Workforce Development - Meeting the Educational Challenge of the Smart Sustainable Grid

Future Grid Thrust Area 4 White Paper

Power Systems Engineering Research Center

Empowering Minds to Engineer the Future Electric Energy System

Thrust Area 4 White Paper

Workforce Development: Meeting the Educational Challenge of the Smart Sustainable Grid

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Power Systems Engineering Research Center

The Power Systems Engineering Research Center (PSERC) is a multi-university Center conducting research on challenges facing the electric power industry and educating the next generation of power engineers. More information about PSERC can be found at the Center's website: http://www.pserc.org.

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Executive Summary

The issue of workforce development for a sustainable smart grid is important for several reasons. First there is a projected shortage of qualified engineers and technicians in this area. Second this workforce will need to be educated with a new set of skills and tools. It is understood that all research activities as a part of this initiative as well as other research efforts in this area will contribute to the development of this workforce by educating graduate students, and possibly undergraduates, through participation in the research projects. The education through this channel will be deep but relatively speaking narrowly focused both in terms of content and the targeted audience. The scope of this thrust is thus broader, i.e., education of a much wider audience as well as giving a more comprehensive content to those engaged in research on particular topics.

In addition to the regular power systems engineering education on generation, transmission and distribution, six areas of technology are identified as essential for the education of the workforce for the smart grid. These are *cyber technology*, *power electronics*, *energy conversion, smart grid sensing technologies, reliability and risk assessment*, and *market and economics*.

There are several challenges for the education of this workforce. In the environment of restricted hours available in the curriculum, the struggle between the depth and breadth of coverage is always a problem and in addition in most schools the pace and rigor of the course also typically needs to be geared towards the average student. Most of the power system related programs are relatively small and have access to only a narrow set of specialties. Even in the larger programs, the expertise of faculty is determined by the research they engage in. Therefore expertise for all the needed technologies may not be available in a given school. On the other hand, the evolution of the future grid is fast-paced and the key technologies are in constant flux. Therefore, the curriculum and training to develop the workforce that will design and operate the future grid also needs to be fast-paced, flexible and able to quickly adapt to rapid technology developments, while simultaneously ensuring solid foundation in the fundamentals of core power engineering disciplines. The interdisciplinary expertise required for smart grid technologies, including measurements, communication, computing, and control, make the required education and training more challenging. Also the students need to be able to work in interdisciplinary teams.

The vast expertise collectively available in the PSERC schools provides a pool of talent to meet these challenges. Through this process of collective and collaborative wisdom, cutting-edge research and insightfulness can be made accessible to practicing engineers, researchers and students. This talent needs to be tapped to write books and produce educational material that can be used for both the self-education as well as for teaching by instructors in various institutions within and outside PSERC. The being at cutting edge and portability of this material is an important issue - to keep pace with the developments, the material should be periodically developed and disseminated using appropriate technology.

Six specific tasks have been initially undertaken for this thrust to meet the needs of the smart grid engineering workforce. In undertaking these tasks, the intended audience as well as its needs has been considered. It is understood that we need to cater to a diversity of audience and its educational needs and plug the gaps in their current education. To cover a wide spectrum of needs, breadth and depth have been considered in selecting the tasks. Some educational materials will be focused on providing the breadth and the others on depth in needed areas. Task 1 covers a variety of topics and provides a mechanism for disseminating rapid advances in an efficient manner. Tasks 2 and 3 are focused on covering the breadth of the selected topics. The courses in tasks 4, 5 and 6 cover depth in areas of real importance to the emerging grid but are generally not covered in depth because of shortage of faculty expertise in these areas. Collectively these tasks will provide educational material for a comprehensive education of the workforce.

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1 Introduction

The electric power system is transforming into a smart grid that integrates clean and sustainable energy sources. The distinct features of the future grid are heavy penetration of variable energy sources, integrated microgrids, central and distributed energy storage and massive deployment of distributed communication and computational technologies allowing smarter utilization of resources and consumer participation. In addition, greater emphasis on reliability, resilience to physical and cyber-attacks, as well as use of energy storage and emergence of new loads and generation operating conditions make the monitoring, control and protection of electricity grid more challenging than ever. These factors, together with emphasis on markets and integration of variable sources of energy, result in a higher uncertainty in the planning and operation of future energy systems. The objective of this thrust is development of educational tools to meet the needs of the current and future engineers that will be managing these complex cyber-physical systems as well as innovators who will bring future transformations. The workforce development is important for several reasons. First, there is a projected workforce shortage [1] in this area and second future workforce will need to be educated with a new set of skills and tools which have not been part of traditional power engineering education [2].

The work force needs will happen at various levels [3]:

1. Skilled workers
2. Engineers
3. Managers

The Department of Energy has given contracts worth more than $100 million for the training of this workforce, mostly for training at the skilled worker level. We are concerned here with the engineering workforce. This workforce will be needed to design, construct and operate the future grid. Also it is this workforce that will produce innovative ideas and transformative changes needed to integrate clean and sustainable energy sources. The relevant education of this workforce is thus critical to the success of the future grid.

