Network Systems Engineering for Meeting the Energy and Environmental Dream

By GÖRAN ANDERSSON, ***Fellow IEEE***
Guest Editor

MARIJA D. ILIĆ, ***Fellow IEEE***
Guest Editor

VAHID MADANI, ***Fellow IEEE***
Guest Editor

DAMIR NOVOSEL, ***Fellow IEEE***
Guest Editor

I. INTRODUCTION

This issue coincides with exciting times when energy and the environment are once again on everyone's mind. No single technology, hardware and/or software, is likely to meet the huge needs for energy. The producers of primary energy have entered the race for making traditional energy resources cleaner and safer, as well as for coming up with scientific breakthroughs toward entirely new energy resources. There has also been an increasing awareness that traditionally passive energy consumers have a larger role to play than in the past. At the same time, we do not have the infrastructure to integrate and transport these new energy resources effectively. The infrastructure for converting primary energy and delivering it in a form required by the end users was designed with qualitatively different objectives in mind from the functionalities which are likely to be needed in the near future; this infrastructure is also aging and far from what it should and could become given technological advances. Recently, investments have been made by governments worldwide to demonstrate proof- of-concept and the feasibility of deploying some of the new infrastructure technologies. Unfortunately, it cannot be assumed that large-scale penetration of the most promising solutions would take place once the feasibility of these technologies has been demonstrated on relatively small pilot projects. On the contrary, the initial conditions in today's industry, combined with various technological, economic and regulatory driving forces, have led to unprecedented industry complexity. It has therefore become increasingly difficult to streamline the progress

In this issue, we review the current technology and set a basis for further R&D into network systems engineering for enabling the implementation of sustainable energy as it relates to the overall state of the industry and the need for more systematic design and operational approaches.

Digital Object Identifier: 10.1109/JPROC.2010.2083830

0018-9219/$26.00 ©2010 IEEE

toward meeting energy and environmental goals through innovation.

II. NEW SYSTEM OBJECTIVES

This issue is motivated by the recognition that in order to effectively deploy many new resources and supply diverse users' needs it is essential to rethink the evolving system objectives first. In particular, it is important to do this with a clear understanding of today's operating and planning industry practice, as well as the underlying assumptions and the related roadblocks to enabling the implementation of qualitatively different objectives key to sustainable energy utilization. Once this is understood, it becomes possible to conceptualize new network system paradigms which no longer rest on the same assumptions, and which may be better suited for efficient implementation of the evolving objectives. If this is not done, major problems may occur while deploying the new technologies. Problems may be reflected in unreliable service, excessively high energy cost, environmentally unacceptable solutions, as well as in the deployment of technologies whose cost cannot be recovered at value. It is one of the main premises in this issue that these challenges could be overcome by enabling the evolving physical energy systems with better monitoring and decision-making tools based on large amounts of data collected and communicated online throughout the vast energy network systems. The industry has already begun to deploy powerful sensing and communications for online data monitoring. Technologies such as phasor measurement units (PMUs, known more generally as synchrophasors), dynamic line rating (DLR) units for online sensing of transmission line thermal limits, advanced metering infrastructures (AMIs), and fiber and power line carrier-communications networks are being deployed. Well-established computing and communication platforms, middle-ware, and extremely fast powerful computers are likely to be deployed next as part of the grid modernization process under way. If these information communications technologies (ICT) are deployed systematically, it may become possible to achieve major gains in the utilization of existing energy resources and not to have to depend on building much new capacity.

III. ICT IMPACT

The dynamics of electric power grids will begin to be driven by the unprecedented data-intensive computing and decision-making with humans in the loop as well as by much automated sensing, communications, and control. This embedding of ICT may modify the basic physical responses of the interconnected energy systems, resources, users, and delivery systems from the responses we have gotten to know and understand. It should be clear that the role of ICT in shaping the energy systems dynamics could critically determine the utilization of today's and future energy resources. Never before have energy systems come so close to becoming so critically dependent on intensive data-driven network systems in which much can be gained by managing intertemporal and interspatial dynamics with a clear design for desired performance not achievable by relying on passive delivery systems.

