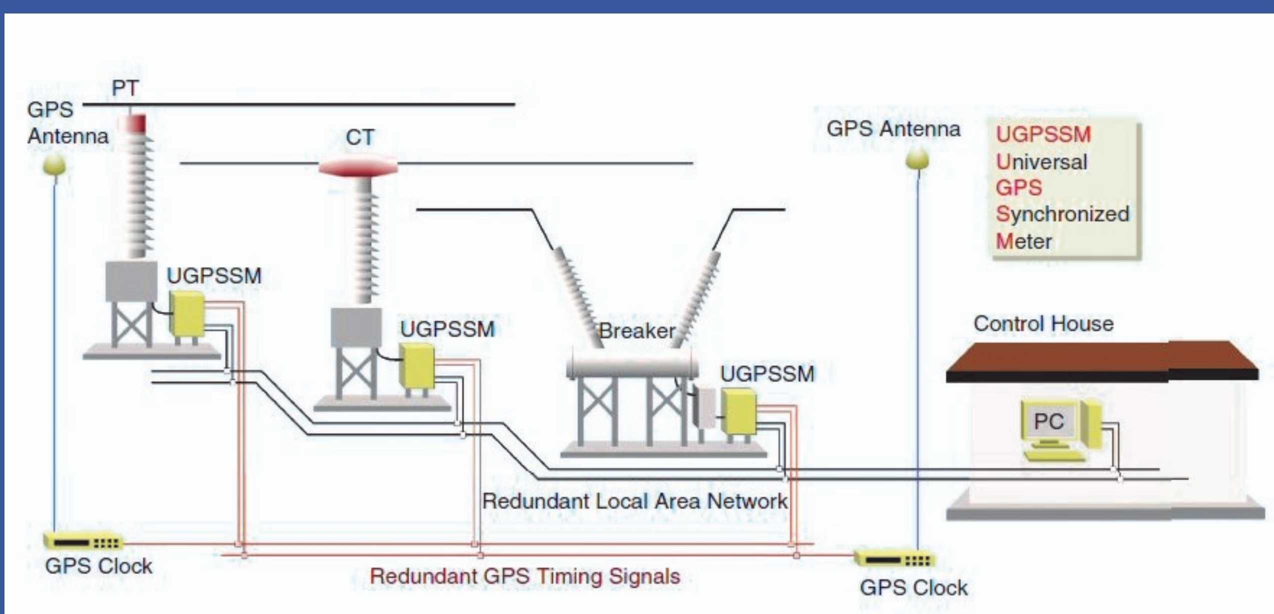

Figure 4. Future substation physical diagram.

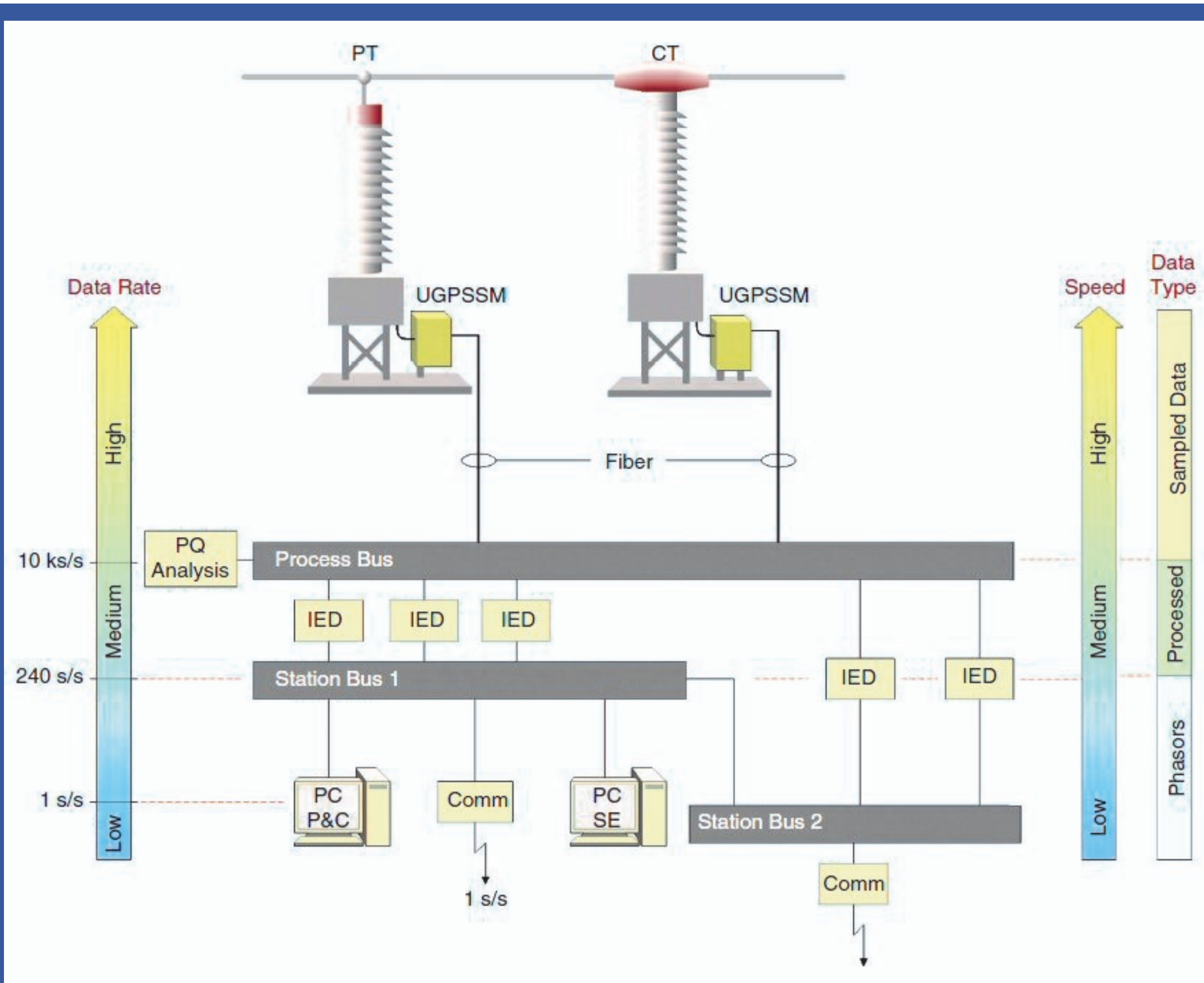

Figure 5. Substation architecture with data rates and data types.

today and assures full validation and redundancy of data. In Figure 4, the redundant substation local-area network that connects all substation measurement and power devices to the substation control center (SCC) via a digital network is deployed. In addition, the presence of a merging unit (a universal GPS-synchronized meter, or UGPSSM) on each high-power device is assumed. The UGPSSM performs digitization and time synchronization of measurements and communicates the time-tagged information to the SCC. Finally, the SCC communicates with the power system's wide-area network (WAN) via a single communication channel. This lets the SCC communicate with external power system entities, such as a utility control center or other smart substations, to provide data necessary for smart grid wide-area functions.

In terms of device connectivity, Figure 5 shows the architecture of the system depicted in Figure 4. This architecture has evolved over many decades, and technology exists today to fully implement this architecture. The data acquired by merging units are available on a process bus where other equipment can be connected and can process the data for a variety of applications, including state estimation (SE) and data validation, protection, power quality analysis, and phasor data computation. The intelligent electronic devices (IEDs) connected to the process bus can post the processed data on the substation bus. The data at the substation bus can be accessed by other devices for additional applications and to communicate this data to other entities, such as the control center and the enterprise. In terms of future design requirements Figure 5 illustrates typical data types and data rates. As smart grid technologies are further developed, data rates will increase.

Validating the data with techniques such as SE is becoming essential. At present, SE methods provide a practical technique for validating data. The architecture described above deals effectively with several well-known limitations of centralized SE and preemptively addresses many future goals of power system operations.

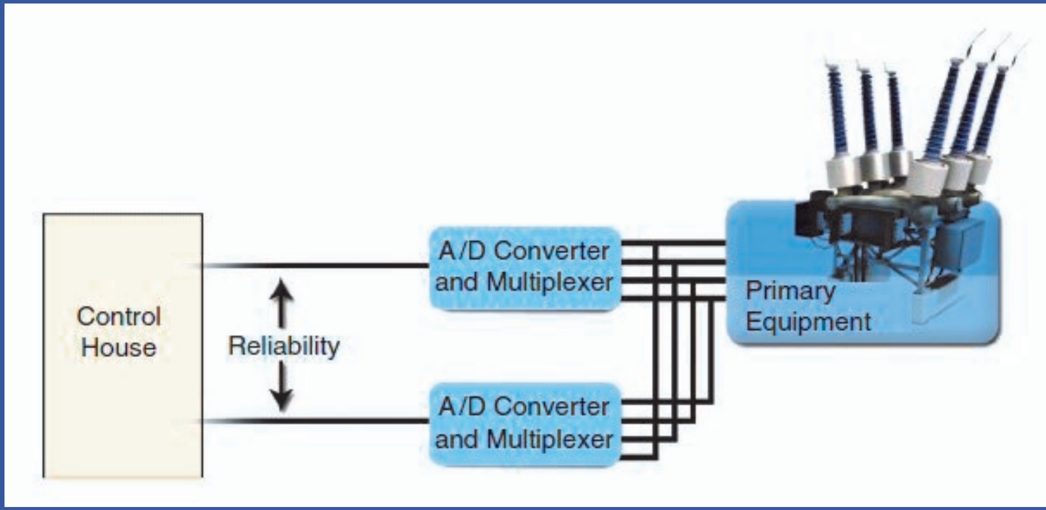

Figure 6. Integrating field data by multiplexing multiple measurements on a single fiber.

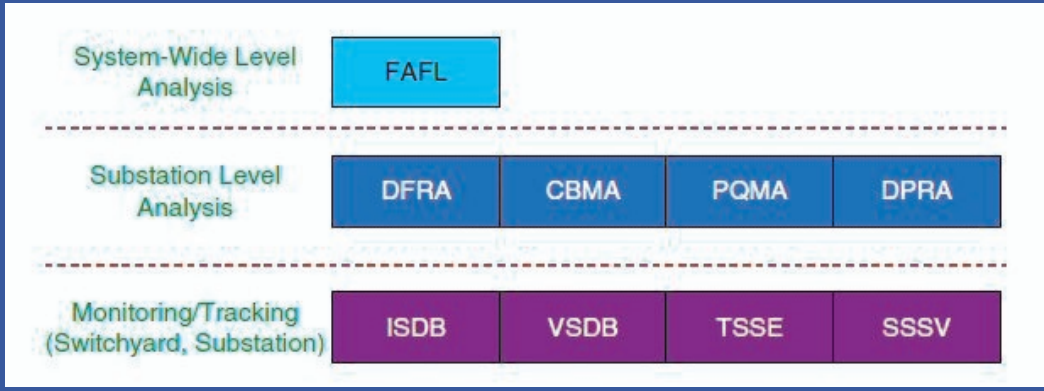

Figure 7. Software architecture for fault and disturbance analysis.

The scalability of the smart grid infrastructure is of paramount importance, since the amount of data captured in the smart grid will be huge. The proposed scheme can be implemented independently of the size of the grid because it is a distributed system. This is a major advantage for large regional transmission organizations as compared with competing centralized schemes. Currently, the amount of data to be transmitted between the substation and the control center and its frequency of transmission are fixed, but the proposed scheme can make this completely flexible, with the data amount and frequency adjusted to the particular control center application, which can also be made to run more or less often depending on the state of the system. The proposed scheme enables wide-area protection and wide-area control, which will be designed and implemented much more easily than they can be today.

The availability of large amount of data leads to the need for highly efficient and flexible data processing that will allow the integration of data from various IEDs, the extraction of information needed by various applications, and (eventually) the identification of the knowledge required for executing actions. In the future, data integration will start from the field, where sensor data will be multiplexed on single fibers to be brought to the control house, as shown in Figure 6.

The next level of processing involves extracting necessary information and feeding it to applications at different levels of the processing hierarchy: IEDs, substations, control centers, and market operators. To illustrate the concept, we will discuss automated analysis of faults and disturbances. Figure 7 shows different levels of automated software-based analysis that is information intensive and aims to convert data into information that provides further details about the causes of faults and disturbances. As an example, the system-wide analysis includes fault analysis and fault location (FAFL). The substation-level analysis includes digital fault recorder analysis (DFRA), circuit breaker monitor analysis (CBMA), power quality monitor analysis (PQMA) and digital protection relay analysis (DPRA). The monitoring and tracking analysis includes verification of substation database (VSDB), two-stage SE (TSSE), substation switching sequence verification (SSSV), and integration of substation database (ISDB). In this example, substation-level analysis provides information to serve control center applications such as fault location, topology processing for SE, and alarm processing. This analysis, together with power system component models, can provide the system with a wide-level disturbance monitoring and analysis solution that is unavailable today.

An important observation for the applications shown in Figure 7 is the step that facilitates data integration and information exchange from multiple types of IEDs to serve the automated analysis applications that start with individual IED types. Figure 8 illustrates the substation-level data processing needed to implement such data integration and information extraction concepts.

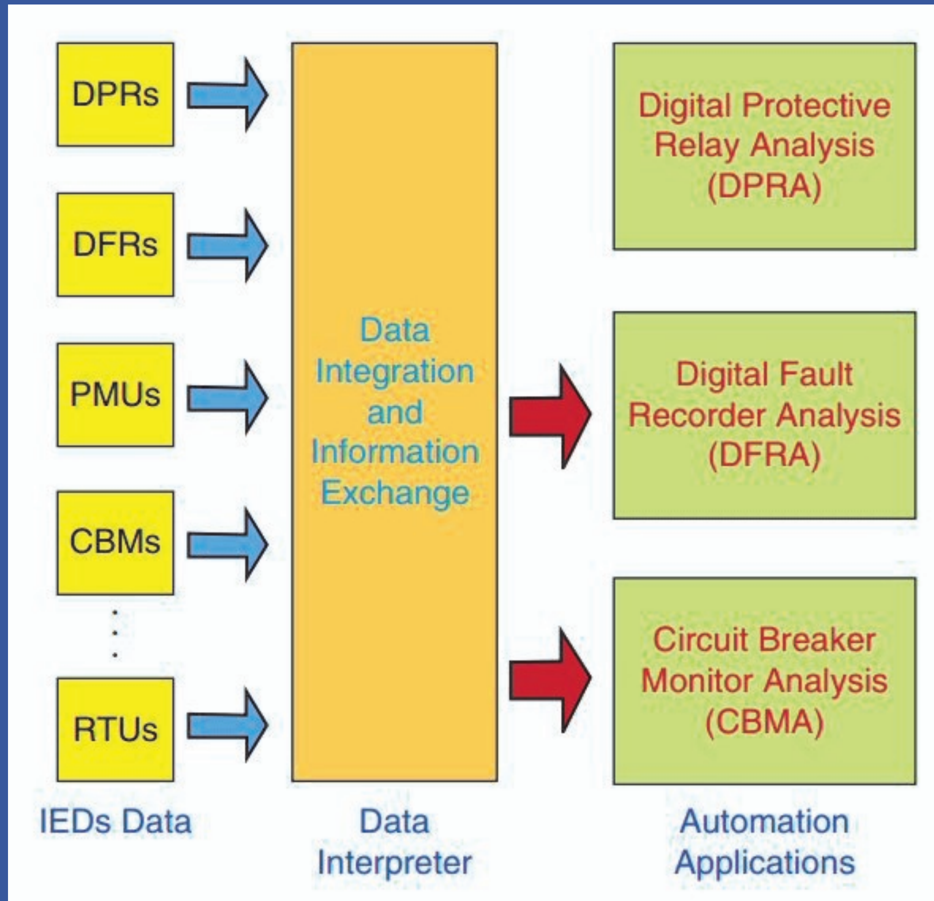

Figure 8. Substation-level data integration and information exchange.

Conducting R&D to Create an Integrated Smart Grid Solution

Much attention is being paid to customer-level smart grid devices in current smart grid discussions. There also needs to be planning for the implementation of a smart grid at the bulk transmission level. This planning must address the challenges that must be overcome in order to achieve a high penetration of renewable energy resources at different voltage and power levels in an environment where operating margins are declining due to load growth and the retirement of legacy generation resources. The following tasks are needed to create an integrated smart grid bulk transmission solution that ensures the seamless accommodation of green resources and guarantees that operating criteria will be satisfied even under extreme system loading conditions.

Develop and Establish Forward-Looking, Updated Operations Criteria

Regional entities of the North American Electric Reliability Corporation (NERC) establish the reliability criteria necessary to implement, augment, or comply with reliability standards. In broad terms, the regional criteria describe how planning and operations need to be done to ensure grid reliability. The criteria can therefore include, for example, operating practices and protocols, tools, methods, and organizational processes. A critical element of an integrated solution for the smart grid will be developing appropriate system operations criteria that account for variable power output from renewable resources. New risk-based operations criteria will also be needed to balance economic and reliability goals while accounting for the increased uncertainty in the system.

The updated operations criteria will need to include control area and balancing area designs that account for an increased penetration of renewables. The criteria must provide interoperability standards and criteria that enable the flexible deployment of new and old generation sources. The criteria must ensure that the grid continues to be resilient in the face of increased uncertainty about system conditions and resource availability.

Models, operational structure, and analysis tools for studying requirements for interoperability standards will be needed. These tools must allow for the examination of legacy and new criteria and be able to quantify the impact of proposed criteria on power system economics and reliability, particularly under extreme events.

R&D should be conducted in a number of areas. These include:

1) **Measurements and sensors:** Development of high bandwidth, high-accuracy current and voltage transformers and other types of sensors, such as sensors that monitor mechanical variables of the transmission infrastructure, is needed. Phasor measurement units (PMUs) and other GPS-enabled IEDs will play a critical role in the smart grid solution being envisioned. Methods will also be needed for intrasubstation data collection and storage. As an example, Figure 9 illustrates the future use of PMUs in conjunction with data-mining tools such as decision trees to conduct online dynamic security assessment for a range of phenomena, including transient stability, small-signal stability, and voltage stability.

2) **Communications:** A high-bandwidth network capable of intrasubstation, intersubstation, and control center communication will be required to facilitate large-scale data collection, local processing, and distilled information transfer. A key feature of this architecture will be communications management via advanced middleware.