It is understood that all research activities as a part of this initiative as well as other research efforts in this area will contribute, to some extent, to the development of the workforce by educating graduate students through participation in the research projects. The education through this channel will be deep but relatively speaking more narrowly focused. The scope of this thrust is, however, broader, i.e., education of a much wider audience as well as giving a more comprehensive view to those engaged in research on particular topics. The intent here is to offer a set of courses for well-rounded education and reference that has as broad an impact as possible by allowing access to this material as conveniently as possible using the modern educational technologies. The being at the cutting edge and portability of the educational material will be thus an important feature.

Availability of text books as well the development of integrated course material can go a long way in providing a suitable education for this workforce. Few people have the time and background to study research papers and get educated, especially in the areas that undergo fast paced development. However a well-thought out and well written book can fulfill this need. The authors of these books have sometimes nurtured these ideas for a long time and the insights they can provide can lead to a better understanding on the part of the readers. The same is true for the course material prepared by experts in those areas. This dissemination of high quality cutting-edge educational materials can have a massive effect on the development of the field. The broad dissemination of such material is invaluable for professional development of current and future workforce and would make a long-lasting impact. As a Chinese Proverb says, “A book is like a garden carried in the pocket”. The availability of such material can have a transformative effect on the management and growth of the future grid.

2 The Opportunities and the Challenges

2.1 State of the Art and Major Challenges

The engineering workforce graduates from universities at various levels. The first level and most common source of this engineering workforce are the BSEE degree programs. At this level, the students typically take 3 to 4 courses in power systems or a combination of power systems and power electronics. As a result, only a limited depth can be expected at this level. The next level is the MSEE where the students can take more courses in their area of interest and have more depth. The highest level is of course the PhD where the students not only get more knowledge but also develop what is called evaluation abilities in Bloom's Taxonomy [2]. The evaluation level is the highest level of understanding which allows the individual to argue and debate alternatives and to evaluate arguments. The successful orchestration of the smart grid will need workforce at all the three levels in different proportions.

Let us examine what may be needed for the education of the work force for the smart grid. In addition to the regular power systems engineering education, the workforce will need the following as summarized in Figure 1.

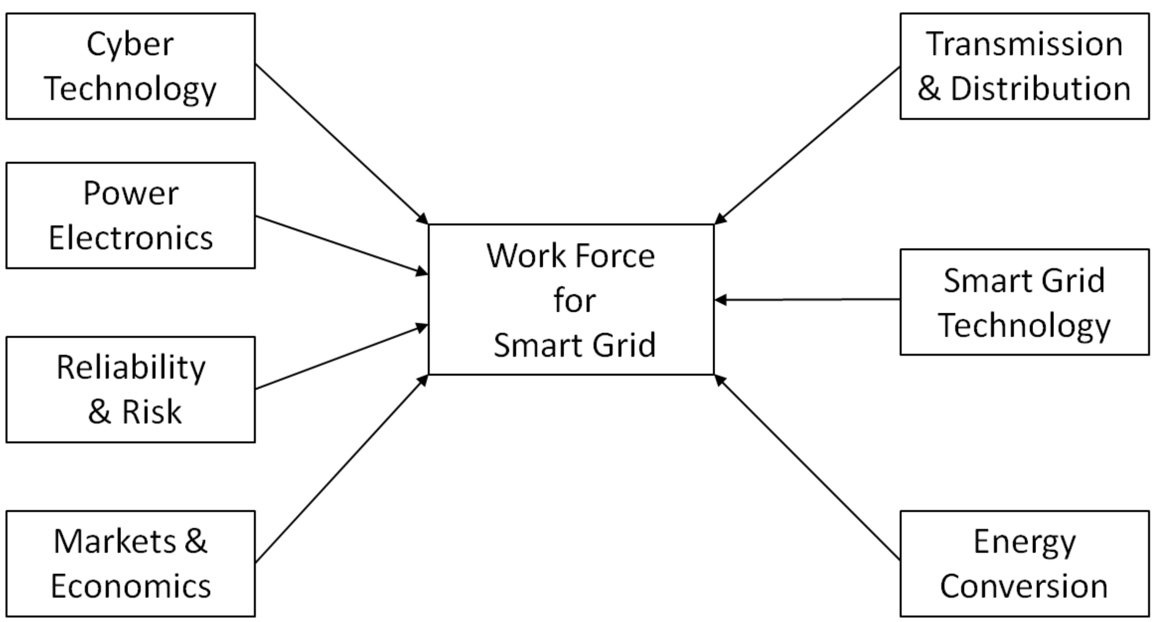

Figure 1: Education of Workforce for Smart Grid

Cyber Technology

With the massive infusion of telecommunication and computing technology, the power system is becoming one of the largest, if not the largest, cyber-physical system. The power engineer of the future will need sufficient knowledge in cyber technologies to be able to interact with the experts in these disciplines and articulate their needs from the grid perspective. He/she will need to become an interdisciplinary agent to be able to properly utilize the services of these experts.

Power Electronics

With the significant integration of renewable energy sources and the demand responsive loads, power electronics will be one of the enabling technologies for power conditioning and control for the interface between the grid and the renewables on one side and the loads on the other.

Energy Conversion

Various types of energy conversion technologies will be used for converting wind, solar and other "green" energy resources into electrical energy and utilization in the EVs and PHEVs.