IV. COMPLEX R&D PROBLEMS

However, the complexity of the expected energy industry evolution is overwhelming at present. It is this complexity that is the key roadblock to progress. In this issue, we stress that the open R&D problems which require breakthrough solutions in which ICT would begin to make a difference in the performance of future energy systems are equal to if not harder than the science of producing more efficient and clean resources. The theoretical challenges underlying problem posing, objectives, and possible approaches to transforming today's industry operation and planning happen to be the same ones seen in many other man-made infrastructures which require a multidisciplinary approach to complex network systems. While specific methods exist for solving particular subproblems, there is at present no single systematic framework for designing the overall cyber-physical networks for provable performance.

Viewed this way, future energy systems become key test beds for new large man-made infrastructure frameworks and their ICT. The problem of future electric energy systems is therefore posed in this issue as a problem of network design, monitoring, and control for enabling the implementation of multiple objectives by the actors embedded at various network layers. Typical tradeoffs of interest are efficiency, cost, emissions, network congestion, profits, differentiated reliability, and long-term sustainable services. It is pointed out that there exists a major need for cyber-physical modeling of future electric energy systems. While conceiving most general modeling approaches to cyber-physical systems may remain the key challenge for quite some time to come, developing classes of models which draw on well-understood structural properties of electric power networks is doable. Understanding what to measure, communicate and adjust as system conditions vary should directly follow from understanding how the models are changed and by formally posing multiple objectives of the future energy systems. Frameworks for deploying truly used and useful ICT in future energy systems must be based on using leading-edge theoretical approaches to distributed network systems while keeping an eye on the structural characteristics of physical energy network systems.

V. EVOLVING GRID MODELS

It is important to recognize that a historically slow adoption of online monitoring and decision-making in the electric power industry has been to a large extent a consequence of operating and planning principles in place. The complex network power grids have been organized, operated, and planned as hierarchical systems whose main objective has been uninterrupted, safe, and reliable electricity service. The overall complexity of large electrically interconnected power grids has been made manageable by intended spatial decomposition of objectives to the level of individual utilities, as well as on temporal decomposition into protection, stabilization, scheduling, unit commitment, long-term maintenance, and investment planning functions. Over time, computer methods based on these decompositions have been developed and deployed in most of the major control centers. This industry structure has ensured a very high reliability electric energy service by building redundant assets and has not relied much on real-time sensing, communications, and control. The striking fact is that all of these methods are used for offline extensive simulations to determine the worst case scenarios for which preventive actions are put in place to avoid problems in case these events happen. In particular, time-critical engineering phenomena, such as unacceptably large short-circuit currents and loss of synchronism, are studied offline, and protection and primary control of power plants, such as governors and voltage regulators, are designed to ensure that, even during what has been found to be the worst case scenarios, such problems do not occur. Given the time criticality of these problems, the design generally does not concern efficiency. Robustness of protection and closed-loop stabilizing controllers have remained the key priorities.

The optimization of cost reduction and efficiency, on the other hand, has been done for quite some time in a feedforward way a day ahead or, at most, a week ahead to schedule and turn on/off the least expensive generation to supply the forecast system demand. Neither T&D voltage support nor demand side is optimized when scheduling for least cost generation. Notably, the optimization has not been multitemporal; instead, it has been strictly static and deterministic. As a consequence, major inefficiencies from not accounting for intertemporal trends are currently present in a typical industry operation. Moreover, there is at present no optimization of resources across very large spatial distances. No regional optimization of generation dispatch and unit commitment is in place. This, too, results in inefficiencies from not correlating load peaks, for example, across large geographical areas. This basic industry approach has, therefore, not required much reliance on the ICT generally needed to capture intertemporal and interspatial correlations and efficiencies. Today's Supervisory Control and Data Acquisition (SCADA) is primarily used to detect bad data and equipment status using slow measurements, not for online adjustments. In addition, there is generally not much communication at the local, distribution, network levels between the small energy users and the energy providers. As a result of today's practice, electric power systems are operated subefficiently. This situation points out that, even prior to becoming concerned with the challenges of integrating novel intermittent energy resources, there are major opportunities to enhance the utilization of existing resources without endangering reliability of service. However, getting there will require much more online sensing, communications, computing, and decision-making in support of coordinating controllable T&D equipment adjustments and demand side management when scheduling generation. While there have been estimates in the literature reporting potential benefits from doing this, not much progress has been made by the traditional regulated industry. When all is said and done, the fundamental challenge is hidden behind the lack of optimization methods and software tools for highly nonlinear large-scale networks with temporally correlated energy resources. A closer look is needed into the fundamental limits to optimization of complex interconnected electric power grids.