3) Integration of information technology: The envisioned

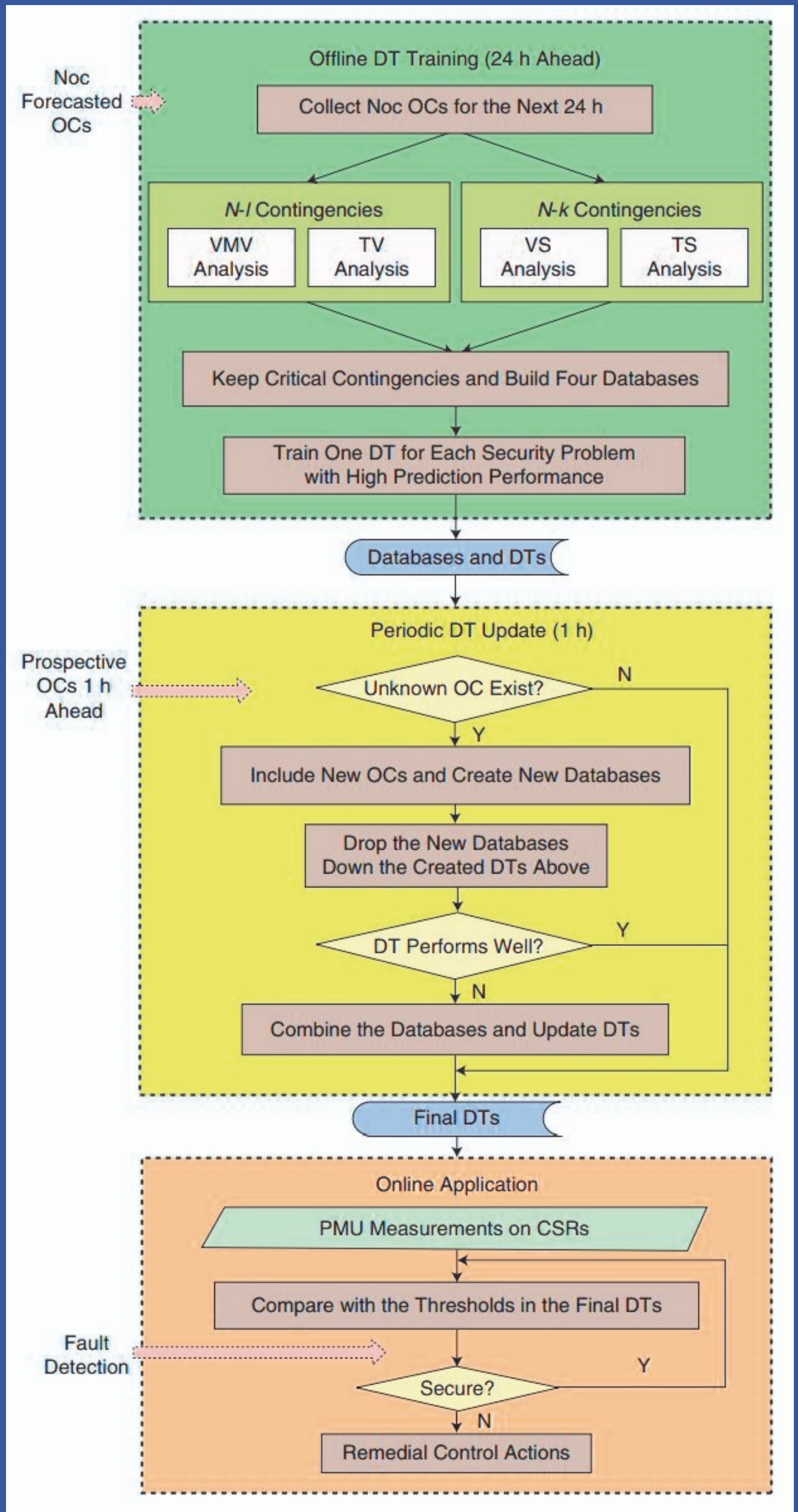

Figure 9. Applications of PMU measurements in an online security assessment envisioned as part of the proposed smart grid solution.

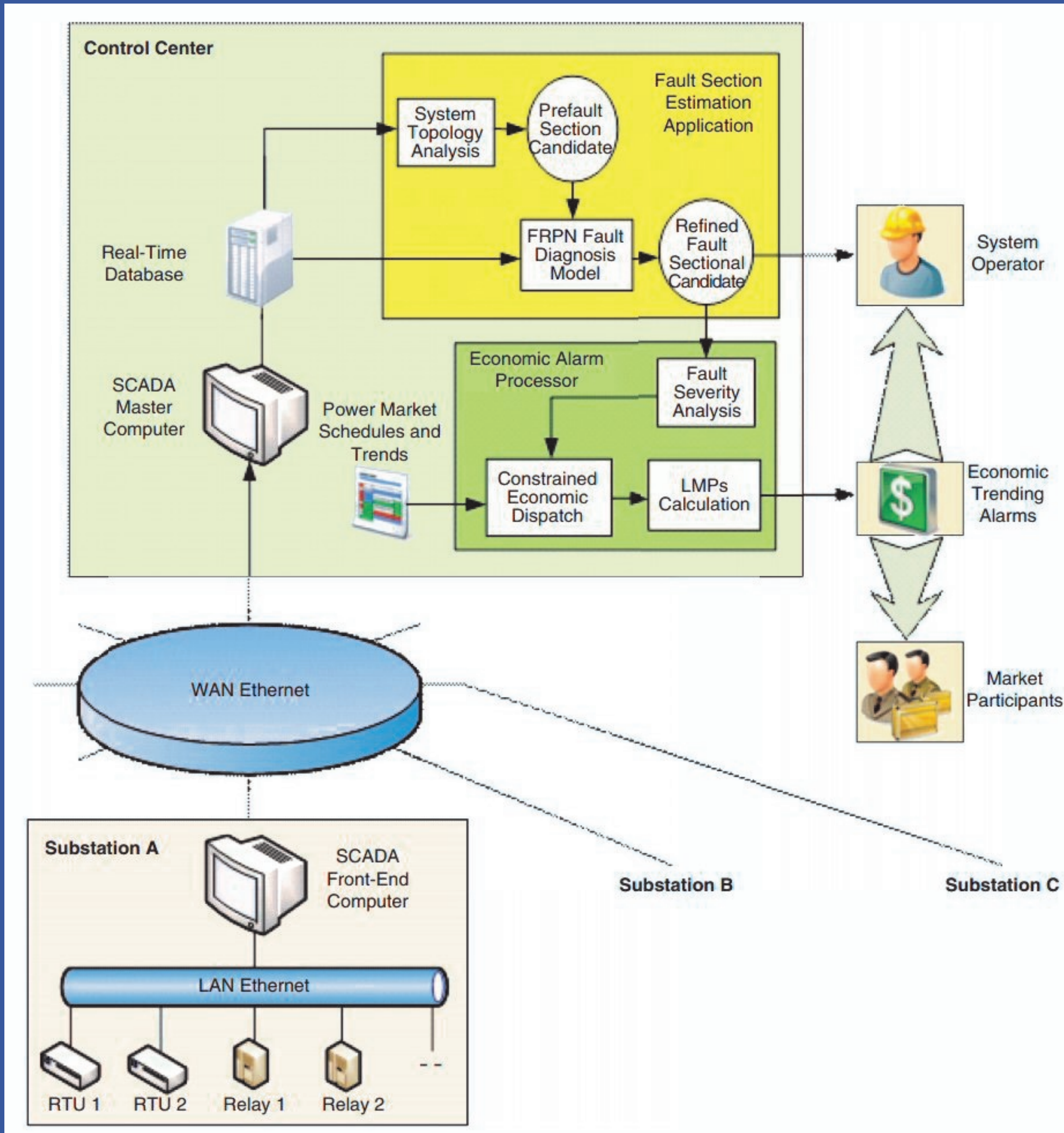

Figure 10. Architecture of an intelligent economic alarm processor.

information technology infrastructure will include distributed databases that require local and distributed management capable of addressing both real-time and off-line requirements. The architecture relies on local processing capabilities to perform data integration and information extraction. Cybersecurity and data integrity issues will need to be addressed to ensure that operational criteria are met.

4) **Monitoring and supervisory control:** The proposed smart grid solution needs to provide advanced visualization and situation awareness, intelligent alarming and alarms management, the ability to quantify reliability and market performance as operation aids, and supervisory control aids during alert and emergency conditions. An example of future research in this area is the concept of “economic alarms.” Figure 10 shows an integration of alarms associated

with faults and disturbances in a physical network with electricity market functions. Such integration would allow automated knowledge extraction that could provide market operators with an understanding of the impact of power system events on economic dispatch and local marginal prices (LMPs). This would create economic alarms indicating that either the electricity market was in an emergency state due to the violation of market parameters or that power system connectivity was disturbed and required immediate restorative action.

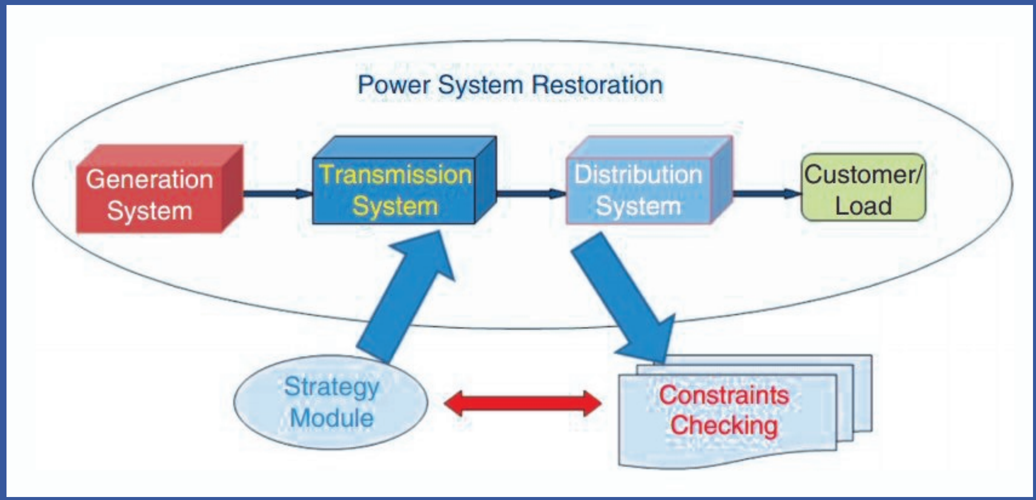

Figure 11. Automated integrated restoration with constraint checking.

5) **Intelligent recovery and restoration:** Given the need to monitor and control a system existing on diverse spatial and temporal scales, a high degree of coordination and automation is imperative for system restoration following major outages. This will require the development of special monitoring methods and online analytical tools not currently in use and will also involve the development of operator aids to translate restoration procedures into actions. Figure 11 depicts a proposed automatic restoration scheme that includes an integrated restoration plan for generation, transmission, and distribution in conjunction with a detailed constraint-checking approach to guarantee that the system meets reliability requirements as it is restored.

6) **Wide-area control and protection:** New requirements for control and protection will result from the wide diversity of the distributed energy resources interconnected to the grid at a range of voltage levels. To manage and enhance the speed and effectiveness of such functions, innovations will be needed in synchrophasor-based monitoring, relaying, and control; fast utilization of flexible alternative current transmission systems (FACTS) devices for changing systemwide conditions; suppression of interarea oscillations; system integrity protection schemes; and, as a last resort, adaptive islanding.

7) **Online grid control and management tools:** The increasing complexity and size of the electric energy system will also necessitate new developments in fast state estimation that will replace SCADA data for operator displays; intelligent integrated (static, dynamic, voltage) contingency analysis; optimal power flow (OPF)–based control decisions during reliability or market deterioration; direct state measurements that enhance state estimation; fast simulation techniques for real-time contingency applications; and system representation and modeling for operations (real-time) and planning (off-line) applications.

Analyze the Interactions of Renewables and Storage with Transmission

The increased penetration of renewable resources will necessitate the need for large-scale energy storage at the bulk transmission level. It will be complex to conduct a rigorous investigation of the interactions between renewable resources and large-scale storage in the bulk transmission system. The investigation will need to account for the variability of power and energy output from renewable resources and incorporate interactions among diverse renewable resources (e.g., wind, solar, and biomass). The effect of renewable resources and storage on power system operation should be examined, including balancing authority functions, automatic generation control, and market operation.

Such analyses have not yet been carried out for large scale integration of renewables. Novel analytical approaches and tools will have to be developed.

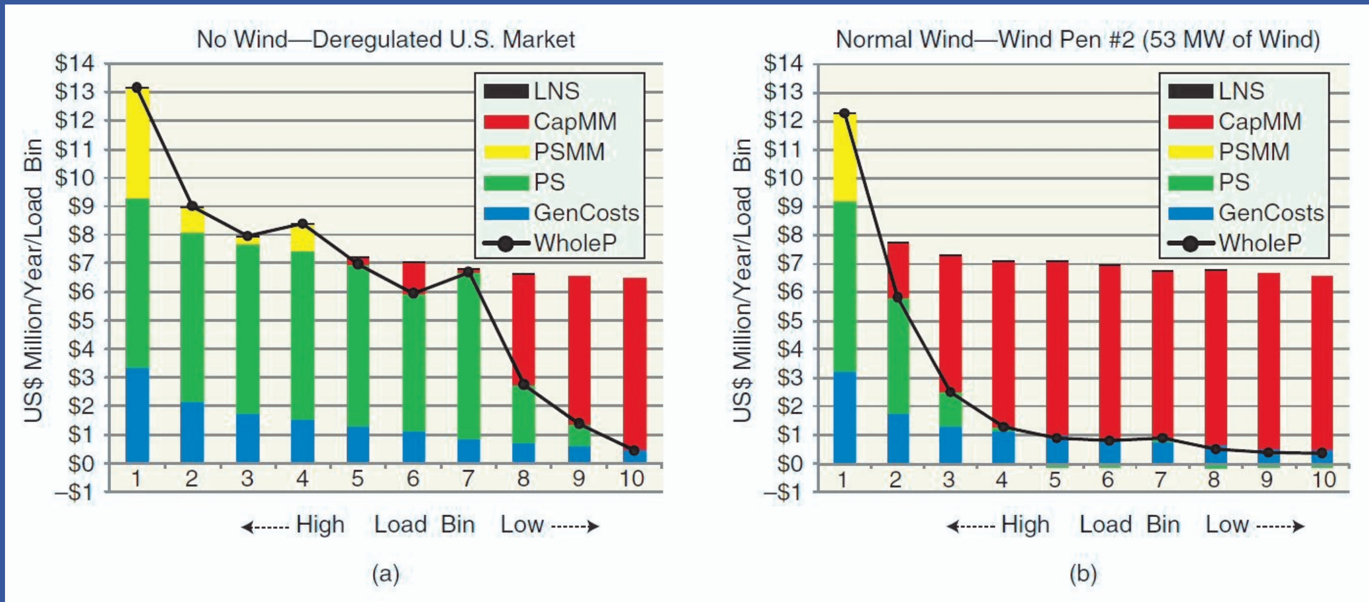

Figure 12. The composition of production costs for networks (a) without and (b) with wind generation.

Assess Effects of High Penetration of Low- Carbon Solutions and Policy Scenarios

To facilitate the penetration of renewable resources, an integrated approach that accounts for both system operations and underlying market mechanisms is essential. This integrated analysis under plausible future scenarios should account for renewable resources, demand resource programs enabled by a smart grid, massive energy storage, a transmission grid backbone of HVdc and HVac technologies, and central station generation (including legacy generation and new nuclear, clean coal, and other relevant generation technologies).

Develop Tools that Facilitate Customer Participation

Customer response to communications (such as prices) from service providers plays an important role in the scheme envisaged for a smart grid that is integrating renewable energy sources. Technologies and tools that facilitate customer participation must be developed and incorporated in the smart grid. With higher penetrations of variable generation from renewable sources, the need to install effective forms of storage capacity on the electric delivery system is critical. But installing dedicated storage capacity designed only to mitigate the variability of generation from a wind farm, for example, is expensive. Furthermore, demandside storage resources, such as the discharging and charging of electric vehicles, can be used to mitigate variable generation and smooth daily load cycles as well as provide regulation and ramping services to support the reliability of supply. If the owners of electric vehicles are compensated correctly for providing these services, the overall cost of operating the vehicles will be reduced. Since the primary purpose of the batteries in electric vehicles is to provide a means of transportation, the substantial cost of a battery will then be shared between transportation and supporting the grid. As a result, electric vehicles will provide a relatively inexpensive source of controllable load and energy storage for the grid.

The impact of controllable loads can be expanded by including thermal storage, and in particular by the use of ice batteries to replace standard forms of air-conditioning. The potential benefit of this type of storage is that a substantial amount of the peak system load on hot summer afternoons can be moved to off-peak periods at night. Instead of using air conditioners when space cooling is needed, ice can be made when this is convenient for the network. Similar arguments can be made for space heating using oil, for example, to store heat. In this way, thermal storage can be used to mitigate variable generation and reduce the total amount of installed generating capacity needed to maintain system adequacy. At the present time, however, the regulatory procedures for measuring and compensating these types of services are poorly developed. For example, demand-side products for reliability are typically paid on the basis of the reduction of use at peak periods instead of having customers always pay for what they actually do use.

The results in Figure 12 demonstrate how high penetrations of renewable sources of generation affect annual production costs on a test network. Each plot shows ten different load bins representing a load duration curve; the black line represents the wholesale payments made by customers in each bin. The operating and fuel costs (in blue) and the net revenue (the sum of green and yellow. The green part represents the contribution to the “fair share” if the total capital costs are allocated equally to the ten bins. The yellow is the contribution above this fair share.) show the allocation of the wholesale payments by suppliers. This net revenue covers part of the annual capital costs for generation and transmission. The remaining revenue needed to cover the annual capital costs is the “missing money” (red) that is paid indirectly to suppliers (e.g., in a capacity market). The costs below the black line are covered by the price paid for energy (US$/ MWh), and the costs above the black line are covered by the price paid for installed generating capacity (US$/MW/ year). Figure 12(a) shows the results with no wind generation, and Figure 12(b) shows the results with a high penetration of wind generation. The main conclusion that can be drawn is that adding wind generation tends to lower the average wholesale price of energy and increase the annual price of capacity. This increases the economic incentive to reduce the amount of installed capacity needed for system adequacy by reducing peak system loads and mitigating the effects of unexpected drops in wind speeds.

The main limitation of current regulatory practices is that the rate structures paid by most retail customers do not charge real-time prices for energy and do not include explicit payments for capacity. Although there has been a recent effort to install more advanced meters that can give real-time price signals to customers, this step is not sufficient. New efforts should be made by regulators to provide better incentives for customers to manage the timing of their demand more effectively. In addition, the same technologies that can move demand from peak to off-peak periods (e.g., thermal storage) can also be used to provide ramping services to mitigate the inherent variability of wind generation. Rate structures should be designed to recognize that all participants are potential users and providers of services. The traditional distinction between suppliers and buyers will no longer be appropriate for the smart grid. Although retail customers will be the primary users of energy, they may also provide ancillary services and, under certain conditions, energy. In addition, some traditional suppliers of energy may also be users of ancillary services such as ramping, and they should pay for these services. To reiterate the fundamental economic principal for the smart grid, all users of energy and ancillary services should pay for these services, and all providers of these services should be compensated.

Moving Forward: Stakeholder Collaboration and Large-Scale Demonstrations

The next step in the path to smart grid implementation is to conduct large-scale demonstrations using the vision of an integrated solution and architecture and the applications from generation sources to end users. Large-scale demonstrations will facilitate continuing R&D, testing, and implementation of proposed solutions. Examples of such large-scale demonstrations include recent investments in the ARRA demonstration projects.

A number of key steps should be taken to ensure a successful large-scale demonstration. These include:

1) **Engaging stakeholders, from the beginning of the demonstration (defining its scale, scope, and objectives) to the end (when results are evaluated and next steps are discussed):** A comprehensive smart grid solution will require substantial investment in transmission and distribution systems, will affect customers and energy service providers throughout a service territory, and will rely on manufacturers to supply needed hardware and software. The greater the stakeholder collaboration is from the beginning, the less uncertainty there should be about the appropriate technologies and the effects and acceptability of implementing those technologies. In addition, it is useful to clarify smart grid design concepts based on discussions between academics and industry participants fully engaged in R&D as well as deployment of smart grid technologies.

2) **Linking the scale, scope, and objectives of the demonstration to the information needed to commit resources to building a smart grid:** If the demonstration does not fill gaps in the information needed, then there will still be questions at the end of the demonstration as to whether and how the smart grid should be built. Collaboration among stakeholders will be very important in identifying the information that needs to be gained from the demonstration.