Smart Grid Sensing Technologies

It is expected that syncrophasors and other sensors will play a significant role in the smart grid. Recently, there were significant efforts in developing and deploying smart sensors across the grid. Future grid will integrate microgrids with energy generated from small generators, home-scale fuel cells and solar panels centralized or distributed such as roof tops with PV shingles and side panels with PV coating. Future grid will also integrate energy storage components, both centralized as well as widely distributed like the PHEVs or EVs. All these technologies may be lumped under the smart grid technologies. The smart grid engineers will need to be knowledgeable about these technologies.

Reliability and Risk Assessment

Reliability is expected to be the hallmark of the future grid. A reliable system does not, however, happen by itself. Careful analysis and evaluation is needed at the planning and design stage to engineer reliability into a complex system. With active customer participation in demand response, the manner in which reliability is implemented may need to be changed into the Reliability-Economics-Risk models rather than based on traditional fixed criteria for reliability.

Markets and Economics

Markets will be an integral part of the future grid. Markets are instrumental for efficient operation of the grid, as well as integration of renewables. Markets need to be introduced in a manner that ensures the reliable operation of the grid.

Now let us examine the challenges to implement such a vision of the education.

- The tendency at the US universities is to give a broad based education to the students at the BSEE level. This is expected to open more opportunities and lifelong learning capabilities to the graduates. So at the BSEE level, the power curriculums need to compete with other specialization and general education for the credit hours that can be given to power system related courses. The power system related courses therefore need to design their education within these constraints.
- In the environment of restricted hours available, the struggle between the depth and breadth of covering is always a problem and in addition in most schools the

pace and rigor of the course also typically needs to be geared towards the average student.

- Most of the power system related programs are small and have access to only a narrow set of specialties.
- Even in the larger programs, the expertise of faculty is determined by the research they engage in. Therefore expertise for all the needed technologies may not be available.
- The evolution of the future grid is fast-paced and the key technologies are in constant flux. Therefore, the curriculum and training to develop the workforce that will design and operate the future grid also needs to be fast-paced, flexible and able to quickly adapt to rapid technology developments, while simultaneously ensuring solid foundation in the fundamentals of core power engineering disciplines.
- The interdisciplinary expertise required for smart grid technologies, including measurements, communication, computing, and control, make the required education and training more challenging. Also the students need to be able to work in interdisciplinary teams.

2.2 New Opportunities/Technologies

The education of future workforce also provides new opportunities and the available and emerging technologies provide us with the means to address these challenges.

- Collectively, the universities in the PSERC provide a broad spectrum of expertise. This allows us a rare opportunity to tap their expertise to develop text books and course material to meet the interdisciplinary needs of education.
- Advances in e-learning technologies, and ubiquitous access to high speed internet provide a tremendous opportunity to address the above challenges.
- The objective is to develop a collection of educational material, books as well as notes, on various topics of sustainable energy systems, smart grid and power engineering, and on important background topics required to understand these concepts, and make them available to anyone interested. This will make it possible for people to teach a variety of subjects as the availability of such material facilitates offering such courses.
- Through this process of collective and collaborative wisdom, cutting-edge research and insightfulness can be made accessible to practicing engineers, researchers and students.

3 The Research Issues

In educating the workforce, the issues of breadth and depth need to be balanced. Also we need to consider the current gaps in the education of the existing workforce. The nature of audience, whether these are school going graduates, working engineers or other energy professionals also needs to be considered. We also need to make use of the e-learning technologies to provide an as up-to-date education as widely as possible.

After careful thinking, six specific tasks have been undertaken for this thrust. In undertaking these tasks, the intended audience as well as their needs has been considered. It is understood that we need to cater to a diversity of audience and their educational needs and plug the gaps in their current education. To cover a wide spectrum of needs, breadth and depth have been considered in selecting the tasks. Some educational materials will be focused on providing the breadth and the others on depth in needed areas.

Tasks 1, 2 and 3 are focused on covering the breadth of the topics needed. The courses in tasks 4, 5 and 6 are covering depth in areas of real importance to the emerging grid. Task 1 is not focused on any particular topic but rather provides a mechanism for disseminating rapid advances in an efficient manner. This task for PSERC Academy intends to develop a virtual library of short videos and has the potential to make a big impact due to flexibility of its mechanism and approach, short and focused content and availability on demand. This can serve various constituencies but perhaps the biggest beneficiaries would be the working professionals who want to gain an expertise on a given topic within a short time.

The Task 2, which will have participation by many experts, intends to cover a variety of smart grid fundamentals and provide a comprehensive educational package with text book and power points. The course proposed in Task 3 similarly has a broad coverage but with a different slant and more coverage of renewable energy.

The task 4, 5 and 6 serve the areas which are extremely important in this emerging scenario but are currently not served sufficiently because of the shortage of faculty with expertise in these areas. These areas of reliability, markets and infrastructure security will play an important role in these emerging complex cyber-physical systems. The course materials will not only help educate the workforce directly but also provide material for other educators to participate in these areas.