VI. CHANGES ARE NEEDED

The slow progress in ICT for efficiency, and software, in particular, has become even more pronounced in the changing industry. The reasons for this are many. To start with, today's industry paradigm does not provide a means for catalyzing the deployment of equally valuable technologies to the energy consumers. While the strong emphasis remains on reliable and secure service, the efficiency objectives are now distributed and even more decomposed spatially and temporally than in the past. This is despite the available sensing and communications hardware. The simplest example is the one of not having incentives to pay at value for timely delivery of cleaner and less expensive energy from far away instead of using local expensive and dirty power. Moreover, incentives for reflecting the break-even value of cumulative inefficiencies from using the old technology and the capital cost of investing in new more efficient technology are not in place. Instead, planning practices and capacity payment mechanisms are not related to the cumulative underutilization cost, ultimately resulting in poor utilization and lack of innovation.

VII. SPECIAL ISSUE COVERAGE

In this issue, we suggest that one way forward is to take a step back and rethink what needs to be done, why, and, ultimately, how. The contributed papers attempt various aspects of these difficult questions. They jointly set a basis for further R&D into network systems engineering for enabling the implementation of sustainable energy provision. In what follows we have organized the contributions into several categories and have described how they begin to relate to the overall state of the industry and the needs for more systematic design and operation.

VIII. FUNDAMENTAL CHANGES IN PHYSICAL ENERGY DELIVERY SYSTEMS

To start with, two papers are concerned with the physical delivery systems of the future, their models, and operating challenges. The paper by Krause *et al.* introduces a possible unifying framework for modeling and supporting multiple energy delivery systems composed of heterogeneous energy carriers. This paper is timely as the basic role of the electric power grid begins to transform to an enabler of integrating unconventional energy resources. The paper assumes that heterogeneous energy forms will be converted in an energy hub, and then delivered via electric power networks, gas grids, and perhaps by hydrogen networks. A basic mathematical formulation of energy flows in such multiple energy networks is presented first. This paper further offers a unifying framework for energy flow analysis in steady state, and for optimal energy dispatch in multiple energy delivery systems, much the same way as conventional calculations are done in today's control centers dispatching electric energy only. This approach could become very useful as different alternative energy delivery systems and resources are selected, as well as for efficient utilization across several energy types. The authors provide an example of the efficient distributed utilization of plug-in-hybrid electric vehicles (PHEVs) using the proposed modeling framework.

The second paper by Coster *et al.* describes the impact on the physical response of connecting distributed generation (DG) to low-voltage (LV) and medium-voltage (MV) electric power grids. Of particular interest are problems concerning the voltage profile in future distribution networks, and the need to control voltage more proactively to enable DG integration without experiencing unacceptable voltage deviations. Also, problems of harmonic pollution due to fast power electronically based switching are assessed. The Dutch LV- and MV-power grid with many microcombined heat and power plants already implemented by the greenhouse owners is modeled, simulated, and analyzed for possible operating problems. It is concluded that no voltage control problems are likely to take place. However, protection and fault localization are likely to need major advances in the future in order to accommodate two-directional power flows in local distribution networks. While the conclusions are somewhat unique to the specific power grid and the type of DG technology, a similar thought process can be followed to assess possible operating problems and challenges in any given LV/MV distribution network.