3) **Defining metrics for evaluating demonstration results:** The evaluation metrics should be specified from the beginning to ensure that the necessary data are gathered during the course of the demonstration. Of course, the metrics should be related to the information gaps that the demonstration is seeking to fill. An evaluation analysis team should be formed as the demonstration is being planned so that its input can be considered in

the design. This team should be multidisciplinary (it could include, for example, engineers, statisticians, consumer market researchers, and economists) so as to provide the multifaceted information needed to decide whether and how to implement a smart grid solution.

4) **Coordinating the planning of the demonstration with other demonstration projects:** The implementation of large-scale demonstration projects demands considerable resources and time. The efficiency and effectiveness of the demonstration will be well served by coordinating with other demonstration projects that are being planned or are in progress and reviewing the results of completed demonstration projects. This coordination will be facilitated by the common demonstration project database being planned by the DOE.

5) **Using scientific study methodologies rather than just technology demonstrations, as appropriate:** Just because a proposed solution works technically does not mean that it is the preferred solution. The results obtained from a technology-based demonstration may not be useful in making inferences about how all customers (be they end-use customers, distributed generation customers, or other types of customers) will change their electric energy consumption or production decisions in response to a particular solution. There may also be customer adoption barriers that should be considered in developing or selling the solution. Using scientific approaches where appropriate, e.g., when trying to understand customer response, could provide results generalizable to an entire service territory. Good estimates of customer response are needed to evaluate smart grid solutions even at the bulk transmission level, where planners need to know how transmission flows will be affected by customer response to smart grid solutions.

Conclusions

This article represents an edited version of opinions expressed in an extensive white paper created by many individuals associated with the Power Systems Engineering Research Center (PSERC) of the National Science Foundation (NSF) and posted on PSERC's Web site, www.pserc. org. The four tasks described above are considered crucial to smart grid R&D, demonstration, and eventual deployment. As learning and innovation occur during the course of a demonstration, changes may be needed in the architecture, the components, and the way they are integrated operationally. The goal is to acquire the best information possible for the eventual decisions on whether and how an integrated smart grid solution should be implemented, so adjusting demonstrations as needed to provide that information is very appropriate. It is also important that demonstrations be designed and implemented to gain the knowledge needed for a system-wide deployment of a smart grid. The bulk transmission system should be included in the design. There are a great number of unknowns in moving toward the national goal of a low-carbon economy. That uncertainty can be reduced by effectively designed large-scale demonstrations drawing on the results of prior R&D efforts.

For Further Reading

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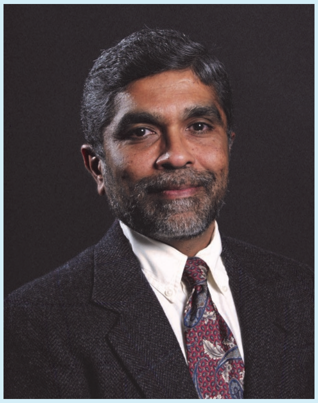
About the Authors:

Mladen Kezunovic (S'77-M'80–SM'85–F'99) is the Eugene Webb Professor of Electrical and Computer Engineering at Texas A&M University, which he joined in 1986. His research interest is the monitoring, control and protection of power systems. He currently serves as the Director of the Smart Grid Center and Site Director of the Power Systems Engineering Research Center. He is a Fellow of the IEEE, and a Fellow of CIGRE.



Vijay Vittal (S'78 - F'97) received the Ph. D. degree from Iowa State University, Ames, in 1982. He is currently the director of the Power System Engineering Research Center (PSERC) and is the Ira. A. Fulton Chair Professor in the School of Electrical, Computer and Energy Engineering at Arizona State University, Tempe. In 2013 he was awarded the IEEE Herman Halperin T&D Field Award. He is the co-author of four textbooks. Dr. Vittal is also a member of the National Academy of Engineering.

P. Sakis Meliopoulos (M '76, SM '83, F '93) joined the Faculty of Electrical Engineering, Georgia Institute of Technology, in 1976, where he is presently a Georgia Power Distinguished Professor. He has made significant contributions to power system grounding, harmonics, protection and reliability assessment of power systems. In 2005, he received the IEEE Richard Kaufman Award and in 2010 he received the George Montefiore Award from the Montefiore Institute, Belgium. Dr. Meliopoulos is the Chairman of the Georgia Tech Protective Relaying Conference, a Fellow of the IEEE and a member of Sigma Xi.

Tim Mount is a professor in the Dyson School of Applied Economics and Management at Cornell University. He has conducted research on the use of fuels and electricity and the environmental consequences for forty years. His current research focuses on the restructuring of markets for electricity and the implications for (1) price behavior in auctions for electricity, (2) the rates charged to customers, (3) investment decisions for maintaining system reliability, and (4) the potential role of deferrable demand and aggregators for mitigating stochastic sources of renewable energy and reducing system costs.

IEEE Educational Activities Board Awards

Presented November 2014

Highlights from November 2014 Awards Ceremony

At the Educational Activities Board Award Dinner held on 22 November, 2014 in New Brunswick, NJ, IEEE-HKN presented the Outstanding Young Professional Award and the C. Holmes Macdonald Teaching Award; and bestowed the Eminent Member status to two icons of Engineering.

The 2014 IEEE-HKN Outstanding Young Professional Award, “for exemplary work on biomedical radar devices and dedication to the IEEE local section and Microwave Theory and Techniques Society” was presented to Dr. Changzhi Li.

Dr. Li has been an Associate Professor at Texas Tech University in the Department of Electrical and Computer Engineering since 2009. Dr. Li designed and built an RF-Microwave device focused on non-contact detection of human activities and vital signs such as gait, heartbeat, and respiration. Based on the same technology, he has developed a low-power portable radar device which can remotely monitor a patient without any sensors attached to the body. He has expanded this technique to enable accurate tumor tracking during lung cancer treatment for precisely targeted radiotherapy.

Dr. Li has published more than 140 journal and conference publications, two book chapters, and a book, “Microwave Motion Sensing and Analysis,” and he holds three U.S. patents. He has worked with seven Ph.D., and thirteen Master’s Degree students, and is also serving as the faculty member of the Texas Tech Clark Scholars Program, which is an intensive summer research program for high school students. Dr. Li is also an associate editor for the IEEE Transactions on Circuits and Systems II, and has served as Technical Program Committee co-chair for the IEEE Wireless and Microwave Technology Conference.

In his spare time, Dr. Li is currently the Secretary of the IEEE South Plains Section, where he coordinates IEEE seminars, student chapter meetings, and IEEE regional competitions.

The C. Holmes MacDonald Outstanding Teacher Award recognizes the central and crucial role of university professors in educating, training and motivating future electrical and computer engineers.

The 2014 IEEE-HKN C. Holmes MacDonald Outstanding Teacher Award was presented to Dr. Dmitriy Garmatyuk “for outstanding teaching performance, demonstrating exemplary ability in conveying understanding of complex material to his students while also stimulating deep interest in the subject matter.”

Dr. Garmatyuk is Associate Professor of Electrical and Computer Engineering at Miami University, Oxford, Ohio. He earned the engineer’s degree in 1996 and his Ph.D. in 2001. He became a Senior Analog Design Engineer with the Circuit Design Technology and Automation Group of Intel Corporation in Folsom, California the same year.

In 2005, he joined the Department of Electrical and Computer Engineering at Miami University, where he developed and delivered courses in electromagnetics and very large scale integrated circuit design. His research interests are in the areas of electromagnetics, radar imaging, and signal/power integrity analysis. He has also taken on the responsibility for developing a complete Electromagnetics curriculum at Miami University.

In 2007, Dr. Garmatyuk received a grant from the National Science Foundation for developing innovative methods of teaching Electromagnetics to undergraduate students. Along with his students, he established and equipped a new laboratory, which has become the teaching venue for electromagnetics-related classes and senior design projects.

IEEE-Eta Kappa Nu established the Eminent Member Recognition in 1950 as the Society’s highest membership classification. It is conferred upon those select few, whose attainments and contributions to society have resulted in significant benefits to humankind. Since 1950, only 134 individuals have received this honor.

Dr. Hermann W. Dommel, an IEEE Fellow, is known for his work on electromagnetic transients in power systems. He is currently Professor Emeritus at the University of British Columbia in Vancouver, Canada. Previously he worked for the Bonneville Power Administration in Portland, Oregon, on computer applications in power systems, including what became known as the Electromagnetic Transients Program (EMTP). He is widely recognized as the "Father of EMTP." The software, used by many utility companies and manufacturers throughout the world, predicts overvoltage surges caused by network switching, system faults, and lightning, and has become an indispensable tool in the power industry.

Dr. Dommel also developed methods for optimal power flow that were quickly implemented in power system operations centers for real-time monitoring and analysis of the power grid. His paper detailing this work was voted among the five important papers concerning 20th century power system analysis. His optimal power flow solutions still play an important role in the efficient operation of large power systems.

Dr. Dommel is the author and co-author of 79 papers in journals, and 95 papers in conference proceedings, and was the recipient of the 2013 IEEE Medal in Power Engineering.

Standing, Left to Right: Roger Fujii, Gloria Rezek, Ed Rezek, Anthony Matos, John Paul Rodriguez
Seated, Left to Right: Peter Staecker, Susan Staecker, Sean Mulligan

Ray Kurzweil is an American author, computer scientist, inventor, futurist, and a Director of Engineering at Google.

Dr. Kurzweil was the principal inventor of the first CCD flatbed scanner, the first omni-font optical character recognition system, the first print-to-speech reading machine for the blind, the first text-to-speech synthesizer, and the first commercially marketed large-vocabulary speech recognition system. A 1982 meeting with Stevie Wonder inspired Dr. Kurzweil to create a new generation of music synthesizers which were able to reproduce the sounds of a variety of instruments with near-perfect accuracy. This instrument made it possible for a single person to play an entire orchestral piece.

Standing, Left to Right: Neil Limaye, Evelyn Hirt, David Daut, Lingling Xie, Changzhi Li
Seated, Left to Right: Dr. Dmitriy Garmatyuk, Ivan Garmatyuk, Oksana Dikhtyar

Dr. Kurzweil was inducted into the U.S. National Inventors Hall of Fame in 2002. He has honors from three U.S. Presidents; has authored seven books, including “The Age of Intelligent Machines” and “The Singularity is Near,” and maintains a news website, “Kurzweil Accelerating Intelligence,” which has over three million readers annually.

The Public Broadcast System included Dr. Kurzweil as one of 16 “revolutionaries who made America.” Inc. magazine called him “rightful heir to Thomas Edison.”

Growing the Smarter Grid Workforce

By Peter W. Sauer, IEEE Life Fellow,
University of Illinois

Abstract—Advances in technology and major programs to enhance the electric power system throughout the world have led to the concept of the "Smart Grid." This concept has been formally defined in various places and is driving many of the current changes in educational curricula and research activities at all levels. This paper provides a brief summary of the known definitions and the resulting challenges and opportunities for the workforce of the future.

Index Terms—Smart grid; power engineering education and research; power engineering curriculum; power engineering resources; workforce training.

The Smart Grid-Something for Everyone

The "SMART GRID" and related concepts propose to move the technology of electric power systems to the next level for improved efficiency, reliability, and environmental sustainability. The National Academy of Engineering identified the electrification of our planet as the number one achievement of the 20th century [1]. The main criterion for selection was not technical, but how much an achievement improved people's quality of life. The U.S. Energy Independence and Security Act of 2007 indicated that it is the policy of the United States to support the modernization of the nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet further demand growth and achieve the following [2] (Title XIII is quoted directly here):

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.

(2) Dynamic optimization of grid operations and resources, with full cyber-security.

(3) Deployment and integration of distributed resources and generation, including renewable resources.

(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.

(5) Deployment of ''smart'' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.

(6) Integration of ''smart'' appliances and consumer devices.

(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.

(8) Provision to consumers of timely information and control options.

(9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

A closer look at these ten goals reveals that virtually all of Electrical and Computer Engineering is included in some form. One could conclude that there is something for everyone in the smart grid space. Central to the smart grid concept is the addition of computing capability and a communication network to complement the electrical transmission infrastructure. As shown in Figure 1, smart grid capability promotes greater control of electrical power generation, transmission, and distributions as well as the active participation of customers and markets.

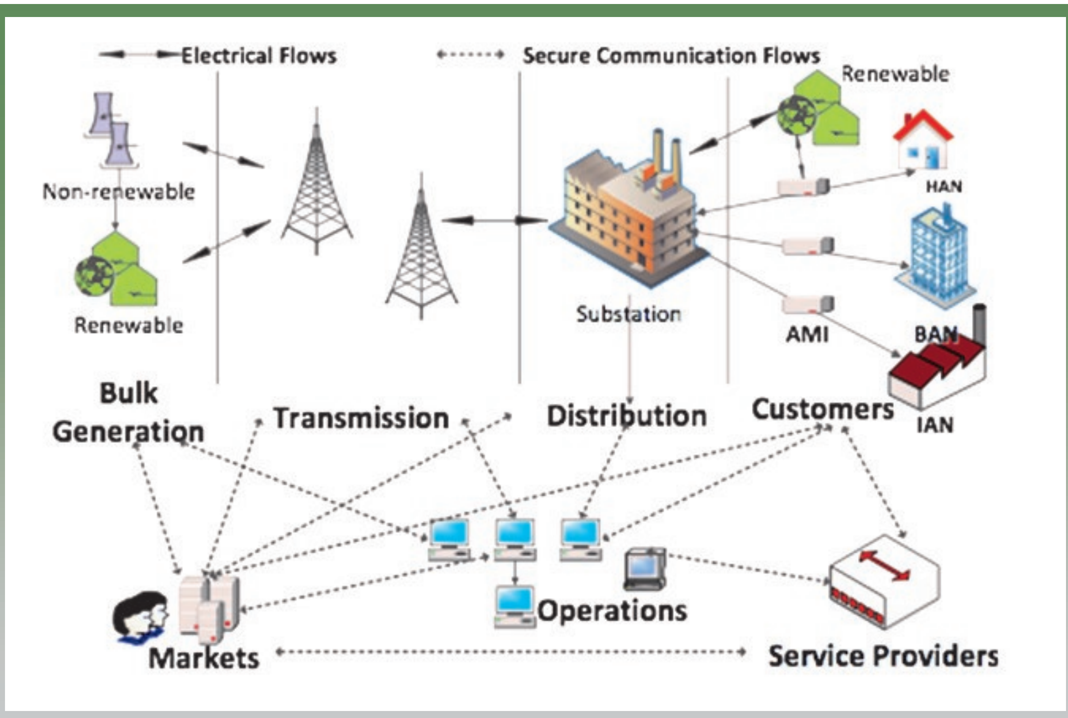


Fig. 1 Smart Grid Conceptual Model per the National Institute of Standards and Technology

Specific Programs

The EIASA reference above continues by listing the specific programs needed to develop the Smart Grid of the future. The following is a sample of these programs and needs:

- Develop advanced techniques for measuring peak load reductions and energy-efficiency savings from smart metering, demand response, distributed generation, and electricity storage systems;
- Investigate means for demand response, distributed generation, and storage to provide ancillary services;
- Conduct research to advance the use of wide-area measurement and control networks, including data mining, visualization, advanced computing, and secure and dependable communications in a highly-distributed environment;
- Test new reliability technologies, including those concerning communications network capabilities, in a grid control room environment against a representative set of local outage and wide area blackout scenarios;
- Identify communications network capacity needed to implement advanced technologies.
- Investigate the feasibility of a transition to time-of-use and real-time electricity pricing;
- Develop algorithms for use in electric transmission system software applications;
- Promote the use of underutilized electricity generation capacity in any substitution of electricity for liquid fuels in the transportation system of the United States; and
- Propose interconnection protocols to enable electric utilities to access electricity stored in vehicles to help meet peak demand loads.

The workforce to support the development and implementation of these technologies will need greater awareness of interdependences than was needed for traditional electrical power systems.

The Integrative Requirements of the Smart Grid

A panel paper [3] presented the main elements of an integrative approach to smart grid design and operation as shown in Figure 2. These elements identify several topics that are needed to train the future workforce. Electrical power engineering curricula is changing to meet these new requirements. Also, concerns regarding business, security, privacy, and regulation are closely intertwined with the technology.

For instance, the power engineering curricula at the University of Illinois at Urbana-Champaign discuss such diverse topics as sensors, communication networks, cyber security, and smart metering in the context of electrical power. Teaching laboratories must support the integrated emphasis.

Missouri University of Science and Technology has created a microgrid that links four solar-powered homes created for the US Department of Energy Solar Decathlon [4,5]. This Solar Village is a living laboratory for investigations of smart grid technology and for training students (see Figure 3 and Figure 4). Localized hardware allows the four-house facility to operate independently as well as to be integrated into the larger electrical power grid. This microgrid illustrates the use of alternative energy as a component of smart grid technology and the possibility of not only two-way information flow, but of two-way energy flow.

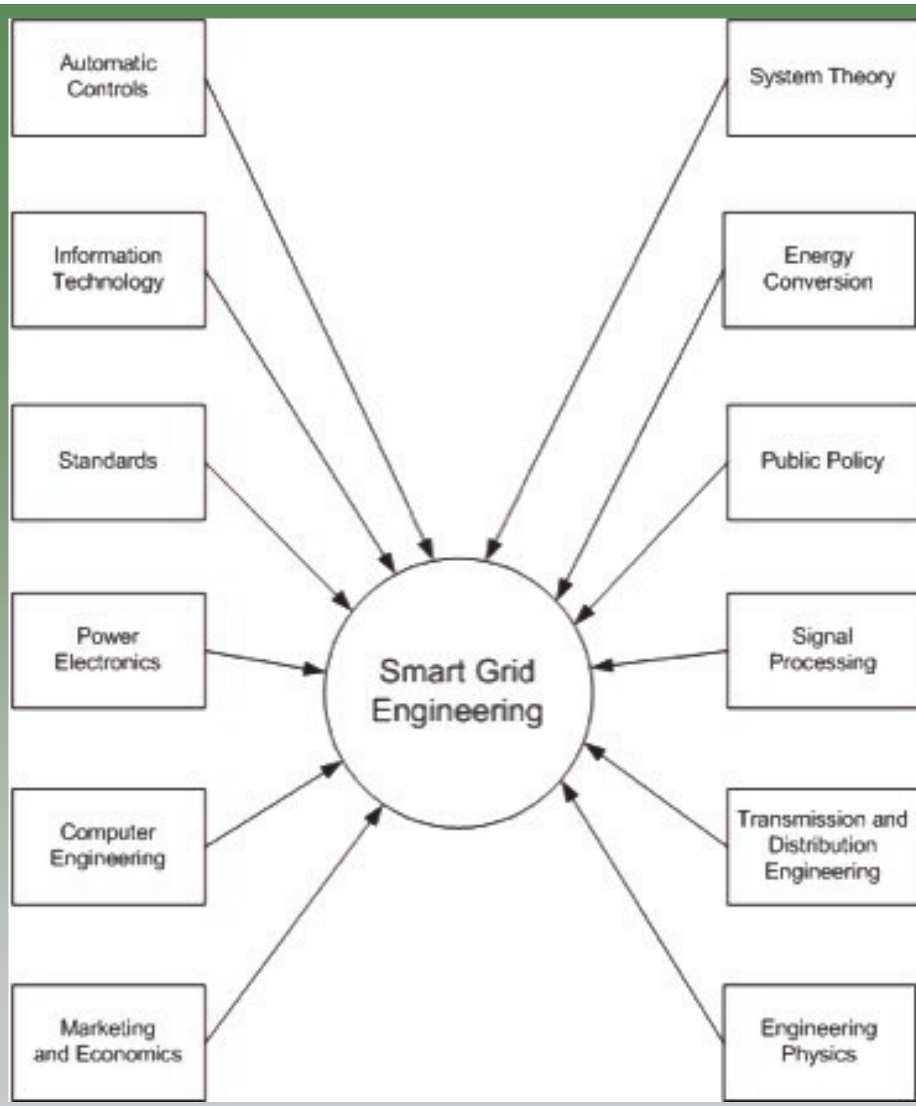


Fig. 2 Main elements of an integrative approach to smart grid design and operation [3]

A Recent Survey on the Smart Grid

The Colorado School of Mines recently completed a survey on smart distribution systems. H. Brown and S. Surynarayanan provide some characteristics of a smart distribution system (briefly summarized here):

It optimizes distributed assets through the use of real-time pricing, smart metering infrastructure, two-way communicating devices, and networked connections between feeders. It incorporates Distributed Energy Resources (DER) at all distribution voltage levels enabled with two-way communications. It integrates massively deployed sensors and smart meters.