3.1 Task 1: PSERC Academy - A Virtual Library of Thousand Short Videos

3.1.1 Importance

Advances in e-learning technologies, and ubiquitous access to high speed internet provide a tremendous opportunity to address the challenges to educating the workforce. The objective of this task is to develop an *online library* of short, 15-20 minute videos on various topics of sustainable energy systems, smart grid and power engineering, and on important background topics required to understand these concepts, and make them available on demand to anyone interested. The online library complements conventional curriculum as well as addresses the needs of practicing engineers. Flexibility by design, ability to adapt based on continuous feedback, and self-paced learning for individual students are some of the major advantages of this online resource. As the library grows in volume and with the collective resources of PSERC, most of the advanced and specialized topics in sustainably energy systems can be covered in depth. In addition, cutting-edge research can also be quickly made accessible to practicing engineers and researchers.

3.1.2 The Vision of PSERC Academy

The vision is to develop, over a period of about 3-5 years, hundreds or even thousands of such online videos covering a wide spectrum ranging from basic introductory material to advanced topics, delivered using a range of methods from simple lectures and derivations of equations to sophisticated multi-media delivery. While the other tasks in the workforce development thrust area develop well-defined courses based on the identified gaps in existing curriculum and projected requirements, the PSERC Academy by design is more flexible and adaptive, both in terms of contents and format. It is by design meant to evolve over time based on user and expert feedback, changing needs and changing learning technologies.

It should be emphasized that the objective of PSERC Academy is not to just provide superficial overview of various topics because of the short duration of each video (20 minutes or less). It is just the opposite – with thousands of videos, the objective is to provide as much details and analytical rigor as needed and in as many different topics as is relevant, in order to gain a thorough understanding of a particular field and the ability to use them in practical applications. For example, the topic of photovoltaic inverters which is being developed in Year I of the project will have an 'overview' video that provides an overview of the functions of a PV inverter. But it will also include about twenty or more videos in Year I that go into the detailed design of PV inverters including various converter topologies, control methods, PV models, MPPT algorithms, standards, anti-islanding methods, microgrid operation, and several design examples and simulation validation. These videos together with several more delivered as part of basic power electronics module will give a student or a practicing engineer enough information to help in the actual design of PV inverters. In addition, there will be several more videos on modeling of PV inverters in power system analysis tools that will help power systems engineers to directly apply these in their system level studies without going through the details of inverter design. Over several years, through continuous additions based on emerging needs, it is possible that the topic of PV inverter alone may have more than a hundred videos.

3.1.3 Results of the Task

The videos are currently being developed use 'screencast' tools, since the videos will have a combination of power point slides, extensive simulation, derivations of equations by hand (with power point slides in the background) and animations. A screencast is a method to digitally record the computer screen output combined with audio narration in the background. As an example, the videos on the analysis and design of a basic buck dc-dc converter are available at http://youtu.be/Roqc4rTMzU4, and http://youtu.be/4bZMWoAZuM0, http://youtu.be/4XUKbnVn5R0 respectively.

In Year 1 of the project, i.e., by end of summer 2012, the task leader will develop three modules - power electronics, grid interface of photovoltaics and grid interface of wind energy, totaling approximately one hundred videos. In the second year, several PSERC faculty and industry members will also be invited, and together with the task leader will add another hundred videos on other power systems and smart grid topics. Plans to sustain the effort and grow the academy beyond this project duration will also be developed.

A dedicated website for PSERC Academy is under development. This will host the videos in logical modules and will be provide extensive search features for easy access to relevant videos. The videos will also be posted in YouTube for reaching out to a much wider audience. The website will also complement the videos with user-paced exercises with automated assessment/feedback, and online peer-to-peer correspondence.

3.2 Task 2: Smart Grid Education for Students and Professionals

3.2.1 Importance of this Task

In the Energy Independence and Security Act (EISA) of 2007, the focus on the Smart Grid was clearly stated in the Article XIII. In continuation of this focus, the American Recovery and Reinvestment Act (ARRA) of 2009 has served as a vehicle to get several major synchrophasor projects funded recently. This and other industry-wide projects in this area are creating a need to educate large groups of emerging engineers about synchrophasor fundamentals. While there is an excellent book published on the subject [4], the need for more elaborate instructional material is felt throughout the industry as the fundamental issues are being encountered and explored.

3.2.2 The Vision

A group of authors has engaged in development of instructional materials for this fundamental area. This effort includes:

- Develop comprehensive educational package that will reach out to educators, students, practicing engineers, managers, legislators, and public officials;
- Write a text book and prepare a set of presentations that may be used to:
  - **a)** Help educators in guiding students at different levels of education in their research efforts,
  - **b)** Help instructors in offering university courses, tutorials and short courses for practicing engineers and managers, and
  - **c)** Help public officials in presenting the issues to legislators and public at large (customers).

3.2.3 Expected Result

The results of this effort are expected to be summarized in a book with the following topics and also the instructional material.