IX. TOWARD POSSIBLE NEW OPERATING AND PLANNING PARADIGMS FOR FUTURE ENERGY SYSTEMS

Two papers in this issue introduce possible paths forward to new paradigms needed to more efficiently manage the emerging energy systems without endangering reliability. The paper by Wu *et al.* introduces a concept of risk-free dispatch amenable to managing large amounts of intermittent resources. Rigorous mathematical formulation of this problem using a probabilistic approach is presented first. This formulation is then used to pose a risk-free approach to economic dispatch. Financial instruments in support of implementing such dispatch are proposed as the basis for providing incentives to the energy providers and consumers to contribute at value to the desired quality of service (QoS) despite the high presence of unconventional resources.

The paper by Ilic puts forward a vision for dynamic monitoring and decision systems (DYMONDS) as the key enablers of achieving smart grid functionalities. It is proposed that it is fundamentally impossible to meet the energy and environment objectives set by the society without transforming the current operating and planning industry practices based on top-down hierarchical management to practices which enable just-in-context (JIC), just-in-time (JIT), and just-in-place (JIP) actions. A JIC–JIT–JIP paradigm will require much embedded intelligence at different industry layers and communications among the layers for cooperation and/or coordination. This is dictated by the very nature of new resources which are highly variable, and spread across vast geographical and electrical distances; how effectively they are utilized will be determined by how correlated they are in time and space and how capable they are of providing the best context-dependent functionality. Functionality and goals depend on the context determined by the organizational rules, rights, and regulations (3Rs) as well as by the constantly evolving system conditions. Once this is understood, the need for paradigm shift becomes clear and the design of supporting tools takes place. In the second part of this paper, formal relations between the objectives of future energy systems and the role of man-made physical and ICT-enabled delivery network systems are attempted by building on the recent multidisciplinary socioecological systems (SES) framework proposed by the recent Nobel Prize winner Elinor Ostrom. In particular, the interaction variables used in engineering modeling of electric power grids and the second and deeper level variables used in the SES framework are related. Monitoring and managing interaction variables, otherwise shaped by internal dynamics and decision-making, become a key rationale for defining information exchange patterns within a multilayered complex energy system. It is claimed that ensuring as sustainable a service as possible by aligning temporally and spatially groups of energy resources and users becomes a key objective of ICT design. Last, but not least, the sensitivity of system-wide performance to how well this alignment is done depends on the type of starting socioecological energy system (SEES). An SEES with many small distributed resources will require perhaps much peer-to-peer collaborative information exchange and very little top-down coordination. An SEES built around economies of scale will require much more hierarchical coordination.

X. TOWARD ICT ARCHITECTURES FOR IMPLEMENTING SUSTAINABLE ENERGY SYSTEMS

There are several papers in this issue whose major contribution could be thought of as introducing a vision for system-wide information and communication architectures for connecting selected local information to remote locations in support of system management in real time. It is stressed in these papers that the implementation of new paradigms for operating future energy systems would not be possible without recent synchronized measurement technology (SMC) as an enabler of wide-area monitoring, protection, and control. It is explained in the paper by Terzija *et al.* why this vision is critical to ensuring adequate protection and control in the future. The authors suggest that the availability of these technologies presents truly exciting challenges and opportunities to enabling adaptation at a very fast time scale. A vision is laid out, together with many open R&D problems, of making the use of technologies such as SMC used and useful, where benefits to both system users and the system as a whole are quantifiable. Major industry pilot deployments, and the design of data concentrators (DCs), are under way worldwide. Figuring out how to convert huge amounts of data into the information needed for model verification at a time scale which has never been attempted in the past, and for stability monitoring and wide-area stabilization, will require conceptualization of new models. At least in principle, it is already clear that a large deployment of SMC and DCs could revolutionize the modeling, protection, and fast control of large electric power networks by basing these on near-real-time processing of data over wide areas. This is truly a monumental change in operating electric power systems as the transition is being made from having very few decentralized controllers on large power plants, and almost entirely decentralized protection, to wide-area adaptive functionalities. More work is needed to estimate the potential for cost reduction in fast reserves using such adaptation, but it is believed that the cumulative savings are potentially very large. Making these technologies user friendly will require much R&D effort and training, but the overall project is plausible.