It enables consumer participation in demand response through the widespread use of dynamic pricing, with real-time signals. It uses adaptive and self-healing technologies primarily integrated at the 15 kV class.

It makes use of advanced tools (including visualization, analysis, and simulation) to streamline routine operations. It integrates smart appliances and consumer devices. It possesses the ability to operate in either islanded or grid-connected mode.

See reference [6] for details associated with each of these characteristics.

A Note on the Meanings of "Smart Grid"

Reference [7] discusses the many possible meanings of the "Smart Grid" by listing topics briefly summarized here:

(1) At the level of the customer:

- i) Meters that can be read automatically
- ii) Time-of-day and time-of-use meters
- iii) Meters that communicate to customers
- iv) Control of customers' loads

(2) The level of the distribution system

- i) Distribution system automation
- ii) Selective load control
- iii) Managing distributed generation and "islands"

(3) The level of the transmission system

- i) Measurement of phase and other quantities
- ii) FACTS and other advanced control devices
- iii) Distributed and autonomous control

This note also discusses "Who should be in charge and what vulnerabilities could emerge?" The authors suggest that customers should be in charge of day-to-day operations and central operators be in charge for emergencies. Since the smart grid clearly involves communication networks, particular care should be taken to avoid security problems of hackers and information thieves.

Fig. 3 Microgrid Laboratory consisting of four solar-powered homes at the Missouri S&T Solar Village. Photograph courtesy of OSE3, Missouri S&T [4].

Fig. 4 The backbone of the microgrid includes batteries, a fuel cell, and smart switchgears. Photograph courtesy of OSE3, Missouri S&T [4].

A Cyber-Physical System (CPS)

The National Science Foundation has defined a Cyber-Physical System as one in which physical processes are tightly intertwined with networked computing. This has been more broadly interpreted to be a system in which a physical process is dependent on a computer/communication layer for control or function. In the power grid, these computer/communication layers exist in supply resources (Generation), energy transportation resources (Transmission and Distribution), and energy utilization resources (Loads). The interdependencies are pervasive and often critical. As regulation has changed the business aspects of operation, the computer/communication layer more is responsible for efficient dispatch of resources and maintaining reliability.

Conclusions and Recommendations

Based on all of the definitions of the smart grid and new technologies that will be required, it is clear that new types of people, individuals with new skills and a wider understanding of interdependences, are needed in the workforce [8]. Perhaps one of the biggest components of the smart grid will be the customer participation through market mechanisms. This aspect of power system operations should be included in future versions of power system analysis.

On the machines and power electronics sides, it is likely that additional sensing and control of appliances will be a topic that needs to be addressed in more detail. From an electrical engineering principles viewpoint, it is not obvious that major changes need to be made to traditional coursework. The smart grid issues have been considered in other areas of electrical and computer engineering for some time. Their integration into power systems is new and offers a fruitful area for collaboration between various technical areas within electrical and computer engineering.

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Acknowledgements

This article is a revision of my earlier article that appeared in the 2010 IEEE Power and Energy Society General Meeting with the following citation and is reprinted with permission. © 2014 IEEE.

P. W. Sauer, “Educational Needs for the 'Smart Grid' Workforce,” 2010 IEEE Power and Energy Society General Meeting, Minneapolis, MN, 25-29 July 2010, 1-3, (2010).

About the Author:

Peter W. Sauer (StM’73, M’77, SM’82, F’93) received his BSEE from the University of Missouri at Rolla and the MSEE and Ph.D. degrees from Purdue University. He has power facilities design experience with the US Air Force and was a cofounder of the PowerWorld Corporation. He is a registered Professional Engineer in Virginia and Illinois, a Fellow of the IEEE, and a member of the U. S. National Academy of Engineering. He has been at the University of Illinois since 1977, and he is currently the Grainger Chair Professor of Electrical Engineering.

This work was partially supported by the Power Systems Engineering Research Center (PSerc) and the Grainger Endowments to the University of Illinois.

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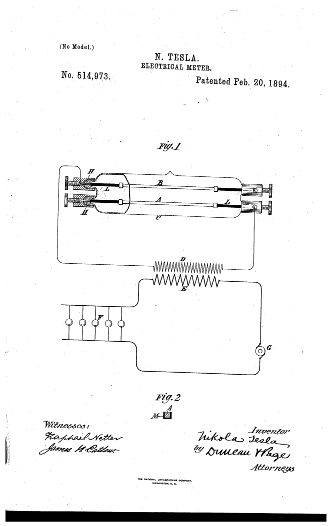
IEEE-HKN HISTORY SPOTLIGHT

NIKOLA TESLA (1856-1943)



Tesla patent involving metering illustrated above.

Nikola Tesla made important contributions to our profession. To IEEE-HKN, his work laid the foundation upon which we base our studies and our organization. In the Induction Ritual of IEEE-HKN we honor Tesla and his peers: " In honor of the great thinkers that built the foundation upon which the fields associated with IEEE-Eta Kappa Nu are based, our induction panel will speak as these pioneers might have spoken to you on the occasion of your initiation. While listing all of the great contributors to our fields would be impractical, we will today honor the following individuals: Charles Wheatstone, William Gilbert, John Bardeen, Grace Hopper, Michael Faraday, Charles Babbage, Nikola Tesla, James Clerk Maxwell, Edith Clarke, and Thomas Edison."

Tesla contributed greatly to the development of the alternating-current electric power industry. A classic paper, "A New System of Alternate Current Motors and Transformers" was presented at an AIEE meeting on May 16, 1888 and published in the AIEE Transactions volume 5, pp. 308-327, 1888 and reprinted in the Proceedings of the IEEE volume 72, pp. 165-173, 1984. Many of his patents were purchased by George Westinghouse. One such patent involved metering as illustrated in the figure at left.

IEEE-HKN Board of Governors Election Results

IEEE-Eta Kappa Nu held the society's annual elections this past October to fill open positions for the IEEE-HKN Board of Governors for 2015. The results were as follows:

- President-Elect: S.K. Ramesh
- Governor, Regions 5&6: Gordon Day
- Governor-at-Large, MGA Representative: Sampathkumar Veeraraghavan
- Student Representative: Kyle Lady, IEEE-HKN Beta Epsilon

These representatives will join the following as the IEEE-HKN 2015 Board of Governors:

- President: Evelyn Hirt
- Past President: John Orr
- Governor – West Central Region: David Jiles
- Governor – Regions 1&2: Kenneth Laker
- Governor – Regions 7-10: Mo El-Hawary
- Governor-at-Large: Timothy Kurzweg
- Governor-at-Large: Nita Patel

Seventy-nine chapters voted in the 2014 election, as compared to 23 in 2013. This turnout is an indication of the increasing active participation and engagement of IEEE-HKN chapters.

Want to know more about the new IEEE-HKN Board of Governors members? Read below.

S. K. Ramesh (President-Elect) serves the IEEE extensively, including the IEEE Educational Activities Board, the IEEE-HKN Board of Governors and the ABET Board of Directors. He was inducted into the Lambda Beta Chapter of IEEE-HKN at California State University, Northridge in 2008, and elected to represent IEEE Region 6 on the IEEE-HKN Board of Governors in 2012 where he has served as Treasurer and Trustee for the past three years. Since 2006, Ramesh has been Dean of the College of Engineering and Computer Science at California State University, Northridge.

Gordon Day (Governor, Regions 5&6), served as the 50th President of IEEE in 2012 and led the organization through a period of substantial global expansion. He was previously President of the IEEE Photonics Society and IEEE-USA. He was inducted into the Alpha Chapter of IEEE-HKN in 1964 and joined IEEE in 1966. Day spent most of his career in research and management at the National Institute of Standards and Technology, where he founded and led the NIST Optoelectronics Division. More recently, he has focused primarily on technology policy, serving as science advisor to U.S. Senator Jay Rockefeller and Director of Government Relations for the Optoelectronics Industry Development Association.

Sampathkumar Veeraraghavan (Governor-at-Large, MGA Representative) is the founder and director of the technology-based humanitarian program “The Brahmam” (meaning knowledge) that addresses pressing global/local humanitarian challenges in developing nations. Veeraraghavan’s exemplary scholarly contributions and leadership accredited him with numerous global honors including the IEEE-HKN “Outstanding Young Professional Award,” IEEE MGA achievement award, IEEE RAB GOLD achievement award, IEEE/IEEE-USA New Faces of Engineering honor, and Tufts University’s distinguished alumnus award.

Ron Jensen (Treasurer) recently retired as Chief Engineering Manager at IBM, managing a team of people across three countries covering IBM server hardware and software. During his career at IBM, he held positions in semiconductor process, chip development, and semiconductor applications, followed by system design, systems architecture and project management. He led in the development of IBM families of computers and servers. He was inducted into the Nu chapter of IEEE- HKN at Iowa State University in 1972. He received the BSEE from Iowa State University and MSEE from Syracuse University and completed Ph. D courses from the University of Minnesota. In addition to his activities with IEEE-HKN, Jensen is a member of the IEEE Computer Society, Technology Management Council, and WIE. He is a member of PMI, and a certified PMP. His professional interests are in systems architecture, embedded systems, technical education, technical management, strategic planning and the use of the web, collaboration tools and social networking to build a professional environment. He is presently consulting with and coaching organizations.

Kyle Lady (Student Representative) joined IEEE-HKN in 2009 and has been active at the local chapter level ever since, having served in a variety of positions including President and Vice President. He currently serves as the graduate student advisor to the Beta Epsilon chapter. Currently enrolled in the Ph.D. program in Computer Science at the University of Michigan, his research area is networks and distributed systems, with a focus on Internet-scale measurement and distributed system performance. Lady served as the inaugural student member of the IEEE-HKN Board of Governors in 2014 and was re-elected for 2015.

FOUNDERS DAY 2014

Happy 110th Eta Kappa Nu

On the 28th of October 2014, Eta Kappa Nu (HKN) celebrated its 110th birthday. In 1904, on the campus of the University of Illinois, a group of 10 students saw the need for an honor society; one that by invitation would recognize scholarship, attitude and character. The vision of these inspired young men was to promote the highest ideals of the engineering profession and form an organization where professionals and students help each other.

Beta Alpha Chapter, Drexel University FD 2014

This year, 53 Chapters ordered a "Founders Day" kit and told us about their "FOUNDERS DAY" plans. These on-campus events included pizza parties, information booths, Ice Cream Social, BBQ, Bowling event, Ultimate Frisbee competition, Laser Tag, Breakfast, HKN Conference, Networking, Resume peer critique, and an Electrical & Computer Engineer Olympics Competition. All chapters reported that hosting these activities did raise awareness of the chapter on campus, helped increase the number of students accepting the invitation to join, and that the event was fun and a great thing to do.

University of Maryland Networking Event

Mark your calendar now! Founders Day falls each year on the 28th of October. Celebrate your chapter, your honor society, your members, and alumni. Chapters who host events and file the report by the deadline receive a $100 prize! It is your FOUNDERS DAY – celebrate it!

University of Florida Raising Awareness

Kappa Theta Chapter UW Platteville

Share Your IEEE-Eta Kappa Nu Pride

Official Society Merchandise Now Available

Medal $20	Honor Stole $20
Three Pin Types:	Honor Cord $30
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Emblem $12	Key Pendant $14
Key $12	Scarf $22
Signature Book . . . $35	Necktie $25

Save $10 by purchasing the "honor combo" of one honor cord and one honor stole for $40

Save $21 by purchasing 10 of the same style pin for $99

All items available at the IEEE-HKN store at:
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HKN

IEEE
Advancing Technology for Humanity

2014 IEEE PES Engineering Colloquium: Interconnection of Renewable Energy to the Power Grid

By
Vincent J. Forte, Jr. PE
IEEE PES
Schenectady
Chapter Chair

INTRODUCTION

In September 2014, the "2014 IEEE PES Engineering Colloquium", was sponsored by the Institute of Electrical and Electronics Engineers (IEEE) Power and Energy Society (PES) Schenectady Chapter to discuss the interconnection of load and distributed generation (DG) customers (sometimes referred to as distributed resources or DR, e.g. renewable energy sources) to the power grid and the associated challenges encountered today by electric power engineers. Electric power engineers from a variety of industry perspectives, including utility, independent system operator (ISO), engineering design firms representing customers, and industry institutions such as the IEEE and Electric Power Research Institute (EPRI) presented to attendees (See Figure 1 and 2). Attending engineers from around the Northeast also represented these three constituencies as well as manufacturers of power equipment and control systems. Also in attendance were university engineering students.

Fig. 1 Speakers pictured left to right are: Stephen Dean, National Grid; Christopher Vance, National Grid; Philip Barker, Nova Energy Specialists; James Barrett, NYISO; Vincent Forte, IEEE PES Schenectady Chapter Chair; John Golde, Golde Engineering. Thomas Short of EPRI is not shown.

The 2014 colloquium presentations discussed utility and ISO processes and requirements that have been developed to help create a coordinated and speedy interconnections process at all system levels (secondary service, primary distribution service, sub-transmission and transmission service) which includes meeting applicable codes, regulatory rules, and best practices while maximizing safety for employees and the public. It was obvious that engineers regardless of their individual industry perspective are focused on safely maintaining or improving reliability performance and further improving economies of the grid and of customer projects. The colloquium presentations and speakers are shown Table 1. This article will provide an overview of what was discussed in this one-day conference and how it relates to current industry trends.

Speaker and Affiliation	Title
Stephen Dean National Grid	Interconnection Process and Requirements: Local Customers
Christopher Vance National Grid	Interconnection Process and Requirements: DG Customers
James Barrett NYISO	Interconnection Process and Requirements
Philip Barker Nova Energy Specialists	DG system grounding and over-voltages
John Golde Golde Engineering	Substation Ground Grid Analysis and Design
Thomas Short EPRI	Open-Source Tools for Power Systems Monitoring
Vincent Forte PES Chapter Chair	Engineering Ethics

Table 1 Colloquium Agenda

CURRENT TRENDS

In New York State and the Northeast portion of the United States interconnection of DG has been an increasing trend for many years. Over the years utilities have adjusted their company processes and safety practices to accept these projects onto the grid. Regulators such as the Public Service Commission (PSC) and Federal Regulatory Energy Commission (FERC) have adjusted rulings to encourage more DG while maintaining system reliability. Due to advances in high speed / high data volume communications and increasing DG penetration, additional distributed resources (such as micro-grids) and technical tools (such as Smart Grid automation) have become more robust and economic in certain situations and are continuing to improve.

Currently the New York State Public Service Commission (NYS PSC) has a new initiative called “Reforming the Energy Vision (REV)”. It is intended to reformulate New York State’s energy industry and regulatory practices in light of the above industry trends with the intended result of

- empowering customers through more choice in how they manage and consume electric energy,
- enhancing the availability of distributed resources to the grid (DG as well as micro-grids, Smart Grid automation, etc.),
- improving reliability, and
- encouraging enhanced system hardening for major storm events.

INTERCONNECTION PROCESS

Utility and ISO engineer presentations focused on the current interconnection process. Attendees gained new insights into the scope and depth of engineering analysis necessary to be completed in short time frames by the utility, ISO, and the customer’s design engineer, and how these are orchestrated to maximize overall business efficiency for everyone.

Smaller projects, such as a residential home with photovoltaics (PV) on the roof, are handled using minimal review and study by relying on the National Electric Code (NEC) and other codes as well as NYS PSC sanctioned guidelines to be enforced by the local authority having jurisdiction (AHJ). As projects grow in size they become more complex and thus increasing levels of review become necessary. The most complex projects are typically customer-owned substations served at the transmission level and that require customers to engage their own design engineer. Thus the process keeps the interconnection time and cost minimal for small customers and these gradually increase corresponding to increasing project size and complexity.

For larger projects, such as wind farms, system modeling studies are conducted by the utility and ISO to reduce exposure of the system and of the customer's facilities to damage, potential decrease in reliability or power quality, and to the minimization of restoration times or the risk of public and worker safety. These studies are simple for small projects and grow in complexity and number for larger projects. Some large transmission level projects can be grouped into common studies by the ISO to allow for parallel analysis instead of sequential by project.

DESIGN ISSUES

Typical design steps involve both the design team for the customer and utility engineering team. All engineers work together to detail a proposed DG project and to coordinate study, design, and construction schedules. Local authorities having jurisdiction (AHJ) inspect completed facilities to ensure compliance with applicable safety codes, such as the NEC and the National Electrical Safety Code (NESC). Utility engineers inspect to ensure the service equipment meets requirements of the utility for safety and reliability purposes and the customer's engineering firm inspects to ensure the facility meets their design and the customer's needs.

Utilities are also responsible to meet federal procedures such as FERC SGIP (a small generator interconnection procedure) and state Public Service Commission (PSC) tariffs and regulatory rules applicable to each individual utility. (For example, Niagara Mohawk Power Corp Electricity Tariff No. 220, Rule 53 addresses standard interconnection requirements and application process for new DG 2 MW or less connected to the utility. Other tariffs and rules address other customer sizes and types.)

In addition to government (NERC, FERC and PSC) rules (such as, NERC standard FAC-001-0 for facility connection requirements and Standard PRC-0020NPCC-01 for disturbance monitoring), utility tariffs (NY PSC 220 for example), and codes (NEC and NESC), there are utility company policies and procedures developed to address contractual requirements with unions for compliance with mutual safety agreements, meet best practices gained through decades of experience, etc. These company-specific issues are addressed in service bulletins to assist customers and their engineers in developing projects compatible with the power system and other customers served by it. They cover such things as general requirements for services above 600V, services above 15kV, distribution primary meter pole installations, outdoor pad mounted or vault enclosed three phase transformers, operation and maintenance requirements, and parallel generation requirements not covered elsewhere). There are also industry guides, standards, and codes for DG interconnections (such as IEEE 929 "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems", IEEE 1094 "IEEE Recommended Practice for the Electrical Design and Operation of Wind farm Generating Stations", IEEE 1547 "Standard for Distributed Resources Interconnected with Electric Power Systems", UL 1741 "Inverters, Converters and Charge Controllers for Use in Independent Power Systems".

DESIGN DETAILS

Overvoltage issues are key design concerns and they affect both DG facilities and the larger power grid. Overvoltage can occur due to a variety of causes, such as lightning, capacitor switching, load switching, out of phase reclosing, voltage regulation equipment problems, temporary overvoltages (TOV) due to ground fault/neutral shift, load rejection, and ferroresonance. Load rejection (sudden loss of load) and ground fault overvoltages are major concerns with DG integration studies. Load characteristics and minimum load-to-generation ratio are key factors for increased risk of TOV.