Book

- Introduction

  -Definitions
  -Motivation
  -History
  -State-of-the-art

- Technology Background

  -Standalone PMUs
  -PMU-enabled IEDs
  -PDCs
  -System Architecture and Visualization

- Time Synchronization

  -GPS receivers
  -Local time synchronization
  -Time synchronization over a communication network
  -Time synchronization interface protocols

- Communications

  -PMU-PDC communications
  -Routers and gateways
  -NaspiNet
  -Quality of service

- Stability Monitoring

  -Requirements
  -New algorithms
  -Implementation
  -Benefits

- Stability Assessment and Control Applications

  -Requirements
  -New algorithms
  -Implementation
  -Benefits

- Protection and Fault Analysis

  -Requirements
  -New algorithms
  -Implementation
  -Benefits

- Energy management systems

  -Requirements
  -New algorithms

-Implementation
-Benefits

- Deployment Issues

  -Standards and interoperability
  -Testing
  -Upgrades and maintenance
  -Cyber security

- Conclusion

Development of Instructional Material so that Synchrophasor Knowledge may be Disseminated

The team will develop comprehensive educational package that will reach out to educators, students, practicing engineers, managers, legislators, public officials, etc. The group will work on the means to improve dissemination of the material about synchrophasor technology and applications. This will include development of teaching topics with corresponding PP slides, as well as development of short courses and short lectures that can convey "Synchrophasor 101" ideas to a larger audience of individuals not familiar with the engineering issues.

3.3 Task 3: Energy Processing for Smart Grid Technology

3.3.1 Importance of this Task

The Energy Processing for The Smart Grid course provides a fundamental understanding of energy processing and technologies needed for building smart grid. The current curriculum in energy conversion covers principles of transformer design and operation as well as the fundamentals of electric machine modeling characterization, and performance.

In preparing for the workforce needed to handle smart grid, new curriculum is desirable to include some of the new facets of smart grid development.

The Howard University contribution in this task is to develop a one semester course for senior undergraduates and first year graduate students without similar experience. The course will be done so the other PSERC schools can benefit from these modules.

The course outcome will assist in attracting and sustaining students in power systems and encourage them to face the challenges in the new electric networks.

3.3.2 The Vision

The course will ensure that students have the ability to model fundamentals of electric machines and transformers and also their operations performance and applications. In addition, it also provides modeling of renewable energy such as wind and solar resources while accounting for variability.

Students will be provided with the ability to model and analyze power electronics building blocks of inverters or converters.

Students will be equipped with the ability to understand real time measurements using phasor measurement units (PMU), smart meters and consequently use the measurements to perform real time stability, power flow and optimal power flow of the grid under different contingencies.

Students will be equipped with the ability to analyze control issues for both local and wide area in Smart Grid.

Students will be trained to design new protection schemes for new devices that have the capability to be integrated to the legacy system with appropriate communication and control protocols.

The course dissemination means will include e-book, white paper, pdf and power-point with outcome assessment. This will be done in each of the courses. We have presented different modules of the course and have also written position papers in IEEE meetings.

3.3.3 The Expected Results

The results will be course material for a semester long and a short course. The first draft of modules for the semester long course has been developed. These cover the following topics.

A. Overview of Fundamentals of Smart Grid

i. Definition of Smart Grid - Working definition given in terms of attributes of Smart Grid. The definition of smart grid was discussed to address the recent technological advancement in power grid.

ii. Stakeholders and global activity in Smart Grid.

iii. Architecture – the architectures of smart grid from both the consumers and utility perspective were evaluated.

iv. Comparison of smart grid, micro grid, and macro grid.

v. Real time measurements using the following instruments – PMU, Smart metering and state estimation.

vi. Communication, control and computational tools.

vii. Security in Smart Grid and role of Cyber Security.

viii. Grand challenges in Smart grid development.

B. Fundamentals of Energy Conversion and Power Electronics

The purpose of energy conversion is based upon electromechanical systems that are studied to determine the levels of efficiency of their use in the grid. We include power electronics concepts in the module to aid in the energy conversion processes. This course also evaluates renewable energy sources to include solar power, wind, biomass and other such sources in terms of cost, penetration level, grid connected environmental.

C. Storage Techniques

This includes evaluation and selection criteria of storage technology in terms of their characteristics, size, power, modeling, limitation, cost and construction. The value of storage techniques in Smart Grid is evaluated in a bid to ascertain the reliability enhancements of the grid:

D. Real Time Measurement for Energy Processing in Smart Grid

i. Phasor Measurement Units (PMU) or Synchrophasors PMU

ii. Smart meters.

E. State Estimation

Static and Distributed State Estimator Functions and Analysis are discussed specifically

F. Design for Local and Wide Area in Smart Grids

The Smart Grid requires different control schemes to ensure security, reliability and performance. In this course module we have reviewed the following control schemes for both global and local areas management of control problems. Here we provide the concept, modeling, and analysis of controls for both speed and fast control including the following: Load flowing in the grid was studied using both fast and slow; Voltage var, frequency control, protection under frequency load shedding techniques and stability assessment of the grid will be performed. This module is being covered as a lecture discussion and homework assignments.

G. Security and Cyber-security

The Smart Grid network to a large extent is concerned with the security which has been centered mostly on cyber threats instead of physical threats.

Standards on cyber security were discussed along with other indices for measuring the security of smart grid. We review the smart grid technologies that are being used in other countries so that we can provide the guidance on securing the networks.

H. Performance studies and activities securing the smart grid

These could be measured in terms of resilience, controllability; assessments and vulnerability of smart grid. Evaluation of optimization tools for performance assessment will be studied.