The paper by Zhang *et al.* introduces a concept of smart distributed relays whose logic is not prefixed, but rather is adaptive to the conditions sensed and to previously learned main features differentiating normal and fault conditions. The role of protective relays has been crucial in large-scale blackouts and numerous investigations have been carried out to further understand their roles and to improve their performance. One approach is to use so-called smart relays, which discriminate between normal conditions and fault conditions via local measurements. In this paper, an approach based on machine learning based on binary hypothesis testing, support vector machines, and communications between protective relays is presented. Their suitability is demonstrated for a number of cases and situations and their integration into the control systems of power systems is elaborated upon. In particular, a support vector machine (SVM)-based distributed learning by key relays in the IEEE 118 Test System is shown to reduce the probability of widespread blackouts compared to what today's protection logic would do. To document this claim, a scenario resembling the 2007 blackout was simulated for this test system using extensive simulations and learning. Balancing the need for learning tools which do not lead to excessive cost of the proposed smart relays with the complexity and the cost and complexity associated with SMC and DCs remains at present an obvious difficult research question on the way to more adaptive and smarter protection capable of being dependable and, at the same time, not creating detrimental avoidable system-wide failures and blackouts.

The paper by Vaccaro *et al.* offers a vision for an integrated ICT framework in support of deploying microgrids and adaptive LV local distribution networks. A service-oriented architecture is envisioned as a means of enabling modeling, verification, and the control of microgrids. Many open questions that must be addressed in order for sustainable microgrids to become plausible technical and business models, and the role ICT plays in facilitating this evolution, are discussed. The main emphasis is on the design of the underlying Web services in support of microgrids.

Next, a paper by the Future Renewable Electric Energy Delivery and Management (FREEDM) team offers a vision of future local distribution system architectures. The paper strongly suggests that it is indeed plausible to move toward an entirely plug-and-play approach to connecting renewable resources to the LV distribution networks. A vision of energy sharing by ordinary citizens through an Energy Internet is put forward as a qualitatively different way of balancing supply and demand by the small users and resources. Each device which is connected in a plug-and-play manner can be recognized by an intelligent energy manager (IEM), effectively an aggregating router. Also, in addition to the IEM, an intelligent fault manager (IFM) is envisioned to be capable of localizing faults and isolating them seamlessly. Furthermore, just as any other computer system recognizes a new USB, the FREEDM architecture would recognize new loads and their characteristics over time as they connect or disconnect. The QoS in such plug-and-play architecture relies very heavily on high-quality power electronically controlled inverters and other devices to ensure that no emerging problems—harmonic resonance in particular—occur in such systems. Finally, a fundamental link between the Energy Internet based on the ICT and the solid-state transformer (SST) as a powerful manager of physical energy flows is described. The team is currently conceptualizing a silicon carbide design of such an SST. The vision offered in this paper is far reaching, yet it requires major conceptual breakthroughs if it is to become a reality. The experimental support is essential to build confidence as one progresses, and this is fully recognized by the FREEDM team.

Finally, a rather novel stab at assessing the potential of nonstandard computing architectures, in support of implementing large data management and processing it, is presented by Baliga *et al.* In particular, questions concerning energy efficiency in traditional distributed networked systems for parallel computing, on the one hand, and cloud computing, on the other hand, are raised and presented in considerable depth. Cloud computing is rapidly emerging as an alternative to office-based computing, and it is based on transferring data from far distances into one single place equipped with very powerful computers. The authors propose that while actual computing may be more energy efficient when done by very large computers where economies of scale contribute to the basic efficiency, the management and switching of communications infrastructure may contribute significantly to large energy consumption. Therefore, the authors suggest that it is not necessarily clear that centralized cloud computing is the green technology for processing large amounts of data. We find the reverse trend from distributed to centralized computing in order to extract economies of scale puzzling just as energy systems are undergoing the reverse transformation.