TOV generally occurs when loads are low, typically nights and evenings or weekends and off shoulder times of the year during a brief interim condition after a distribution feeder breaker opens but before the DG anti-islanding protection takes generation off line. If identified through a study mitigation measures exist, such as direct transfer trip (DTT) to resolve the risk of damage.

The IEEE 80 guide for Substation Grounding Calculations was reviewed in detail during one colloquium presentation. This guide explains the calculation for assuring that people near a grounded facility are not exposed to dangerous electric shock. A proper grounding system design provides a "means to carry currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service." Fault currents and their duration, soil resistivity, alternative ground current paths, and contact resistance are all things that can contribute to electric shock accidents and must be considered by engineers. Typical grounding calculation procedures include determination of safe step and touch potentials, substation ground grid resistance, available fault current, results evaluation and if necessary design modifications to improve safety performance.

ETHICS

The colloquium ethics presentation and discussion reviewed the IEEE code of ethics and related aspects of New York State Professional Engineering licensing law. Actual scenarios and imagined scenarios were described to improve readiness to address ethical issues that may be encountered on the job.

NEW TOOLS

Scripting languages such as Python, Matlab, R, Julia, and Octave were discussed during the colloquium. These can be helpful when combined with some open-source power system tools such as OpenDSS, EPRI-OpenETran, Modelica/Open Modelica. Open source software reduces costs and is available to all engineers, thus reducing some barriers to entry for engineers wishing to enter the business as independents.

For example, OpenDSS is a distribution system simulator originally designed for unbalanced, multiphase distribution systems commonly found in North America. It has been used for a number of analyses such as:

- Hybrid simulation of communications and power networks
- Geomagnetically-Induced Current (GIC) flow (solar storms)
- Power delivery loss evaluations
- Voltage optimization
- High-frequency harmonic/interharmonic interference
- Various unusual transformer configurations
- Transformer frequency response analysis
- Distribution automation control algorithm assessment
- Wind farm collector simulations and interaction with transmission
- Wind generation impact on capacitor switching and regulator/LTC tap changer operations
- Protection system simulation
- Open-conductor fault conditions
- Circulating currents on transmission sky wires

- Ground voltage rise during faults on lines
- Stray voltage simulations
- harmonics studies/filter design

It can be used for:

- Interconnection studies/screening
- Value of service studies (risk based)
- Solar PV voltage rise/fluctuation
- Wind power variations impact
- Hi-penetration solar PV impacts
- Harmonic distortion
- Dynamics/islanding

It is not appropriate to use for ferroresonance on a distribution circuit with a generator and a capacitor bank because modeling of the electric and magnetic circuits is not combined.

SUMMARY

New technical tools such as open source software and advances in communications have shifted the price points for DG interconnection studies and solution sets including for micro-grids and Smart Grid automation. This has helped to sparked increased customer interests in DG as study costs drop and review time frames shorten.

Customer desires for choice are increasing. The industry has responded by adjusting work practices, standards, and processes to facilitate greater DG penetration on the power system. Engineers meet regularly at local and other venues to discuss and collaborate new ways to continuously improve safe, reliable, and economical interconnection of distributed resources. This paper briefly discussed issues covered at one recent local industry conference. Future colloquiums may focus on Smart Grid, regulatory changes, or other areas to create the power system of tomorrow.

About the Author:

Vincent J. Forte, P.E. – Vince Forte is a registered professional engineer with 35 years of experience in engineering management, transmission planning, long range distribution planning as well as special studies. Mr. Forte earned both his Bachelor and Master of Engineering degrees from Rensselaer Polytechnic Institute (RPI) before embarking on a 34-year career in the utility industry. All but two of those 34 years were spent with Niagara Mohawk and National Grid. Mr. Forte has spent the past 7 years leading several aspects of the National Grid effort in the investigation and implementation of Smart Grid technology. Vince is a Senior Member of IEEE and is presently the Chair of the Schenectady Section Power & Energy Society. Mr. Forte has won multiple awards, including the 2013 IEEE Power & Energy Society Prize Paper Award, and has multiple publications and presentations. Since retiring from National Grid, Mr. Forte continues to be active in the industry as an Engineering and Management Consultant. He was inducted into Eta Kappa Nu by the Beta Nu Chapter of RPI.

IEEE POWER & ENERGY SOCIETY

IEEE offers more than 35 Societies that focus on technical information in specialized technology fields. Each issue of THE BRIDGE will feature an IEEE Society and include information on activities and information that can benefit IEEE-HKN members.

The IEEE Power & Energy Society (PES) has experienced unprecedented growth of membership, business activities, and member services over the last few years. The membership has almost doubled to over 32,000 members, and the Society maintains the position as the third-largest IEEE Society. PES members see the value of their PES membership and recognize that it is an exceptional, cost effective way to acquire the latest information about all aspects of the electric power and energy industry. PES helps members become successful through:

- Technical Committees
- Standards Development
- Local Chapters
- Meetings and Conferences
- Educational Opportunities – Webinars, Plain Talk Courses, PES Distinguished Lecturer Program
- Publications – Power & Energy, Electrification, PES Transactions and Open Access
- Resource Center - The Resource Center has over 1,700 papers, presentations free for PES Members.

Ian Jacobsen, Stony Brook University (Graduating - May 2016)

Since 2011, 733 scholarships have been distributed to 466 undergraduate students within the USA and Canada as part of the IEEE Power & Energy Society (PES) Scholarship Plus Initiative. PES is very proud to have been able to recognize the achievements of 57 HKN undergraduate members as IEEE PES Scholarship Plus Initiative recipients. This program was created in response to the looming workforce shortfall in the power and energy industry within the USA & Canada. The goal of the program is to increase the number of well-qualified, entry-level engineers by helping students with their education and career goals and getting more undergraduate students involved in the power and energy industry.

Applications are being accepted for the 2015–2016 academic year for the IEEE Power & Energy Society Scholarship Plus Initiative. Under this program, recipients can graduate with recognition as an IEEE PES Scholar, receive up to US$7,000 in multiyear scholarships, and gain career experience. The application period is 1 March to 30 June 2015.

2014 IEEE PES Scholars who are HKN Members:

- William Duren - Kansas State University
- Jordan Ehren - University of Florida
- Theodore Graves - Stony Brook University
- Matthew Hildreth - Clarkson University
- Ian Jacobsen - Stony Brook University
- Andrew Jennings - South Dakota School of Mines and Technology
- Zachary Langbartels - Rose-Hulman Institute of Technology
- Patrick McAuliff - Georgia Institute of Technology
- Adam Sumner - Illinois Institute of Technology
- Andri Teneqexhi - University of Illinois at Urbana-Champaign

Smart Grid—Safe, Secure, Self-Healing

Challenges and Opportunities in Power System Security, Resiliency, and Privacy

By S. Massoud Amin and Anthony M. Giacomoni

The existing power delivery system is vulnerable to both natural disasters and intentional attack. 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 electric system is fundamental to national and international economic systems, security, and quality of life.

This is not new: both the importance and the difficulty of protecting power systems have long been recognized. In 1990, the U.S. Office of Technology Assessment (OTA) issued a detailed report, Physical Vulnerability of the Electric System to Natural Disasters and Sabotage. The report concluded: "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 costs of widespread outages, estimating them to be in the range of US$1 to US$5 per kWh of disrupted service, depending on the length of the outage, the types of customers affected, and a variety of other factors. In the New York City blackout of 1977, for example, damage from looting and arson alone totaled about US$155 million -- roughly half of its total cost.

During the 20 years since the OTA report, the situation has become even more complex. Accounting for all critical assets includes thousands of transformers, line reactors, series capacitors, and transmission lines. Protecting all these diverse and widely dispersed assets is impractical. Moreover, cyber, communication, and control layers add new benefits only if they are designed correctly and securely.

Electricity Infrastructure: Increasing Interdependencies

Energy, telecommunications, transportation, and financial infrastructures are becoming increasingly interconnected, thus posing new challenges for their secure, reliable, and efficient operation. All of these infrastructures are complex networks—geographically dispersed, nonlinear, and interacting both among themselves and with their human owners, operators, and users (see Figure 1).

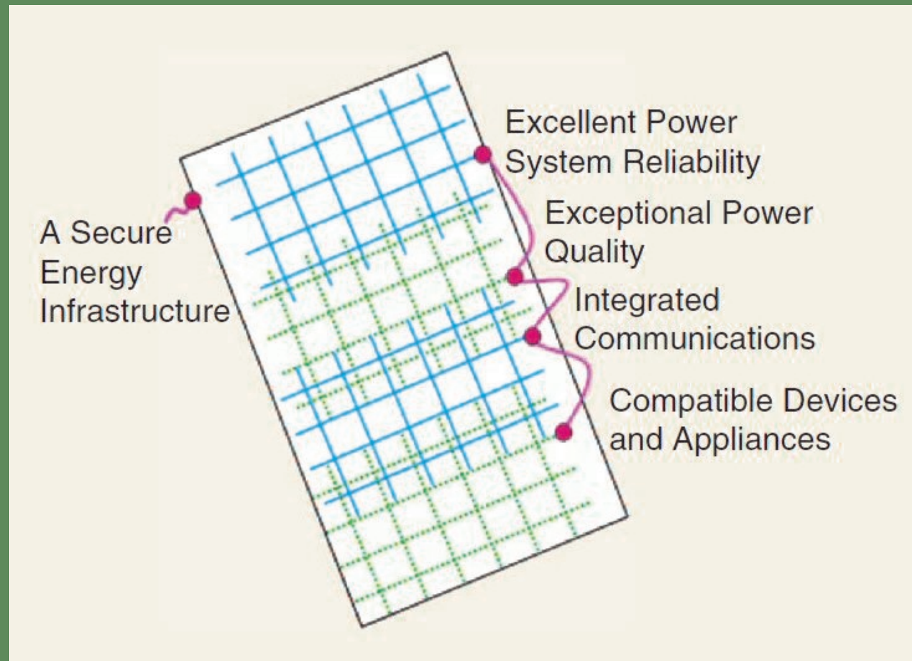

Figure 1. A complex set of interconnected webs (source: EPRI, 2002–present).

Virtually every crucial economic and social function depends on the secure and reliable operation of these infrastructures. Indeed, they have provided much of the high standard of living that the more developed countries enjoy. With increased benefit, however, has come increased risk. As these infrastructures have grown more complex in order to handle increasing demands, they have become increasingly interdependent. The Internet, computer networks, and our digital economy have all increased the demand for reliable and disturbance-free electricity; banking and finance depend on the robustness of electric power, cable, and wireless telecommunications infrastructure. Transportation systems, including military and commercial aircraft and land and sea vessels, depend on communication and energy networks. Links between the power grid and telecommunications systems as well as between electrical power lines and oil, water, and gas pipelines continue to be the lynchpins of energy supply networks. This strong interdependence means that an action in one part of an infrastructure network can rapidly create global effects by cascading throughout the same network and even into other networks.

In the aftermath of the tragic events of 11 September 2001 and recent natural disasters and major power outages, there have been increased national and international concerns expressed about the security, resilience, and robustness of critical infrastructures in response to an evolving spectrum of threats. There is reasonable concern that national and international energy and information infrastructures have reached a level of complexity and interconnection that makes them particularly vulnerable to cascading outages, whether initiated by material failure, natural calamities, intentional attack, or human error. The potential ramifications of network failures have never been greater, as the transportation, telecommunications, oil and gas, banking and finance, and other infrastructures depend on the continental power grid to energize and control their operations. Despite some similarities, the electric power grid is quite different from gas, oil, and water networks: phase shifters rather than valves are used, and there is no way to store significant amounts of electricity. Providing the desired flow on one line often results in “loop flows” on several other lines.

Potential Route Ahead: A Smarter Grid

The key challenge is to enable secure and very high-confidence sensing, communications, and control of a heterogeneous, widely dispersed, yet globally interconnected system. It is even more complex and difficult to control it for optimal efficiency and maximum benefit to the ultimate consumers while still allowing all its business components to compete fairly and freely.

To achieve this goal, a new “mega infrastructure” is emerging from the convergence of energy, telecommunications, transportation, the Internet, and electronic commerce. In the electric power industry and other critical infrastructures, new ways are being sought to improve network efficiency by eliminating congestion problems without seriously diminishing reliability and security. Nevertheless, the goal of transforming the current infrastructures into self-healing energy delivery, computer, and communications networks with unprecedented robustness, reliability, efficiency, and quality for customers and our society is ambitious.

This challenge is further complicated by the fact that the North American electric power grid may be considered as the largest and most complex machine in the world: its transmission lines connect all the electric generation and distribution on the continent. This network represents an enormous investment, including more than 15,000 generators in 10,000 power plants and hundreds of thousands of miles of transmission and distribution lines. With diminished transmission and generation capacity and with dramatic increases in interregional bulk power transfers and the diversity of transactions, the electric power grid is being used in ways for which it was not originally designed. Grid congestion and atypical power flows have been increasing during the last 25 years, while customer expectations of reliability and cyber and physical security are rising to meet the needs of a pervasively digital world.

Upgrading the control and communication systems for the power grid will present many new security challenges that must be dealt with before extensive deployment and implementation of smart grid technologies can begin. The digitization of such systems may enable remote attacks to grow rapidly, potentially spanning countries or even continents. Moreover, the number of threats against computer systems is rapidly increasing due to the increased availability of highly sophisticated hacker tools on the Internet and the decrease in technical knowledge required to use them to cause damage. While the digitization of such systems will present many new security challenges, it will also provide the grid with increased flexibility to prevent and withstand potential threats.

Key Smart Grid Security Challenges

Physical Challenges

The size and complexity of the North American electric power grid makes it impossible both financially and logistically to physically protect the entire infrastructure. There currently exist more than 450,000 mi of 100-kV or higher transmission lines and many more thousands of miles of lower-voltage lines. As an increasing amount of electricity is generated from distributed renewable sources, the problem will only be exacerbated; the U.S. Department of Energy (DOE) has concluded that generating 20% of all electricity with land-based wind installations will require at least 20,000 square miles. Thus it is probable that a well-organized, determined group of terrorists could take out portions of the grid as they have previously done in the United States, Colombia, and other locations around the globe. Several such incidents in the United States have been publicly reported during the last 30 years, including saboteurs operating in the Pacific Northwest and those using power lines and transformers for target practice on the East Coast. Colombia, for example, has faced up to 200 terrorist attacks per year on its transmission infrastructure over the last 11 years, as reported in a recent IEEE Power & Energy Magazine article by Corredor and Ruiz. Such attacks, although troublesome and costly to the local region, affect only a small portion of the overall grid, however. To cause physical damage equivalent to that from a small to moderate-size tornado would be extremely difficult, even for a large, well-organized group of terrorists.

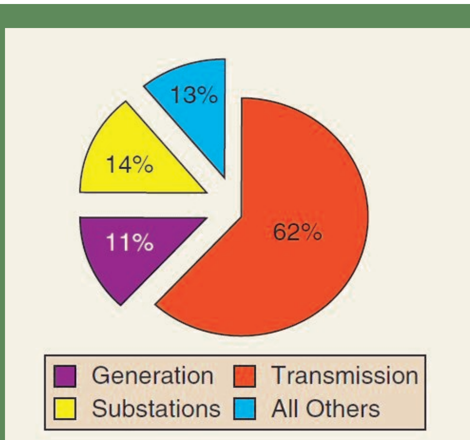

Figure 2. Electric terrorism: grid component targets, 1994–2004 (source: Journal of Energy Security).

Data on terrorist attacks on the world's electricity sector from 1994–2004 from the Oklahoma-based Memorial Institute for the Prevention of Terrorism show that transmission systems are by far the most common target in terms of the total number of physical attacks. Figure 2 shows the percentage of terrorist attacks aimed at each of the major grid components.

One possible means of increasing the physical security of power lines is to bury them. A 2006 study by the Edison Electric Institute (EEI) calculated that putting power lines underground would cost about US$1 million per mile, compared with US$100,000 per mile for overhead lines, making the idea financially infeasible.

Cyber Challenges

The number of documented cyber-attacks and intrusions worldwide has been rising very rapidly in recent years. The results of a 2007 McAfee survey highlight the pervasiveness of such attacks. For example, Figure 3 shows the percentage of IT and security executives from critical infrastructure enterprises located in 14 countries around the world

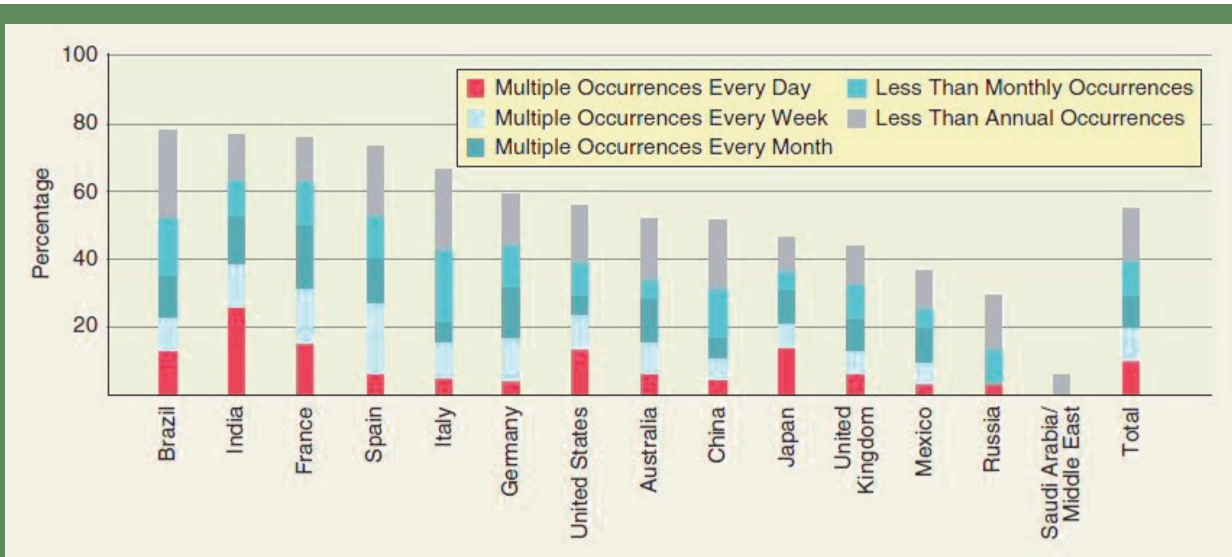

Figure 3. Percentage of critical infrastructure enterprise executives reporting large-scale DDoS attacks and their frequency (source: McAfee).

reporting large-scale distributed denial-of-service (DDoS) attacks and their frequency.

DDoS attacks utilize networks of infected computers -- whose owners often do not even know that they have been infected -- to overwhelm target networks with millions of fake requests for information over the Internet.

Due to the increasingly sophisticated nature and speed of malicious code, intrusions, and DoS attacks, human responses may be inadequate. Figure 4 shows the evolution of cyber threats over the last two decades and the types of responses that can be used to combat them effectively.