Test Beds for Smart Grid

We are reviewing existing test beds for doing smart grid and analyze and design technologies for building test bed for energy processing course. We plan to focus on specific demonstration for the course based on: demand response and some distribution automation functions.

3.4 Task 4: Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid

3.4.1 Importance

The power grid is emerging as a highly complex system with heavy penetration of renewable energy sources, central and distributed energy storage and massive deployment of distributed communication and computational technologies allowing smarter utilization of resources. In addition as the shape of the grid unfolds, there will be higher uncertainty in the planning and operation of these systems. As the complexity and uncertainty increase, the potential for possible failures with a significant effect on industrial complexes and society can increase drastically. In these circumstances maintaining the grid reliability and economy will be a very important objective and will be a challenge for those involved. Although many activities are involved in meeting these goals, educating the engineers in the discipline of reliability provides them with tools of analysis, trade off and mental models for thinking. Reliability cannot be left to the goodwill of those designing or planning systems nor as a byproduct of these processes but must be engineered into the grid and its subsystems in a systematic and deliberate manner. An important step in this process is to model, analyze and predict the effect of design, planning and operating decisions on the reliability of the system. However, there is a lack of educational tools for covering the spectrum of reliability modeling and evaluation tools needed for this emerging complex cyber-physical system.

3.4.2 Vision

The educational material developed through this task will provide the target audience with the state of the art tools for modeling and analysis of reliability of this complex cyber-physical system. This material will be useful for those who need to use these tools as well as those who want to do further research. They will be able to use this knowledge to make tradeoffs between reliability, cost, environmental issues and other factors as needed. The PI has an extensive research, application and educational experience in this field. He has not only developed new methodologies but also implemented them into commercial software and provides consultations to many major corporations on this topic. This effort will transfer this expertise to a very broad audience. All the material will be made available on a website.

3.4.3 Expected Results

The results will be course material for a semester long and a short course. The first draft of modules for the semester long course has been developed. These cover the following topics.

1. Overview of Power System Reliability Analysis:
    - What is quantitative reliability analysis, and why is it needed?
    - Basic probabilistic indices and their interpretations
    - Approaches to reliability considerations

2. Basic Probability Concepts and Calculations:
    - Events and sets
    - Combinatorial calculations and their applications
    - Probability distributions
3. Random Variables and Stochastic Processes:
    - Random variables probability distributions
    - Concept of the hazard rate
    - Stochastic Processes
    - Discrete time and continuous time Markov Chains
4. Frequency Balance Approach for Reliability Analysis:
    - Transition rate and frequency
    - Frequency of subsets or events
    - Equivalent transition rate and state space reduction
5. Methods of Quantitative Reliability Analysis:
    - State space approach
    - Network reduction
    - Minimal cut sets
    - Decomposition
    - Sequential and non-sequential Monte Carlo simulation
6. Overview of Power System Reliability Analysis:
    - Functional zones for reliability analysis
    - Dimensions of development–system coverage and solution approaches
    - Gaps in development
7. Single Area Formulation for Generation Adequacy:
    - Planning
    - Indices and their interpretations
    - Models and computation methods
8. Operational Reliability
9. Multi Area Reliability Analysis:
    - Formulation of multi area model
    - Analytical methods for solutions

- Monte Carlo methods for its solution

10. Composite System Reliability Evaluation:
    - Formulation of composite system reliability problem
    - Analytical methods
    - Monte Carlo methods for its solution
11. Integration of Variable Energy Sources Like Wind and Solar:
    - How they impact reliability
    - Modeling and computation
    - Capacity credit given to them
12. Integration of Cyber and Current Carrying Parts:
    - Modeling
    - Solution approaches

3.5 Task 5: A Course in Energy Economics and Policy

3.5.1 Importance

This track will focus on system level issues relating to the future grid. Within the task, faculty members in economics and engineering have been independently exploring the growing connection between the electricity and transportation sectors from very different perspectives. This task creates a variety of courses, instructional materials, and forums for advanced training that will work to combine the theoretical perspectives and empirical techniques of fields such as economics with the technical expertise and computational capabilities of the engineering and computer science disciplines.

3.5.2 The Vision

Any analysis of the future trajectory of the role of the smart grid must begin with a clear picture of the current and future costs and capabilities of the *existing* grid. Historically within the US, the technical capability of the nation's transmission network has been far more sophisticated than the market institutions put in place to utilize that infrastructure. Over the last 15 years, the advent of Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs) has revolutionized the way in which users of the grid interact with each other at the wholesale level. In some places, this has led to a substantial leap in the utilization of network services, *in the absence of any technological changes to the physical infrastructure.*

However, within the US electricity industry there are still many areas where market design, regulatory policy, and incentives still lag behind technology. About half the country still lacks transparent, formal markets for "balancing" the supply and demand of power in real-time. Many of these regions, particularly in the west outside of California, also contain vast potential for renewable energy development. However, without modern techniques for marketing energy and clearing markets with intermittent supply, the economic development of these resources will be constrained.

Economic policies for utilization of the future grid at the retail level are also relatively primitive compared to those being applied at the wholesale level in some regions. Despite the increasing adoption of "smart-meters" for many retail customers, the structure (but not the level) of retail rates for the vast majority of those customers remains unchanged from those applied 30 years ago when meter technology limited pricing options.