XI. TOWARD EMBEDDING DISTRIBUTED INTELLIGENCE INTO SYSTEM USERS: RESPONSIVE LOADS, PHEVS, WIND GENERATION, AND MICRO-CHPS

The final group of contributed papers has a common theme concerning various distributed technologies and the role of their embedded intelligence in enabling sustainable energy services. Much to the surprise of the editor of this issue in her own research almost one year ago, it became clear that several doctoral students working on seemingly different technologies were developing very similar intelligence for distributed decision-making by these technologies. They all amounted to recognizing that predictions about system conditions, combined with the obvious objectives of maximizing expected profits and/or benefits without taking too much risk invariably amounted to posing fundamentally the same distributed dynamic programming problem, or its variations, notably model-predictive control. The approach enables these distributed decision makers to optimize on the go, with electricity price in particular, as new information becomes available. The result of the optimization is implemented only for the next time interval. Such look-ahead prediction-based decision-making enables the distributed resources to smooth out their decisions and capture intertemporal correlation to the largest extent possible. When each group of distributed decision makers performs such distributed look-ahead optimization it creates simple supply and demand functions which no longer need to carry explicit intertemporal constraints. System aggregators and/or operators, in turn, perform static deterministic optimization to select the best resources for the next 24 hours, for example. Their complexity comes from having to optimize interspatial dependencies and avoid network congestion. Once this is done, the system operator responsible for the feasible delivery of scheduled resources computes the locational prices and posts them for system users to see; they, in turn, optimize their own objectives, and this interactive process continues over time. This solution approaches the solution achievable using a single centralized dynamic programming subject to nonlinear network constraints. The software for the latter is not likely to be developed for large network systems anytime soon.

Therefore, papers by Peças *et al.*, Callaway *et al.*, Xie *et al.*, and Houwing *et al.*, concerning the optimal use of (PH) EVs, demand side response, wind generation, and micro-CHPs, respectively, all offer fundamentally the same approach to integrating specific technologies of interest to them. The predictive distributed look-ahead intelligence is suggested to be embedded into these resources, and this is followed by consequent interactions with the system operators. Of course, the time scales at which these technologies can respond are determined by their actual temporal and physical characteristics, and the levels of controllability available to them through local sensing and automation all lead to qualitatively different supply and demand functions. However, the decision-making protocol and the rules for managing spatial complexity should be done by the layers of system aggregators and operators, while managing the intertemporal dependencies should be embedded into the distributed resources. Different authors claim different potential benefits from such an approach. For the purposes of connecting the dots in this issue, it should be clear that the more distributed decision makers of this type there are, the more sustainable the overall system will be, while the technologies exercise their choice as they decide what to build and what to offer for scheduling according to their own interests. Both risk-free dispatch and the DYMONDS framework are nothing else but implementation frameworks in which much intelligence is embedded in as many technologies and communicated multidirectionally across several network layers.

The papers by Peças *et al.*, Houwing *et al.*, and Callaway *et al.* primarily deal with the customer or load side of the future electric power system. In the first paper by Peças *et al.*, a conceptual framework for integrating electric vehicles into an electric power system is presented. A massive penetration of electric vehicles, either fully electric or plug-in hybrid, will impose new demands and requirements on the grid technical operation and design as well as on the power market environment. On the other hand, this new load can provide reserve power to the grid, vehicle to grid (V2G). The paper illustrates the potential impacts/benefits arising from the electric vehicles grid integration.