In addition, adversaries often have the potential to initiate attacks from nearly any location in the world. A July 2010

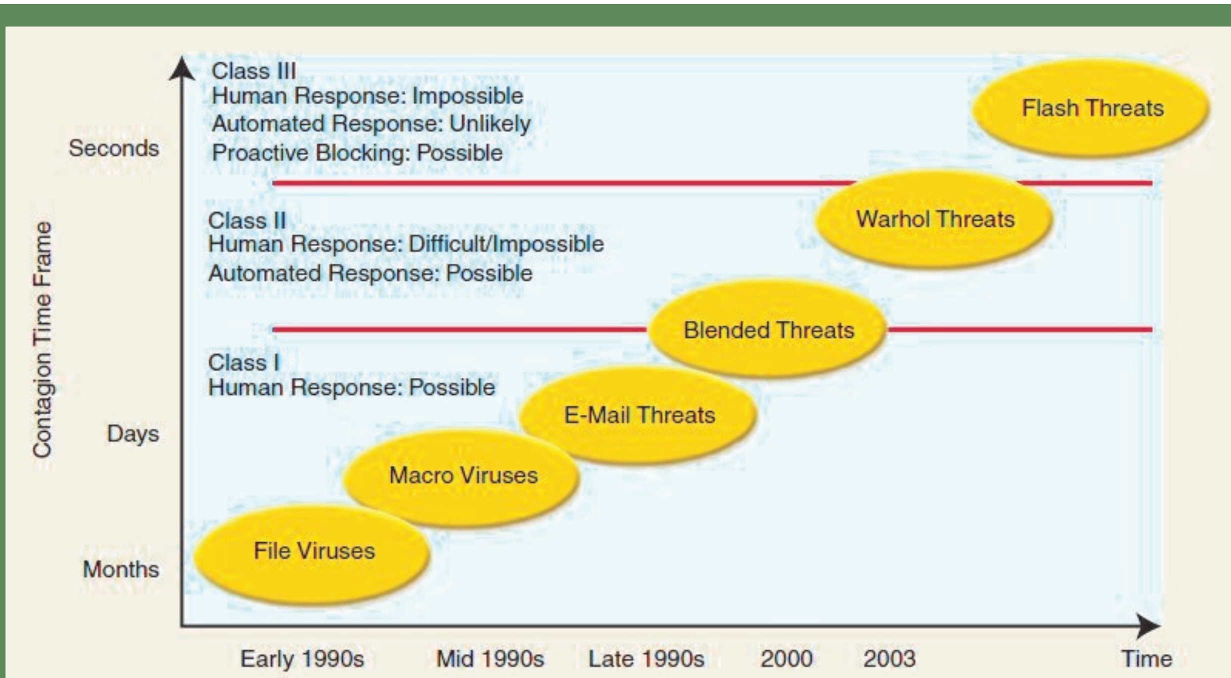

Figure 4. Cyberthreat evolution (source: EPRI).

article in The Economist quoted one senior American military source as saying, “If any country were found to be planting logic bombs on the grid, it would provoke the equivalent of the Cuban missile crisis.” Furthermore, currently more than 90% of successful cyber-attacks take advantage of known vulnerabilities and misconfigured operating systems, servers, and network devices.

The 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 the existing control systems, which were originally designed for use with proprietary, stand-alone 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. Moreover, numerous types of communication media and protocols are used in the communication and control of power systems. Within a substation control network, it is common to find commercial telephone lines as well as wireless, microwave, optical fiber, and Internet connections. The diversity and lack of interoperability among the various communication protocols cause problems for anyone who tries to establish secure communication to and from a substation.

Electric power utilities also typically own and operate at least certain portions of their own telecommunications systems, which often consist of a backbone of fiber optic or microwave links 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.

More specifically, 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. While the direct physical destruction of generators, substations, or power lines may be the most obvious strategy for causing blackouts, activities that compromise the operation of sensors, communications, and control systems by spoofing, jamming, or sending improper commands could also disrupt the system, cause blackouts, and in some cases result in physical damage to key system components.

Any telecommunication link that is even partially outside the control of the organization that owns and operates power plants, supervisory control and data acquisition (SCADA) systems, or energy management systems (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 12–14 years (starting with the preparations for Y2K and continuing after the tragic events of 9/11) have identified these links and the system’s vulnerability to their failure. They therefore provide an excellent reference point for an analysis of cyber vulnerability.

While some of the operations on the system are automatic, human operators in system control centers ultimately make the decisions and take the actions that control the operations of the system. In addition to the physical threats to such centers and the communication links that flow in and out of them, one must be concerned about two other factors: the reliability of the operators within the centers and the possibility that insecure code has been added to a program in a center computer.

The threats posed by “insiders” are real, as is the risk of a “Trojan horse” embedded in the software of one of more of the control centers. A 2008 survey by the Computer Security Institute and the U.S. Federal Bureau of Investigation of data compiled from 522 computer security practitioners and senior executives of U.S. corporations, government agencies, financial and medical institutions, and universities reported that within a 12-month period, 59% of the respondents experienced an attack from a virus, 29% reported unauthorized use of computer services, and 44% reported insider abuse. The threat of a “Trojan horse” embedded in the control center software can only be addressed by means of careful security measures within the commercial firms that develop and supply this software along with careful security screening of the utility and outside service personnel who perform software maintenance within the centers. Today, security patches often are not supplied to end users, or users are not applying the patches, as they fear they will affect system performance. Current practice is to apply an upgrade or patch only after SCADA vendors thoroughly test and validate it, and this sometimes causes deployment to be delayed by several months.

As a result, cybersecurity is just as important as physical security, if not more so. Due to the gravity of these threats, the Federal Energy Regulatory Commission (FERC) policy statement on the smart grid states that cybersecurity is essential to the operation of the smart grid and that the development of cybersecurity standards is a key priority. The

DOE has also stated that the ability to resist attack by identifying and responding to disruptions caused by sabotage is one of the smart grid's seven crucial functions. Much work remains to be done, however, to create standards that, when implemented, will adequately protect the grid from cyber-attacks. Emerging standards fall well short of achieving this ultimate goal.

Smart Grid Security Needs

Layered Security

In order to protect electric infrastructure from the threats outlined above, several layers of security are needed to minimize disruptions to system operations. Layered security (or "defense in depth") involves strategically combining multiple security technologies at each layer of a computing system in order to reduce the risk of unauthorized access due to the failure of any single security technology. It exponentially increases the cost and difficulty of compromising a system by creating a much stronger defense than the use of any individual component alone, thus reducing the likelihood of an attack.

The trend of connecting electrical control systems to the Internet exposes all layers of a system to possible attack. Computing layers that must be considered include:

- ✔ Personnel
- ✔ Networks
- ✔ Operating Systems
- ✔ Applications
- ✔ Databases.

The security features to be employed at each layer include examination, detection, prevention, and encryption. To protect control systems, well-established information security practices must also be used.

Deception

An additional defense mechanism is the use of deception. Deception consists of two possible techniques: dissimulation (hiding the real) and simulation (showing the false). McQueen and Boyer describe several potential dissimulation and simulation techniques that can be used for control systems. Three of the dissimulation techniques described are:

- ✔ masking the real by making a relevant object undetectable or blending it into background irrelevance
- ✔ repackaging, which hides the real by making a relevant object appear to be something it isn't
- ✔ dazzling, which hides the real by making the identification of a relevant object less certain by confusing the adversary about its true nature.

Likewise, three of the simulation techniques described are:

- ✔ inventing the false by creating a perception that a relevant object exists when it doesn't
- ✔ mimicking, which invents the false by presenting characteristics of an actual and relevant object
- ✔ decoying, which displays the false so as to attract attention away from a more relevant object.

Deception will need to play a key role in smart grid defense mechanisms. Since existing control system architectures are not random and therefore response characteristics are reproducible, the strength of potential adversaries is amplified. Defense mechanisms using deception can greatly increase the difficulty of planning and conducting successful attacks on a system by portraying control system response characteristics as random to attackers. They can also alert operators to possible threats before any systems are harmed.

Additional security needs include rapid containment, restoration, and recovery strategies for times when systems are inevitably compromised. Either software patching or the ability to rapidly identify and isolate the exploited systems must be enabled in order to minimize downtime. This is extremely important, since the consequences of an attack are directly proportional to the length of time the service is disrupted.

Advanced Metering Infrastructure

Vulnerabilities

The implementation of advanced metering infrastructure (AMI) is widely seen as one of the first steps in the digitization of the electric grid's control systems. Despite the increase in the utilization of AMI, there has been very little assessment or R&D effort to identify the security needs for such systems. Smart meters, however, are extremely attractive targets for exploitation, since vulnerabilities can be easily monetized through manipulated energy costs and measurement readings. Currently, in the United States alone it is estimated that US$6 billion is lost by electricity providers to consumer fraud in the electric grid. Possible threats to the electrical grid introduced by the use of AMI include:

- fabricating generated energy meter readings
- manipulating energy costs
- disrupting the load balance of local systems by suddenly increasing or decreasing the demand for power
- gaining control of millions of meters and simultaneously shutting them down
- sending false control signals
- disabling grid control center computer systems and monitors
- disabling protective relays.

As more utilities move toward using Internet Protocol (IP)–based systems for wide area communications and as the trend of using standardized protocols continues throughout the industry, maintaining the security of such devices will be critical. AMI introduces serious privacy concerns, as immense amounts of energy use information will be stored at the meter. Breaches into this data could expose customer habits and behaviors. Such arguments have led to the recent moratoriums on AMI installations in numerous northern California communities and other areas throughout the country. As a result, several key privacy concerns need to be addressed, including those outlined by the Cyber Security Working Group of the U.S. National Institute of Standards and Technology (NIST). These include:

- Personal profiling: using personal energy data to determine consumer energy behavioral patterns for commercial purposes
- Real-time remote surveillance: using live energy data to determine whether people are in a specific facility or residence and what they are doing
- Identity theft and home invasions: protecting personal energy data from criminals who could use the information to harm consumers
- Activity censorship: preventing the use of energy for certain activities or taxing those activities at a higher rate
- Decisions based on inaccurate data: shutting off power to life-sustaining electrical devices or providing inaccurate information to government and credit reporting agencies.

In addition, AMI systems will need to be defended against more traditional cyberthreats such as mobile and malicious code, DoS attacks, misuse and malicious insider threats, accidental faults introduced by human error, and the problems associated with software and hardware aging.

Security Needs

In order to defend against the vulnerabilities described above, several security features need to be incorporated into the development of AMI, along with new privacy laws to protect consumers. Current privacy laws in the United States are fragmented and vague and do not specifically address consumer energy usage. Data stored at the meter and transmitted over communication networks must also meet standard cybersecurity requirements, including confidentiality, integrity, availability, and nonrepudiation.

One security feature alone, such as encryption, will not be able to cover all the possible security threats. Since it is imperative that the industry maintain 100% uptime, both the physical security of the AMI system hardware and multiple standard IT security features like encryption and authentication must be provided for. Furthermore, since it will be impossible to protect against all threats, smart meters must be able to detect even the most subtle unauthorized changes and precursors to tampering or intrusion. Additional consideration must also be given to the cost and impact the security features will have on AMI system operations. Smart meters will need to be cost-effective, since millions will need to be purchased and installed to replace antiquated analog devices. And they must also be robust as they will be deployed in very insecure locations.

Current Security Initiatives

Since the terrorist attacks of 11 September 2001, several steps have been taken and initiatives accomplished to enhance the security and reliability of the nation's current electricity infrastructure. These include the Complex Interactive Networks/Systems Initiative (CIN/SI), a joint program sponsored by the Electric Power Research Institute (EPRI) and the U.S. Department of Defense (DOD); EPRI's Enterprise Information Security (EIS) program; EPRI's post–9/11 Infrastructure Security Initiative (ISI); and various North American Electric Reliability Corporation (NERC) initiatives, such as its information sharing and analysis centers (ISACs), public key infrastructure (PKI), and spare equipment database. Information security frameworks for electric power utilities have also been developed by the International Council on Large Electric Systems (CIGRE). A security framework is considered as the skeleton on which various elements are integrated for the appropriate management of security risk. The various elements considered by CIGRE include security domains, baseline controls, and security processes.

Research and Development Needs

The Smart Infrastructure: A Smarter, More Secure I-35W Bridge

Within less than a year after the August 2007 collapse of the I-35W bridge in Minneapolis, Minnesota, a city of sorts on the south side of the former bridge took shape, complete with a host of heavy-duty equipment pieces, temporary on-site areas for casting and other tasks, and crews constantly at work. The days and months that followed required extraordinary efforts from many, including alumni of the University of Minnesota's infrastructure systems engineering program. They incorporated a sensor network into the new I-35W bridge (at less than 0.5% of total cost) that provides full situational awareness of stressors, fatigue, material, and chemical changes, so as to measure and understand the precursors to failure and to enable proactive and a priori corrective actions.

Analogously, customized and cost-effective advancements are both possible and essential to enable smarter and more secure electric power infrastructures. For example, advanced technology now under development or under consideration holds the promise of meeting the electricity needs of a robust digital economy. The end vision of the smart grid consists of a highly developed electrical platform that engages consumers, enhances efficiency, ensures reliability, and enables integration of renewable energy and electric transportation.

One key money- and power-saving element of the smart grid is its ability to measure how and when consumers use the most power. This information allows consumers to be charged variable rates for energy, based upon supply and demand. This variable rate will incentivize consumers to shift their heavy use of electricity to times of the day when demand is low.

The total cost of a stronger transmission system would be about US$82 billion over the next decade. Additionally, to create a smarter end-to-end power delivery system, we must invest between US$17 and US$24 billion over the next 20 years.

Investment in a smart grid would nearly pay for itself by reducing stupendous outage costs, a savings of US$49 billion per year, and improving energy efficiency, a savings of US$20.4 billion per year. Likewise, through smart grid-enhanced energy efficiency, by 2030 carbon dioxide emissions from the electric sector would be reduced by 58%.

Americans should not accept or learn to cope with increasing blackouts, nor should we rest on the notion that the technical know-how, political will, or money to bring our power grid up to 21st century standards do not exist. The truth is that, as a nation, we must and absolutely can meet the power needs of a pervasively digital society if the United States wishes to maintain its role as a global economic and political leader. The best of American innovation is yet to come, and the smart grid must be part of our future. 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.

From a strategic viewpoint, long-term developments and research issues relating to the defense of cyber and physical interdependent infrastructure networks must also be considered. The driving scientific motivation is to further our understanding of adaptive self-healing and self-organizing mechanisms that can be applied to the development of secure, resilient, and robust overlaid and integrated energy, power, sensing, communication, and control networks.

In addition to the above, further research and development needs include the following areas:

1) **Enabling technologies for an end-to-end secure system of sensing and measurement, leading to improved analysis and visualization and eventually to automation and self-healing systems:**
   - monitoring and analysis, automation and control, materials science, power electronics, and integrated distributed energy resources (DERs)
   - sensing, communication, data management, and mathematical and theoretical foundations to support a better, faster, and higher-confidence understanding of what is going on, leading to improved state and topology estimation and fast look-ahead simulation.

2) **Enabling a stronger and smarter grid by means of complex dynamical systems, systems science, controls, and applied mathematics:**
   - modeling, robust control, dynamic interaction in interdependent layered networks, disturbance propagation in networks, and forecasting and handling uncertainty and risk
   - overall systems science and dynamics (including infrastructure, ecology and environment, markets, and data-driven policy designs).

3) **Strategic R&D:**
   - digital control of the energy infrastructure
   - integrated energy, information, and communications for the end user
   - transformation of the meter into a secure, two-way energy and information portal
   - robust advanced power generation portfolio.

Awareness, education, and pragmatic tool development in this vital area continue to remain challenges. Educating stakeholders and colleagues about the cyber and physical interdependencies has often been difficult, as those who are distinguished members of the community and understand power systems well but are less aware of their cybervulnerabilities routinely minimize the importance of these novel and persistent threats.

Conclusion

Cyberconnectivity has increased the complexity of the control systems and facilities it is intended to safely and reliably control. In order to defend electric infrastructure against the impacts of cyber and physical attacks, significant challenges must therefore be overcome before extensive deployment and implementation of smart grid technologies can begin. Cybersecurity and interoperability are two of the key challenges of the smart grid transformation. As for security, it must be built in as part of its design, not glued on as afterthought.

Regarding recent cyberthreat reports, it is fundamental to separate the "hype" from the truth. What is most concerning about such reports is mainly one portion of an early article: "The response to the alert was mixed. An audit of 30 utility companies that received the alert showed that only seven were in full compliance, although all of the audited companies had taken some precautions." This is the reality that needs to be addressed.

Finally, no matter how many layers of security or how much sophistication is used in defense mechanisms, it is essential that the industry hire qualified people. Research findings suggest that human and organizational factors do affect computer and information security performance in a multilayered fashion. Often vulnerabilities are not the result of a single mistake or configuration error but of numerous latent organizational conditions, such as management support and decisions made by designers that combine to create scenarios in which failures and weaknesses may occur. In many complex networks, the human participants themselves are both the most susceptible to failure and the most adaptable in the management of recovery. Thus, staff members must be well trained to respond to a wide variety of emergencies since no amount of technology can replace well-trained personnel.

For Further Reading

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About the Authors

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Massoud Amin (S’80–M’90–SM’00) received the B.S. degree with honors and the M.S. degree in electrical and computer engineering from the University of Massachusetts-Amherst, and the M.S. degree and the D.Sc. degree in systems science and mathematics from Washington University in St. Louis, Missouri. He holds the Honeywell/H.W. Sweatt Chair in Technological Leadership, directs the Technological Leadership Institute (TLI), is a University Distinguished Teaching Professor, and a Professor of Electrical and Computer Engineering at the University of Minnesota, Minneapolis, MN. Dr. Amin serves as chairman of the IEEE Smart Grid, on the Board of MRO, and is the Chairman of Texas RE. He is a member of Eta Kappa Nu, Tau Beta Pi, and is a fellow of the ASME.

Anthony M. Giacomoni

Anthony Giacomoni (S’08-M’12) received the B.S. degree in electric power engineering and economics from Rensselaer Polytechnic Institute, Troy, NY in 2007, and the M.S. and Ph.D. degrees in electrical engineering from the University of Minnesota, Minneapolis, MN in 2009 and 2011 respectively. From 2011-2012 he was a Post-Doctoral Associate in the Electrical and Computer Engineering Department at the University of Minnesota. He is currently an Associate Market Analyst with ISO New England, Inc. in Holyoke, MA. He is a member of Eta Kappa Nu, Tau Beta Pi, and Omicron Delta Epsilon.

Welcome Back!

IEEE-HKN welcomed back several dormant chapters over the past few months.

Thank you to all of the volunteers, faculty and students who were instrumental in working with their respective Universities and Departments to rally support for these reinstatements. IEEE-HKN is stronger because of its dedicated network of chapters, Universities, faculty, students and alumni. We are proud to welcome back:

- University of Texas at Dallas, Kappa Kappa Chapter – Founded 17 November 1995; Reinstated 16 January 2015
- Wichita State University, Epsilon Xi Chapter – Founded 22 May 1966; Reinstated 28 October 2014
- Lehigh University, Chi Chapter – Founded 22 May 1925; Reinstated 5 December 2014
- Florida International University, Kappa Delta Chapter – Founded 3 April 1992; Reinstated 13 December 2014

Kappa Kappa Chapter Reinstatement, University of Texas, Dallas - 16 January 2015

Epsilon Xi Chapter Reinstatement, Wichita State University - 28 October 2014

Chi Chapter Reinstatement, Lehigh University - 5 December 2014

Mu Alpha Induction

On 10 January 2015, IEEE-HKN installed its 236th chapter at UCSI University in Kuala Lumpur, Malaysia. Dr. Catherine Slater, member of the IEEE-HKN Board of Governors, installed the Mu Alpha chapter with its twelve charter members and two Faculty Advisors. The inducted students all attend UCSI's Faculty of Engineering, Technology and Built Environment (FETBE).