In short, unless advances in the economic and market design realms keep pace with those in the technology realm, the full potential smart grid technologies will not come close to being realized.

3.5.3 Expected Results

The expansion of research and workforce capability on these topics therefore needs to focus on the development of human as well as physical capital. Therefore the energy economics task within this track is focusing on coursework that can be applied at a variety of technical levels to a broad set of prospective students. University coursework is being developed for the Master's level as well as doctoral level. In addition, some material is being adapted to a "short-course" format for industry professionals.

The courses will cover the economic fundamentals of both electricity and energy markets. The goal is to provide a deep understanding into the economic and technological drivers that led to the regulatory policies and market institutions that have dominated the electricity industry over the last century. From such a base, one can explore how advances in both technology and economic policy have made possible new market designs and helped to spur increased wholesale trade.

A complete view of the potential role of the future grid within the energy sector must also consider the economic characteristics that permeate the energy industries. The energy industries are heavily influenced by environmental and network externalities, as well as the long-term physical constraints of exhaustible resources. There is also the potential for (and reality of) significant market power in many segments, caused by the relatively concentrated control of both physical resources and intellectual property. While essentially commodities, energy markets are also frequently separated by the costs and limitations of storage and transportation. The presence of all these influences contributes to the large role of government regulation and policy in the energy sector.

Because of all these factors, the behavior of individuals and market segments frequently deviates from the path predicted by technical models whose focus is on minimizing costs. A better understanding of the interplay of these factors is needed to accurately assess the impacts that specific public policies, such as tax-credits, purchasing mandates, and loan-guarantees, can have on market outcomes. The techniques of empirical economics, with their careful consideration of such issues as identification, endogeneity, and data quality, provide invaluable tools for measuring the magnitude and implications of the economic factors usually absent from purely.

3.6 Task 6: Critical Infrastructure Security - The Emerging Smart Grid

3.6.1 The Importance

This new smart grid course in development is in line with the need for interdisciplinary training to support the smart grid. This course will cover communication, computation and control aspects of the smart grid emphasizing cyber-security aspects. After taking this course, students are expected to contribute to security aspects of industrial projects related to the electric grid. Students will be able to understand vulnerabilities and the threats to the power grid and associated infrastructure in addition to understanding the basic principles of smart grid components and operation. Students are expected to critically analyze the interdependencies of related infrastructure in smart grid and apply the interdisciplinary principles that they have learned in building the smart grid.

3.6.2 The Vision

This task relates to design and development of a new smart grid course focused on cyber-security. The course is team-taught by power and computer science faculty members and intended for seniors and graduate students from computer science and engineering. Key areas of research focus include designing such an interdisciplinary course; locating and creating course materials; teaching in efficient manner and disseminating course material to be adopted by other educational institutes.

The course being developed at WSU has four components: smart grid operation and control; communication; data management and computing; and basics of cyber-security. The course will be team taught and titled as, "Critical Infrastructure Security: The Emerging Smart Grid". Our objectives in creating this course were:

- Design a course with multi-disciplinary content integrating topics from data communication, computing, control, cyber-security and power systems that are relevant to secure operations of smart grids.
- Design a course to target audience of senior undergraduate and graduate engineering and computer science students.
- Design a course that could be offered to online distance engineering students or engineers from industry as well as in the conventional classroom setting.
- Design course materials to be easily adopted by instructors at other schools.
- Design course evaluations that allow us to assess course outcomes and improve the content.

3.6.3 Expected Results

Course topic coverage is as follows:

- Smart Electric Grid Overview (3 weeks)
  - *Week 1*: Overview and introduction to the smart grid
  - *Week 2*: Sense, communicate, compute and control in a secure way

- *Week 3*: Performance objectives, SCADA, NERC/FERC, operational standards

- Communication (3 weeks)
  - *Week 1*: Layered communication model, physical & link layers, network layer
  - *Week 2*: Transport layer: datagram and stream protocols; glue protocols: ARP, DNS, Routing
  - *Week 3*: MPLS; Power system application-layer protocols: SCADA, ICCP, IEC 61850, C37.118; multi-cast and its uses
- Power System Data Management and Computation (3 weeks)
  - *Week 1*: Utility IT infrastructures; control center structure & software; CIMs, IEC 61850 and 61970
  - *Week 2*: Fault-tolerant computing basics; distributed computing basics
  - *Week 3*: Distributed computing architectures; middleware; WAMS data delivery requirements and mechanisms
- Cyber-Security (3 weeks)
  - *Week 1*: Basic concepts and applications of cryptography; software vulnerabilities
  - *Week 2*: Malware, network attacks, web security: Stuxnet
  - *Week 3*: Network protection, security testing, security practices, governmental efforts
- Linking All Topics Together (1-2 weeks)
  - Overall system architecture, WAMS application, NERC CIP standards, case studies

This course is being offered for the first time in spring, 2012, in a face-to-face setting and also online. The class meets two times a week with each lecture being approximately 75-minutes. The course is offered to distant students online using the *Tegrity* lecture capture software and the *Angel* course management system available at WSU media services. Student's feedback and evaluation of course will be taken into account to improve the course contents and organization in future offerings. Students' performance on assignments, quizzes, exams and a project will be another measure for learning objectives of this course.