In the second paper by Houwing *et al.*, the possibilities for incorporating the demand side more actively are elaborated upon. Particularly in combination with distributed local microcombined heat and power systems (micro-CHP) an efficient management of both heat and electric loads can be done. A simple control-based price signal only and a more advanced control scheme based on model predictive control are used to demonstrate the potential cost savings for households. It is shown that in a system having both heat and electric demand micro-CHPs can be very efficacious.

The third paper by Callaway *et al.* discusses a conceptual framework for actively involving highly distributed loads in power system control actions. The context for load control is established by providing an overview of system control objectives. In order for the load control to respond fast, it is necessary to enable predictable control opportunities.

The paper by Xie *et al.* concerns the fundamental difficulties of integrating large amounts of wind power into the system and conjectures that these difficulties are due to high intertemporal fluctuations and imperfect predictability. This is manifested in the increased need of power reserves for frequency regulations. Possible alternatives are suggested for a reliable and cost-effective operation. Prediction and operational interdependencies over different time scales will be critical aspects of future research.

XII. TOWARDS THE CLEAN ENERGY DREAM

In conclusion, it is suggested in this issue that much R&D is needed to assess the potential benefits from integrating the new energy network systems frameworks and to compare their potential performance with what is achievable as many more novel resources get deployed on the system according to today's operating and planning practices. Our conservative estimate for the electric energy system alone is that a 25% increase in efficiency can be obtained today by such transformation without degrading the reliability of services. However, while much of the hardware exists, meeting this goal still poses a fundamental challenge to the current state-of-the-art in the systems, networks, and computer sciences. Any large-scale penetration of intermittent resources is practically impossible without equally large-scale sensing, actuation, and online data-assisted decision-making by various industry participants, including independent system operators (ISOs), load service entities (LSEs), power producers/aggregators, and finally the end users. In short, these resources cannot bring full benefits to the consumers and society without significant improvements in how the infrastructure is operated and planned. The seemingly diverse ideas in the contributed papers all converge to a handful of conceptual paradigm shifts which would make a qualitative difference in overall energy utilization. This perhaps means that a faster formalization of carefully mapped state-of-the-art knowledge into a targeted technology transfer toward transforming today's relatively passive T&D into an enabler of system-wide energy provision while allowing for choice should be considered. A planned R&D program in close collaboration with the industry toward modernizing energy network systems in parallel with planning a stronger grid based on today's industry practice would at this point go a very long way to making the clean energy dream we all share a reality. ■

Acknowledgment

M. D. Ilić would like to gratefully acknowledge the help of the three associate editors: Prof. G. Andersson, Dr. D. Novosel, and Dr. V. Madani. They have been part of conceiving this issue from day one and have helped finish it. Their many volunteered hours have made this issue possible despite everyone's very difficult schedules caused by truly dynamic changes in our field. Special thanks go to Prof. Andersson for going beyond the call of duty when it became clear that his help would be the key to the last mile before the job was done. She would also like to acknowledge absolutely superb supportive guidance by Jim Calder, Jo Sun and, most recently, Margery Meyer, our PROCEEDINGS OF THE IEEE team. They have been true masters in streamlining us when all signs seemed to point to slowing down. They have done this in gentle ways which only made us try harder. Thank you all!

MARIJA D. ILIĆ

ABOUT THE GUEST EDITORS

Göran Andersson (Fellow, IEEE) received the M.S. and Ph.D. degrees from the University of Lund, Lund, Sweden, in 1975 and 1980, respectively.

In 1980, he joined ASEA's, now ABB's, HVDC division in Ludvika, Sweden, and in 1986, he was appointed Full Professor in Electric Power Systems at the Royal Institute of Technology (KTH), Stockholm, Sweden. Since 2000, he has been a Full Professor in Electric Power Systems at ETH Zürich (Swiss Federal Institute of Technology), Switzerland, where he also heads the powers systems laboratory. His research interests include power systems dynamics and control, and future energy systems.