Mu Alpha is the first IEEE-HKN chapter in Malaysia, and the third IEEE – HKN chapter in the Asia Pacific region, after Hong Kong University and the National University of Singapore.

Dr. Catherine Slater, a member of the IEEE-HKN Board of Governors, represented the IEEE at the induction ceremony. She was accompanied by five Harvard Business School MBA students who met the UCSI student community during and after the induction ceremony.

The charter members of the Mu Alpha Chapter at their induction on 10 January 2015.

"Today, we will recognize a select group of students for their contributions and achievements by inducting them into IEEE-HKN," Dr. Slater said. "But even more important is the fact that we are establishing a new chapter that will continue to honor and recognize many more students from UCSI in the years to come."

Also present at the ceremony was Associate Professor Dr. Jimmy Mok Vee Hoong, Dean of FETBE, who highlighted that the chapter would benefit not just UCSI's engineering department but also its students.

"I believe this new chapter will foster closer faculty-student interactions and relationships, and provide myriad opportunities for students to work together with their peers on various projects and assignments," he said.

"As such, I would like to thank IEEE-HKN for their support over the past few months and making this day a reality."

UCSI Group founder and chairman Dato' Peter Ng, who also attended the ceremony, added that the chapter has so much to offer. "With this chapter, our students will be trained to think globally and have the opportunity to tap into the resources of over 200 chapters around the globe, especially in the areas of knowledge and leadership," said Dato' Peter Ng. "We are really honored and proud that this installation was held here."

To see photos and videos from the Mu Alpha Induction, please visit Mu Alpha's Facebook page and You Tube videos:

- http://youtu.be/MhS839Hb00g

Installation and Induction Ceremony

- http://youtu.be/enx_NFoHKBA

Short interview with Dr. Catherine Slater

- http://youtu.be/l8L9WubvIow

Preparation for Mu Alpha Installation Ceremony

- http://youtu.be/nxdXEG4bT9k

Facebook page: www.facebook.com/ieeehknmualpha

The newly inducted Mu Alpha class celebrates!

B. Jayant Baliga

Beta Nu Chapter

Professor B. Jayant Baliga joined the faculty of North Carolina State University in 1988 and he currently holds the highest faculty rank of Distinguished University Professor. In 1991, he established an international consortium at NCSU, called the Power Semiconductor Research Center (PSRC), for performing research in the area of power semiconductor devices and has served as its Founding Director. Prof. Baliga has founded four successful companies: Giant Semiconductor Corporation that commercialized the GD-MOSFET for power supplies; Micro-Ohm Corporation that commercialized the TMBS power rectifier for power supplies, battery chargers, and automotive electronics; Silicon Wireless Corporation that commercialized the super-linear silicon RF transistor for application in cellular base-stations; and Silicon Semiconductor Corporation that commercialized a new generation of Power MOSFETs for delivering power to microprocessors in notebooks and servers. From 1974 to 1988, Dr. Baliga performed research and directed a group of 40 scientists at the General Electric Research and Development Center in Schenectady, NY, in the area of power semiconductor devices and high voltage integrated circuits. He has over 550 publications in international journals and conference digests, has authored and edited 18 books, has authored 20 book chapters, and holds 120 U.S. Patents in the solid-state area. He has degrees from Rensselaer Polytechnic Institute and Indian Institute of Technology, Madras.

Professor Baliga is noted for his work regarding semiconductor devices and power electronics. His technical contributions include demonstration of the first high-performance silicon carbide power devices and the invention of the insulated-gate bipolar transistor (IGBT). During the last 20 years, the use of IGBTs has produced electrical energy savings of more than 50,000 Terra-Watt-Hours and gasoline savings of 1 Trillion gallons. For this achievement, he has been labeled at NCSU as the "man with the smallest carbon footprint on earth". He is a member of the National Academy of Engineering, has received the National Medal of Technology and Innovation, and has received North Carolina Award for Science. He is recipient of the 2014 IEEE Medal of Honor, the highest recognition given by the IEEE, for his invention, implementation, and commercialization of power semiconductor devices. His other IEEE awards include Fellow of IEEE, the 1991 IEEE William E. Newell Award (Power Electronics Society), the 1993 IEEE Morris E. Liebman Award (IEEE Board of Governors), the 1998 IEEE J. J. Ebers Award (Electron Devices Society), and the IEEE Lamme Medal (IEEE Board of Governors).

The National Medal of Technology and Innovation is an annual award that is given by the President of the United States. As the nation's highest honor for technical achievement, it recognizes individuals, teams, or companies for technical accomplishments.

Why did you choose to study engineering?

My father was a pioneering electrical engineer who served as Chairman and Managing Director of the largest electronics company (BEL) in India. He was a Founding President of the IRE in India. My home was steeped in electronics and I grew up with an excellent electrical engineering library at home. Reading the books and magazines on electrical engineering while in high school and my father's example inspired my joining the field of electrical engineering.

What do you love about engineering?

I enjoy the opportunity to create new technologies that can be utilized by society to improve the quality of life for people. I have had the privilege of creating innovations that improve the comfort and convenience of billions of people around the world.

What don't you like about engineering?

Engineering creates an embedded technology that is most often hidden from the eyes of the end users. The media fails to provide recognition for great engineering accomplishments in the same manner that athletic achievements enjoy.

Edwin H. Armstrong

Whom do you admire, and why?

I admire the accomplishments of the IEEE Medal of Honor recipients beginning with Edwin Armstrong in 1917. It is wonderful to be chosen to join their ranks in 2014. My decision to work on semiconductors was influenced by reading Richard Feynman's books on physics. I admire his lucid and profoundly incisive explanations.

How has the engineering field changed since you've started?

The research has become increasing cross-disciplinary. As industry moves closer to product development, major innovations through basic work have become relegated to academia.

In what direction do you think that the engineering field is headed in the next 10 years?

Engineering will have to solve the most challenging problems faced by society. These include improved generation and delivery of power to homes and factories, and mitigation of environmental degradation through replacement of fossil fuels with renewable sources.

What's the most important thing you've learned in the field?

I have learned that coming up with a new idea is easy but making the innovation practical so that it can be widely utilized by society takes much more skill and persistence.

What advice would you give to recent graduates entering the field?

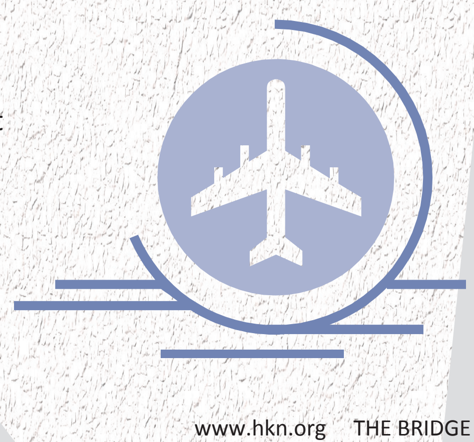
I would tell them to become passionate about their ideas and be prepared to overcome many obstacles from skeptics.

If you weren't in the engineering field, what would you be doing?

After reading Feynman's books on physics, I wanted to join that field but there were no opportunities to make a change from electrical engineering while I was an undergraduate student.

Finish this sentence: "If I had more time, I would…

……do more travelling around the globe to discover beautiful places."



Curtis Ullerich

Nu Chapter

Curtis Ullerich is a recent (December 2013) graduate of Iowa State University in Computer Engineering. With a minor in music technology, he has combined music with engineering through research and many independent projects: He founded a community jazz band in 2010, marched with the Iowa State marching band for four years, and in 2013, he performed a joint recital of electronic music. A lifetime 4-H'er, Ullerich volunteers with youth in the 4-H program and judges at county fairs. Ullerich served as the president of IEEE-HKN Nu Chapter and helped to plan the 2014 IEEE-Eta Kappa Nu Student Leadership Conference in Ames, Iowa. After previous internships with Telligen, Garmin, and Microsoft, he began his career as a Software Engineer with Google, working on YouTube in the San Francisco Bay Area.

Why did you choose to study computer engineering?

I've always loved math and science. I've been building and making things forever, so enrolling in engineering seemed like a natural choice. I took a programming class my first semester and really enjoyed it, so I moved from undeclared engineering to computer engineering. It's only gotten more exciting from there.

What do you love about engineering?

I love being able to solve problems every day and build cool things, especially when those things help people somehow. As far as computer engineering, working with so many levels of abstraction is a cool experience. We get to deal with and discuss things from the binary level up to high-level algorithmic constructs.

What don't you like about engineering?

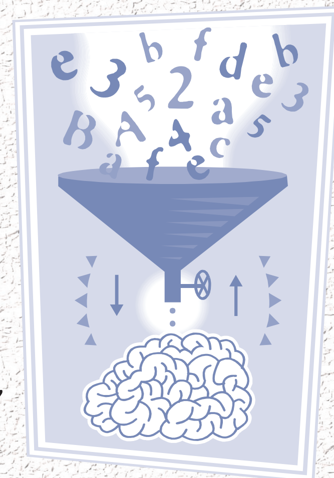
So far, the thing I like least is maintenance of projects, insofar as they prevent you from moving on to building the next cool thing.

What is your dream job?

Dreams can take a lot of forms and levels of specificity. One dream for the last couple of years has been to work for Google. I'm very fortunate that this dream has come true, so I'm excited to see where else my career goes after I start as a software engineer with YouTube.

Whom do you admire, and why?

I had a few weeks of downtime at home before I started my new job, so I've been near a lot of the people around whom I grew up. I've recently gained a better appreciation for the roles individuals (mostly in my family) play in our small town community. I'm seeing their values and actions through the lens of a more developed world view, without the nagging distraction of homework or exams. I admire and am thankful for the nuanced sacrifices that my parents and family have made for each other over our lifetimes.



In what direction do you think that the engineering field is headed in the next 10 years?

Data is becoming a lot more important, and platforms for analyzing, mining, and visualizing it are becoming more prevalent and useful, sometimes scarily so (hello NSA). I think that big data will play a much larger role in most fields.

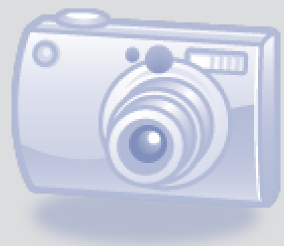
What is the most important thing you have learned in school?

I think most engineers will tell you that college really just teaches you how to learn. I would agree with that. I know how to approach the problem of ignorance better now, which is essential in the constantly-progressing field of software engineering. I'm fortunate to be interested in a field that is still young and dynamic, and being mentally on one's toes is a must throughout a career as a software engineer.

What advice would you give to other students entering college and considering studying your major?

In my view, the two most critical contributors to personal success are initiative and strong communication skills. Those are developed by habit, so start early. Build cool things just for the fun of it. Give yourself enough free time to be able to A) relax and B) explore interesting things throughout college. Set goals for yourself and work toward them proactively.

Finish this sentence: "If I had more time, I would…



……I would build more side projects. I've largely taken the approach of going overboard with class projects up to now, instead of digging heavily into independent projects. I (probably luckily) don't have that opportunity anymore, so I can invest more time into hacking away at pet software projects. One idea that's been floating around my head recently is a CLI photo categorization and searching application.

Smart Grid: The Role of the Information Sciences

By H. Vincent Poor, IEEE Fellow,
Princeton University

Abstract: Smart grid involves the imposition of a cyber layer of sensors, communication networks, and controls, atop the physical layer of the electric power grid in order to improve the efficiency, reliability and security of the grid, and to enable the integration of renewable energy sources and greater consumer participation in making decisions about their energy consumption. The resulting cyber-physical nature of the power delivery system opens the door for the application of tools from the information sciences in this regime. This article provides an overview of this problem, illustrated with several examples from the author's own research.

INTRODUCTION

What Is Smart Grid?

Modern society depends critically on the effective generation, distribution, and use of electric power. Today, the electric power grid is being transformed from a traditional grid into a smart grid. That traditional power grid was primarily an electro-mechanical system, organized to be controlled centrally by its operators. Communication in the grid was typically one-way, from the end points (e.g., electricity meters) to the operators. Generation was also centralized, and there were few sensors, which were monitored manually, and electricity outages were restored manually as well. There were failures and blackouts, limited automatic control, and few customer choices. The smart grid, by contrast, is a cyber-physical system, with two-way communication and distributed generation (including renewable sources such as wind and solar). There are sensors throughout the grid, and these are used to make the grid self-monitoring, self-healing, adaptive, and reliable. Control is pervasive and there are many customer choices.

Why Have a Smart Grid?

Today's power grid is still closer to the traditional model than the envisioned smart version, but it is in a state of transition. This transition is motivated by a desire to improve the reliability and quality of power delivery, to enhance the capacity and efficiency of existing power plants, and to improve the resilience of the system to disruptions. Another motivation is to enable the integration of renewable and other distributed energy sources into the greater power grid in order to have more sustainable sources of energy, and to take advantage of the storage opportunities provided by the use of electric vehicles and other technologies. Added sensors help to improve the security of the grid and to automate many aspects of grid operation and maintenance. And, finally, the smart grid allows greater consumer choices, and enables the development of new products and services. Essentially, it brings the power grid into the 21st Century, allowing greater efficiency, security, reliability, and sustainability of electricity production and consumption.

The Role of Information Sciences

The introduction of a cyber layer into the electricity grid invites the application of methodologies from the information sciences to the modeling, analysis, and design of the grid. These include disciplines such as optimization, game theory, and control; communications, networking and information theory; and statistical inference, machine learning, and signal processing. In this paper, some examples of how these disciplines can be useful in the modeling, design, and operation of the grid are described, including the application of game theory to improve grid efficiency, the use of information theory to understand issues of privacy, and the use of statistical signal processing to enable greater grid reliability. These particular examples are taken from the author's own research program. However, it should be noted that these are only examples and as such are merely representative of a very extensive research and development effort by a very large community of engineers and researchers in this field. Also, it should be kept in mind that the perspective of this article is from the viewpoint of the information sciences, whereas the very complex physical aspects of the electric power grid are not discussed here. However, it should also be kept in mind that these physical considerations are obviously quite central to the operation and effectiveness of electricity distribution and use. A useful survey of smart grid concepts worldwide can be found in [1].

GAMES, PRIVACY and DISTRIBUTED INFERENCE

Game Theory to Improve Grid Efficiency

Game theory is a mathematical approach to the study of strategic decision-making among multiple parties whose decisions affect one another. To motivate the use of game theory in the study of the smart grid, it is useful to consider several salient characteristics of the grid. First, the grid is very heterogeneous: There are many different types of nodes - electric vehicles, smart meters, substations, sensors, generators, loads, etc. - and each node has its own objectives. So there is not one unified objective of all the participants in the grid. Also, it is very extensive in scale: There are potentially millions of nodes in the grid, and its geographical span is continental. Finally, it is also dynamic and stochastic, due to time-varying demands for electricity, the variability of renewable energy sources, and even mobility when one considers electric vehicles. So in short, the grid is a lot like an economic system. Game theory is very good at describing the behavior of participants in an economic system, and similarly it is also useful for describing behavior in the grid, because it captures the behavior of individuals, each of whom is working on his or her own behalf.

There are two branches of game theory: non-cooperative, or competitive, game theory, in which the players are competing with one another selfishly; and cooperative game theory, in which players work together to achieve a common goal. Each of these branches has a role to play in understanding the behavior of participants in the smart grid, and these are illustrated very briefly in the following paragraphs via two examples.

The first example is that of energy trading by plug-in vehicles, such as hybrids or electric vehicles, the use of which is increasing dramatically. The presence of such vehicles will provide a considerable amount of storage at the consumer end of the grid. In this context, we might consider a situation in which people drive to work in the morning in their electric vehicles and then connect them to the grid as part of plug-in vehicle groups, say in a parking garage. These vehicles may have surplus energy in them, so they could be energy sources in themselves, or they may need to be charged. So, they can either sell surplus energy to the grid, or perhaps buy from the grid, depending on their needs and the economics of the situation; i.e., energy trading between the grid and electric vehicle groups is a potential activity for smart electricity grids. (See Fig. 1.)

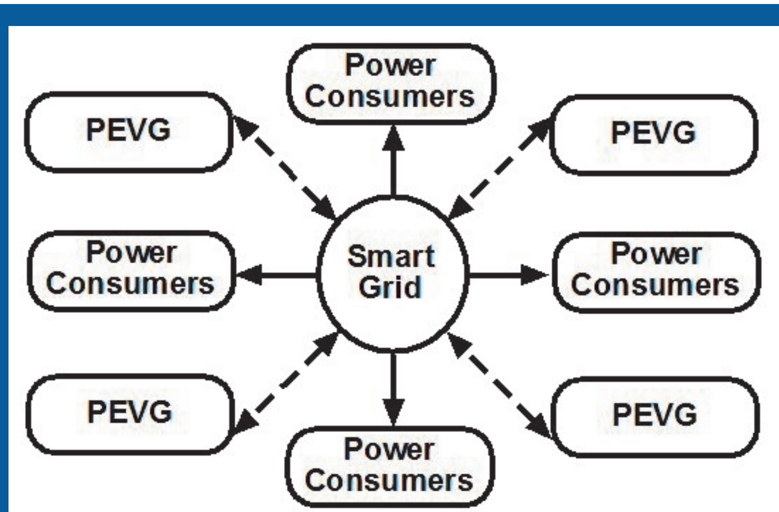


Fig. 1: Plug-in Electric Vehicle Groups (PEVGs) trading energy with the grid.

One way to model the interactions among multiple such groups is to use non-cooperative game theory. There is no reason why these groups should cooperate with one another, as they are actually competitors in trading with the grid. But they are going to interact with the same grid, and so the benefit or *utility* that each electric vehicle group obtains from various decisions that it makes will depend on the decisions made by competing groups. Two different kinds of game theory can be applied in this situation. One is a *Nash game*, which describes the interactions among the electric vehicle groups when they are competing to optimize their own individual utilities. The other is a so-called leader-follow or *Stackelberg game*, in which the grid is a further participant in the game, acting as a leader by setting a price for electricity that will optimize its own utility, assuming that the electric vehicle groups will then behave competitively in response to this price.

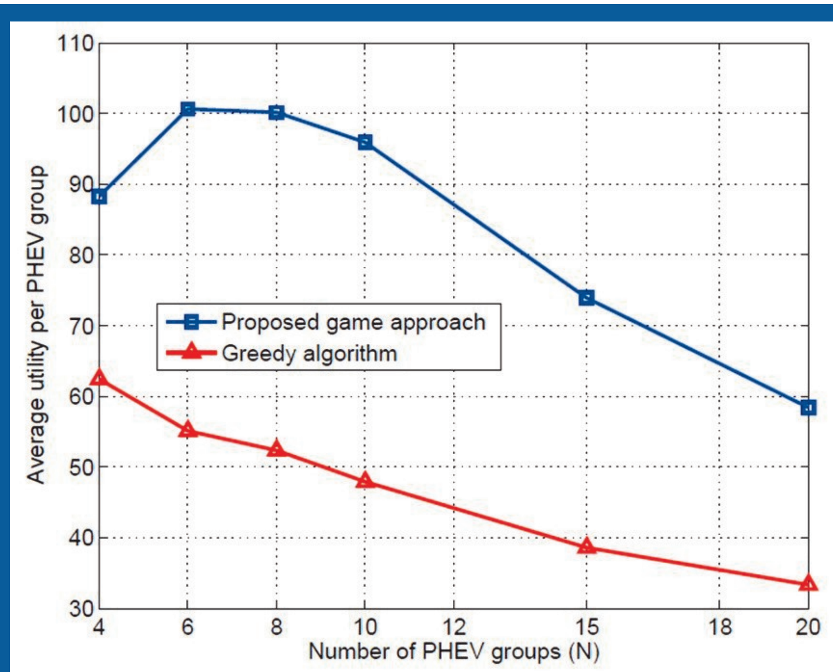


Fig. 2: A comparison of the average utility achieved by the PEVGs through a game theoretic approach to that achieved by an alterative approach [4].