4 The Future Grid & Workforce Development

Education is an enabling and empowering force. It provides knowledge, understanding, and insightfulness to understand problems and situations and make decisions. It also empowers the workforce to make further innovations to serve the power systems industry. Education can serve the workforce involved in the management and operation of existing technology as well as spur the progress to higher levels of accomplishment in the smart grid, through providing insightful and holistic viewpoints. The work done throughout this thrust will thus have a transformative and disruptive influence on the orchestration of the smart grid.

Five areas for development of course and text book material have been identified and pursued. These areas are synchrophasors, reliability, renewable integration, markets and economics, and critical infrastructure security.

In addition, the sixth task is to develop online course systems, named *PSERC Academy*, which serves a very broad clientele. The idea for PSERC Academy is partly inspired by the success and impact of www.khanacademy.org, a not-for-profit initiative, whose 4000+ video library on basic math, science and other topics is one of the most-used educational video resources as measured by YouTube views per day and unique users per month. The PSERC Academy targets a more advanced level of audience such as undergraduate and graduate students and practicing engineers and the format needs to be significantly different, but the vision is to make an equally powerful impact in the area of sustainable energy systems. If successful, in a span of a few years PSERC Academy can become the go-to resource for any technical topic in this area. It could serve as a quick reference material such as Wikipedia, but with an important difference that content is prepared by recognized experts in the respective areas. It could also provide a complete curriculum that instructors can adapt, or serve as a complete self-learning electronic resource. An interesting application for the videos will be to adopt them as the complete lecture component of a class, and use the freed-up class time for a series of highly productive instructor meetings with small groups of students. Finally, the success of PSERC Academy can inspire similar efforts in other disciplines.

PSERC provides a rare opportunity to engage so many internationally recognized experts in different fields in a major educational effort. The collective knowledge, insightfulness and wisdom gained through intensive research and education should be utilized to provide excellent educational materials in the form of books and instructional materials. This thrust will produce great products but this effort needs to be continued in the future to update the material as well as provide more coverage. In today's fast changing environment, education should be a continuous and life-long effort for industry professionals. PSERC's collective intellectual capability and vast expertise can help in achieving this goal.

5 Conclusions

This thrust is directed to development of educational tools to meet the needs of the current and future engineers who will be managing emerging power systems that will be complex cyber-physical systems. We need to focus both on the current and new technologies as well as emphasize fundamental principles enabling future fundamental changes and innovations in how we design and operate power systems.

In addition to the regular power systems engineering education on transmission and distribution, six areas of technology are identified as essential for the education of the workforce for the smart grid. These are cyber technology, power electronics, energy conversion, smart grid sensing technologies, reliability and risk assessment, and market and economics. It is recognized that at the BSEE level, the power area needs to compete with other areas and core curriculum courses for credit hours. So a limited depth can be expected and these engineers would need resources to make up this gap. The MS and doctoral level can gain sufficient knowledge and ability to perform deeper work. The other challenges that we face are availability of faculty with diverse expertise in relatively small programs and fast pace of changing technology.

We feel that the vast expertise collectively available in the PSERC schools provides a pool of talent to meet these challenges. Through this process of collective and collaborative wisdom, cutting-edge research and insightfulness can be made accessible to practicing engineers, researchers and students. This talent needs to be tapped to write books and produce educational materials that can be used for both self-educations as well as for teaching by instructors in various institutions within and outside PSERC. The being at the cutting edge and portability of this material is thus an important issue. Also to keep pace with the developments, the material should be periodically developed and disseminated using appropriate technology.

After careful thinking, we have focused on six specific tasks. In undertaking these tasks, the intended audience as well as their needs has been considered. It is understood that we need to cater to a diversity of audience and their educational needs and plug the gaps in their current education. To cover a wide spectrum of needs, breadth and depth have been considered in selecting the tasks. Some educational materials will be focused on providing the breadth and the others on providing depth in needed areas.

Tasks 1, 2 and 3 are focused on covering the breadth of the topics needed. The courses in tasks 4, 5 and 6 are covering depth in areas of real importance to the emerging grid. Task 1 covers a broad range of topics and provides a mechanism for disseminating rapid advances in an efficient manner. This task for PSERC Academy intends to develop a virtual library of short videos and has the potential to make a big impact due to flexibility of its mechanisms and approaches, short and focused content, and availability on demand. This can serve various constituencies but perhaps the biggest beneficiaries would be the working professionals who want to gain an expertise on a given topic within a short time.

Task 2, which will have participation by many experts, intends to cover a variety of smart grid fundamentals and provide a comprehensive educational package with the text book and power points. The course proposed in Task 3 similarly has a broad coverage but with a different slant and more coverage of renewable energy.

Tasks 4, 5 and 6 serve the areas which are extremely important in this emerging scenario but are currently not served sufficiently because of the shortage of faculty with expertise in these areas. These areas of reliability, markets and infrastructure security will play an important role in these emerging complex cyber-physical systems. The course materials will not only help educate the workforce directly but also provide material for a large group of educators to participate in these areas.

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