Dr. Andersson is a Fellow of the Royal Swedish Academy of Sciences, and of the Royal Swedish Academy of Engineering Sciences. He is the Editor-in-Chief of *IET Proceedings Generation, Transmission and Distribution and recipient of the IEEE PES Outstanding Power Educator Award 2007.*

Marija D. Ilić (Fellow, IEEE) received the Dipl.Eng. and M.E.E. degrees from the University of Belgrade, Belgrade, Yugoslavia, in 1974 and 1977, respectively, and the M.Sc. and D.Sc. degrees in systems science and mathematics from Washington University in St. Louis, St. Louis, MO, in 1977 and 1980, respectively.

Currently, she is a Professor at Carnegie Mellon University, Pittsburgh, PA, with a joint appointment in the Electrical and Computer Engineering and Engineering and Public Policy Departments. She is also the Honorary Chaired Professor for Control of Future Electricity Network Operations at Delft University of Technology, Delft, The Netherlands. She has 30 years of experience in teaching and research in the area of electrical power system modeling and control. Her main interest is in the systems aspects of operations, planning, and economics of the electric power industry. Most recently she became the Director of the Electric Energy Systems Group at Carnegie Mellon University (http://www.eesg.ece.cmu.edu); the group does extensive research on mathematical modeling, analysis, and decision making algorithms for the future energy systems. She is leading the quest for transforming today's electric power grid into an enabler of efficient, reliable, secure, and sustainable integration of many novel energy resources. She has coauthored several books in her field of interest.

Prof. Ilić is an IEEE Distinguished Lecturer.

Vahid Madani (Fellow, IEEE) received the B.S. degree and the M.S. degree in power systems from the University of Idaho, Moscow, in 1983 and 1985, respectively. Currently, he is working towards the Ph.D. degree at the Mississippi State University.

Currently, he is the technology lead for advanced wide-area remedial action schemes, and is a Principal Engineer responsible for standards and modernization at Pacific Gas and Electric Co. (PG&E), San Francisco, CA. He is a Phi Kappa Phi and Tau Beta Pi member, and a registered Electrical Engineer with more than 25 years of academic and utility experience and recipient of many distinguished citations, for leadership, inventiveness and contributions to the power system industry and education. His latest assignment is deployment of the largest scale advanced warning systems and integration of synchrophasor technology into the PG&E's system. He has various technical, advisory, and leadership roles in North America and internationally, and has contributed to the development of many applications in system protection and intelligent restoration. For a decade, he served as Chair of the WECC RAS Reliability Subcommittee. He currently Chairs the Performance Standards within the North American Synchrophasor Initiative (NASPI). He is the author of more than 75 publications in refereed international journals in system automation, protection and control applications, and practical wide-area monitoring systems with advance warning and fast restorations. He is also the coeditor of the 2006 McGraw-Hill year book of science technology, and the 2008 Edition of *International Journal of Reliability and Safety* (IJRS) for InderScience Publishing.

Damir Novosel (Fellow, IEEE) received the M.Sc. degree in electrical engineering from the University of Zagreb, Zagreb, Croatia and the Ph.D. degree in electrical engineering from the Mississippi State University.

Currently, he is the President of Quanta Technology and Energized Services. He has over 29 years of experience working with electric utilities and vendors. He has developed and consulted on a number of products and methods to improve power system performance. He has created and managed several reputable and successful organizations that developed innovative technology and industry best practices in various areas of power systems. Prior to joining Quanta Technology, he was the President of T&D Consulting at KEMA in the United States. He has also held various positions in ABB including Vice President of global development and product management for automation products. He currently holds 16 U.S. and international patents. He published over 100 articles in refereed journals and conference proceedings in various areas of power systems.

Dr. Novosel is currently Vice President of the IEEE PES Technical Council and member of the IEEE PES Governing Board. He is co-chairing Performance Requirement Task Team for the North American Synchro Phasor Initiative (NASPI), large-scale activity of the North American utilities on implementation of Synchronized Phasor Measurements. His work in electrical power system monitoring, protection, control, and automation earned him international recognition and he was elected IEEE Fellow.