Using these models, the behavior of electric vehicle groups that are trading energy with the grid can be analyzed, and optimal strategies for such trading can be devised. Studies of this problem indicate that considerable potential efficiencies can be obtained through this process. An example is shown in Fig. 2.

Another example of a problem in which game theory can provide insights into more efficient grid management is that of energy trading within the distribution network. A power system typically involves a transmission network, which is the high-voltage part of the grid, and a distribution network, which is the lower-voltage part of the grid where, for example, our residences and office buildings are connected.

Some of the elements in that distribution network are micro-grid elements - that is, localized elements such as solar arrays, wind farms, loads of various types, and so forth. One way for micro-grid elements to operate is to interact directly with the transmission grid (also known as the “macro grid” in this context) to buy or sell electricity. That is, if you look at the distribution grid, each micro-grid element could interact directly, buying and selling energy, with the macro grid. But another possibility is that the micro-grid elements could exchange energy among themselves. That is, rather than trading with the macro grid, they could trade with each other - either selling surplus if they are a solar array or a wind farm, or buying from these element if they are loads. This might be advantageous for various reasons, e.g., economically if better prices can be obtained this way, or in terms of efficiency if power losses can somehow be reduced through more efficient inter-connections.

This is a situation in which cooperative games - in particular, *coalition game*s - can be useful in studying the smart grid. A coalition game consists of a set of players and a utility or value function. The players group themselves into coalitions, and by doing so they create value. Each player within a coalition will receive some part of that value that accrues to the coalition as a payoff for being part of the coalition. Different coalitions can be compared based on whether they create more value for all of the participants, i.e., using the so-called *social ordering*. There are algorithms for finding coalitions that are stable with respect to this ordering, and applying such algorithms in models for groups of micro-grids again shows considerable potential for improved efficiency of operation within the distribution through the use of this approach. An example illustrating a formed coalition is shown in Fig. 3, and the advantage of coalition formation (in this case, in terms of reduced power losses) is illustrated in Fig. 4.

These are only two examples in which game theory can have a role in the study of smart grid efficiency. To explore further into these and other game theoretic approaches to the smart grid, please see [2-5].

Note that it has been noticed in economic analyses that individuals do not behave fully rationally when making economic decisions, and an alternative formulation known as *prospect theory* has been developed to account for this human behavior. This theory, for which the Nobel prize in economics was awarded in 2002, has also been applied recently to smart grid problems in which the human perception of risk is taken into account; the interested reader is referred to [6] for further details.

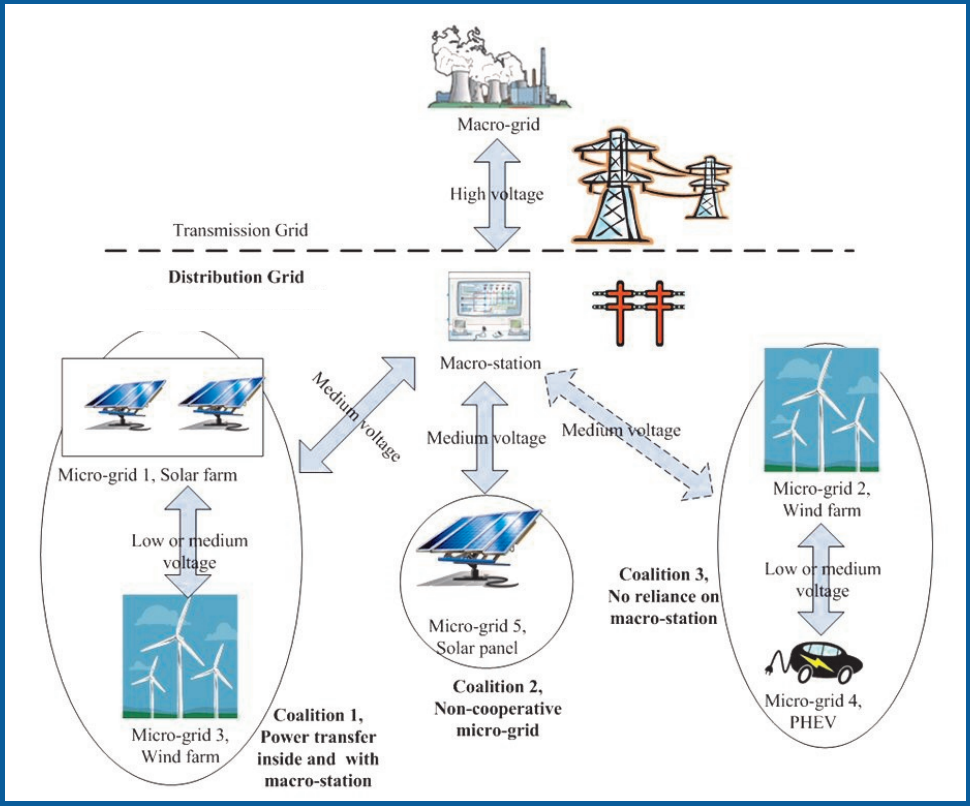


Fig. 3: Coalition formation among micro-grid elements.

Information Theory to Help Understand Privacy Issues

Information theory is a mathematical approach to the quantification of information and the fundamental limits on various tasks involving information, including its transmission, storage, compression, etc. Information theory provides another area in which information sciences can play a role in smart grid, namely in understanding the issue of privacy in the grid. One consequence of greater monitoring of the grid and electricity usage is that such monitoring creates a great deal of electronic data that contains information about electricity consumers and companies. The reason this data is collected, of course, is because it is useful. And the utility of data depends on its accessibility. On the other hand, accessibility to such data means that private information can also be leaked. So there is an inherent tradeoff between the accessibility of data to give it utility, and the lack of accessibility of data to keep it private.

A general formalism to understand this tradeoff between utility and privacy of data has recently been developed in [7]. Without going into too much detail, data in an information source can be divided into two types - public and private - and these two types of information can be correlated with one another. So, revealing public data can also reveal information about private data. Using this dichotomy, the so-called utility/privacy tradeoff can be formulated mathematically using information theory. In particular, by measuring utility in terms of how distorted public data is when revealed to a user of the data, and measuring privacy in terms of information leakage, the optimal tradeoff between these two opposing goals can be determined for many problems of interest, not only in smart grid but in a variety of problems involving data repositories. Two examples from smart grid in which these ideas can be applied are discussed briefly in the following paragraphs.

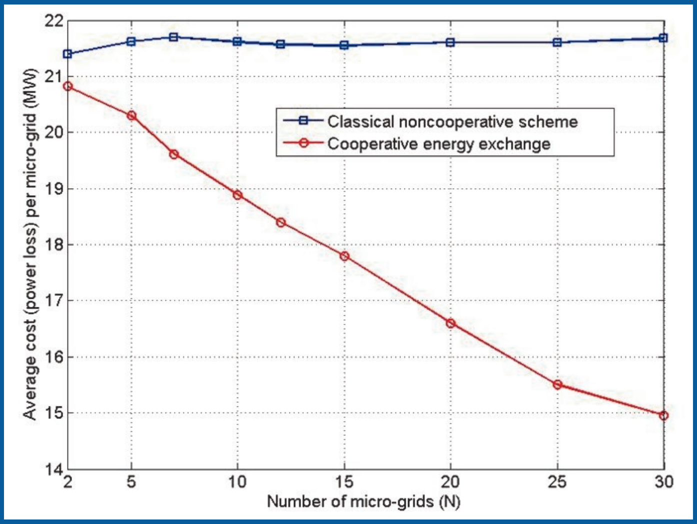


Fig. 4: Comparison of power losses incurred through cooperative energy exchange via coalition formation to those incurred through non-cooperative energy exchange between micro-grid elements and the macro grid [2].

One such problem is smart metering. Smart meters are a type of electricity meters that send data about electricity usage in a home or other premises to the power company on an almost real-time basis. Such data is very useful to both the power company and the consumer, because it aids in load balancing, dynamic pricing, etc. On the other hand, smart meters can leak information about what is happening in the home. Various appliances and other electrical devices produce a distinctive signature in the smart meter output, and so information about activity in the home or more generally about the lifestyle of the occupants can be inferred from smart meter data. So a utility/privacy tradeoff arises in reporting of smart meter data.

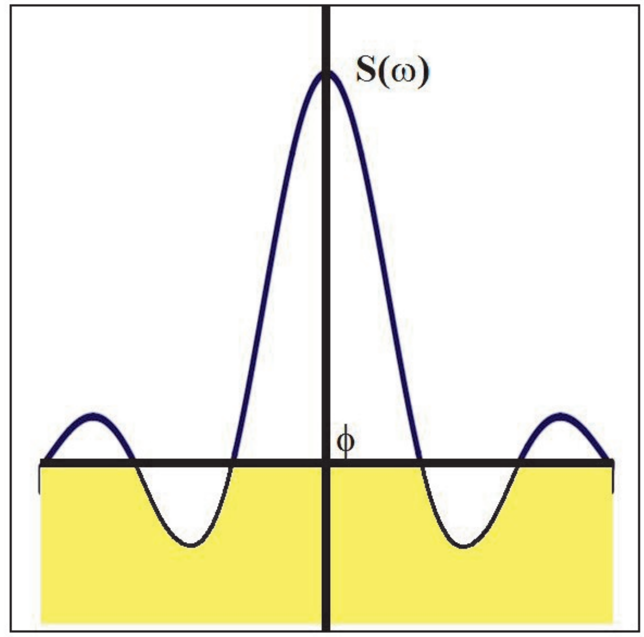


Fig. 5: "Reverse water filling" in the power spectral density of electricity usage. The smart meter reports only that usage at frequencies whose power level is above the "water level" ϕ.

The formalism mentioned above can be applied to understand this tradeoff and to suggest techniques for achieving an optimal tradeoff. One such technique is known as "reverse water filling" and essentially involves the suppression of low-power frequency content from smart meter data reported to the power company. (See Fig. 5.) This has the effect of suppressing information about transient events, such as turning appliances on and off, which tend to have relatively low average power but also to be the most informative about in-home activity. At the same time, these are perhaps less important for efficiency in power delivery, as compared to devices such as air conditioners and refrigerators, which are less informative about individual activity. The so-called "water level" determines the power level below which frequency components are suppressed, and this level can be varied to achieve a desired level of tradeoff: lower water level means greater utility and less privacy, and a higher level gives the opposite effect. This solution can be found in [8].

This tradeoff can be further enhanced through the use of in-home energy storage, such as an electric vehicle, which can be used as alternative power source to modulate information revealed at the meter (see [9] and [10]).

Another application arises when considering the mechanism for managing the electricity grid in North America. In particular, the North American grid is managed by multiple regional entities (known at Regional Transmission Organizations, or RTOs - see Fig. 6), and as part of that management the entities want to estimate the state of the grid in their regions of responsibility. Since the grid is inter-connected, this can be best done if these regional entities exchange measurements and other information. On the other hand, the grid is also a marketplace, and so there may be motivations of economic competitiveness for not exchanging such information. So, a utility/privacy tradeoff emerges from this situation, but this one has another wrinkle in that there are multiple participants in the process, each with its own tradeoff to consider. But, on the other hand, the entities' actions in terms of sharing information affect the quality of each others' state estimates. This is an example of a problem of *competitive privacy*; i.e., a utility/privacy tradeoff problem with multiple competing players.

This problem can also be addressed by combining the information theoretic formulation mentioned above with the game theoretic formulation mentioned in the previous section. In particular, the issue of how to best share information to operate at different levels of utility/privacy tradeoff can be solved using information-theoretic methods, and in fact reduces to an optimal distributed data compression problem, known as the Wyner-Ziv problem. On the other hand, the issue of how much information to share via this sharing mechanism can be determined by treating the competitive nature of the problem as a Nash game. These issues are described in [11].

Statistical Signal Processing to Aid in Improved Grid Reliability

The problem of state estimation that was mentioned above also provides a good example of how advanced techniques in statistical signal processing can also be of use in the smart grid. In particular, one of the issues arising in smart grid is that of "big data." In addition to the data created by smart meters, there is also data generated by sensors. For example, one of the new technologies used in smart grid is a new type of sensor called a phasor measurement unit, or PMU, which generates greater amounts of data than the SCADA (system control and data acquisition) systems used traditionally to monitor the grid. In order for the data from these sources to be useful, it needs to be collected in a common place, and this can cause communication bottlenecks when the amount of data is large.

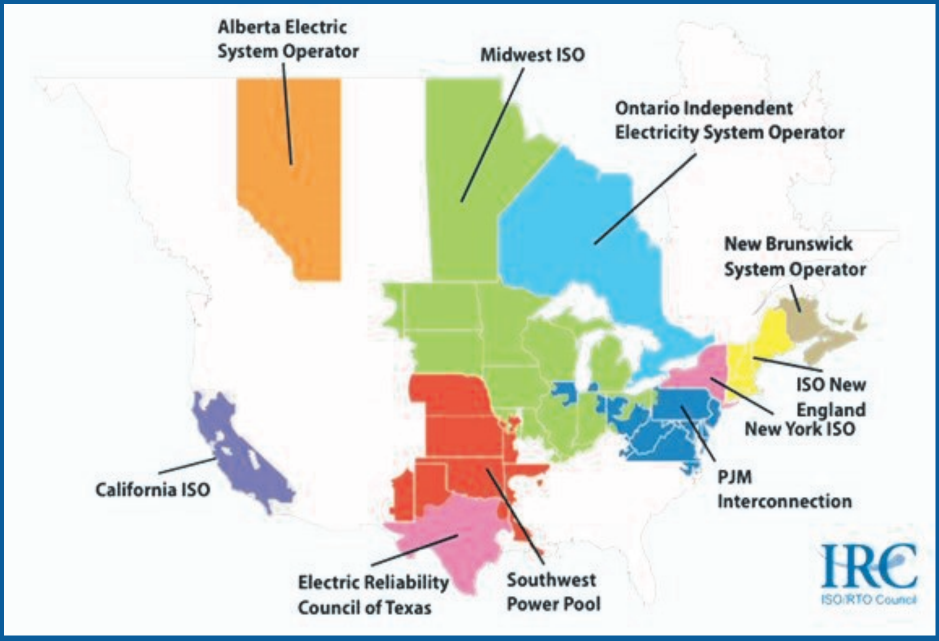


Fig. 6: Regional Transmission Organization (RTOs) in the North American power grid. (Image courtesy of U.S. Energy Information Administration.)

An alternative to collecting this data in one place for centralized processing is to use the data in a distributed fashion, allowing data to be processed closer to where it is generated. This, then, brings up the issue of *distributed state estimation,* in which each of a number of local control areas uses data that it collects locally, together with data that it exchanges with its neighbors, to construct estimates of the global state of the electricity grid. Here, the state of interest consists of the vector of all voltage phase angles on all buses in the grid. But, since only a small subset of these buses can be observed by an individual control area, the estimation of the global state is a challenge.

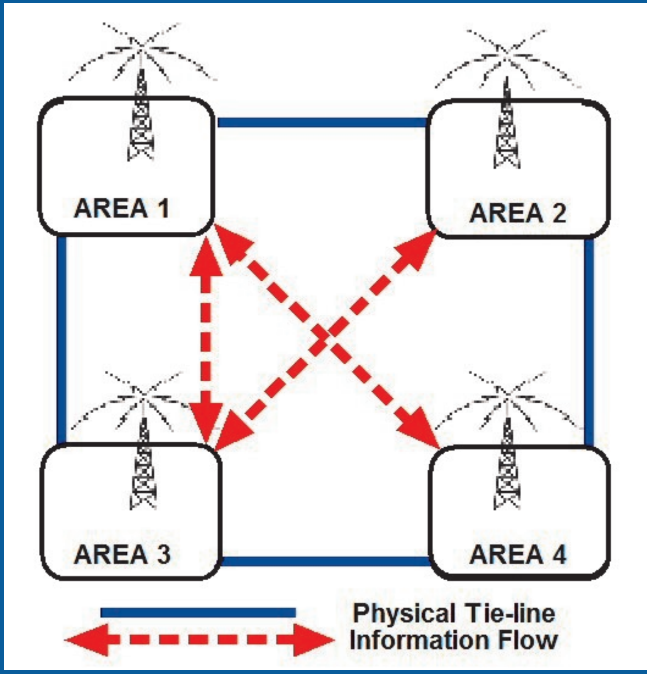


Fig. 7: The smart grid involves two networks: the physical network of the electricity grid, and the cyber network on the cyber infrastructure. Electrical energy flows through the former, while information about that energy flow flows through the latter.

This kind of problem - i.e., distributed state estimation - is not new. It goes back at least to the 1970s. But an interesting twist here is that in the smart grid there are really two networks. First, there is the power grid, which is a network of physical connections. And then there is the cyber network, which is the communication network over which data can be exchanged. And these two networks do not necessary have the same topology. In particular, the network whose state we are trying to estimate has one topology, and the network through which the data is distributed has another topology. (See Fig. 7.) So that dichotomy gives this problem of distributed state estimation a new twist and a new level of difficulty.

This problem can be approached using recently developed ideas in statistical signal processing. In particular, each control area has measurements of the bus phase angles in its own area - these measurements are "filtered" through a matrix that describes the local connectivity of the electricity grid. A control area can also share measurements with its neighbors, where proximity is determined via the cyber network. If the global grid is observable (meaning that the state of the physical grid can be estimated from measurements at all control areas) and the cyber network is connected (meaning that messages from any point in the network can be reached from any other point, perhaps through multiple hops), then these two types of data can be combined to allow each control area to estimate the global state as if it had all the data available to all control areas. This approach involves two types of estimation goals: consistency with the locally observed data (which involves the physical network), and consensus with the estimates of neighboring control areas (which involves the cyber network). Remarkably, this ability to achieve global state estimates is present even if the local control areas are not locally observable, that is, they cannot even estimate their own local states without outside data. Further discussion of the problem of distributed state estimation in smart grid and other cyber-physical systems can be found in [12] and [13].

CONCLUSION

As the above examples have illustrated, the information sciences have considerable potential for contributing to the understanding and development of the smart grid. Again, these examples are merely representative of a very extensive research and development effort aimed at the effective integration of cyber-infrastructure into the electricity grid for a more efficient, reliable and secure energy future.

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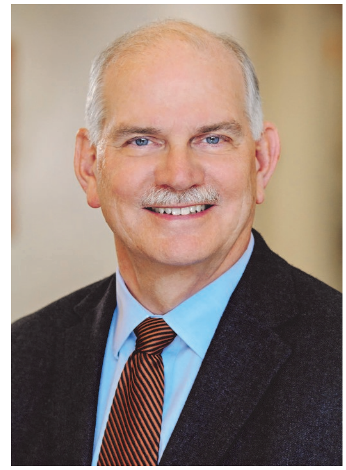

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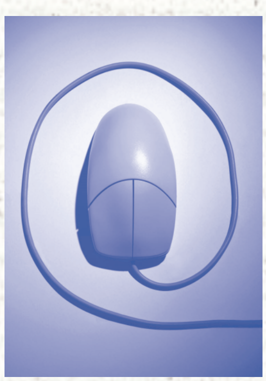

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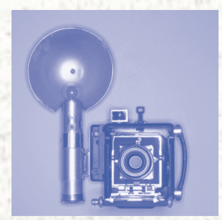

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