Foreword for the Special Section on Power and Energy Education

THE last decade has seen significantly increased activities in the power and energy field. Specifically, the renewable generation has increased multi-fold and many technologies associated with *Smart Grid* are being implemented by utilities. Along with increased activities in the industry, there has been a resurgence of the power systems area at the universities. The enrollments in power and energy related classes are at an all-time high and more universities are engaged in research in the area. Several agencies have targeted research and educational funding to meet the needs of the growing area. New courses, laboratories, curricula, outreach activities, and pedagogy are being developed both in academia and industry to capitalize the opportunities. Despite a high level of activities on these topics, very few papers related to them have been published over the last ten years.

The last time a special section devoted to power and energy education was published was in 2004. In that special section, with Dr. Peter Sauer, Dr. G. T. Heydt, and Dr. Vijay Vittal as Guest Editors, twenty (20) papers on various aspects of power and energy education were published. Following the special section, the number of papers on power and energy education dropped significantly as visible from Table I. The data clearly showed a need to stimulate activities in this arena. This special section was created to meet this need and to capture activities going on around the world for the benefit of professionals engaged in power and energy education. Another goal is to promote interactions between the academia and practicing engineers to further advance the activities.

Over 100 abstract were submitted in response to a call for papers for the special section. Out of those, 47 authors were invited to submit full papers. The papers submitted by the authors were reviewed and following that, 15 were selected for publication in the special section. These papers can be broadly placed into four categories, which are

- outreach;
- course and curriculum development;
- laboratory development;
- software tools.

A brief summary of each paper in the four categories follows.

A. Outreach

Chen, Tomsovic, and Aydeniz discuss two outreach programs of the NSF-DOE funded Center for Ultra-wide-area Resilient Electrical Energy Transmission Networks' (CURENT). The curricula of the two summer programs exposes middle and high school students to electric and renewable energy concepts, engineering design, and microgrid projects. Results of assessment focused on improvement in areas such as engineering knowledge, confidence in succeeding in STEM (Science, Technology, Engineering and Mathematics) fields, and attitude toward engineering are presented in the paper. While the programs have been successful in increasing students' intention to choose an engineering career, they have been less successful at helping students feel they could be successful in STEM fields.

TABLE I
EDUCATION PAPERS PUBLISHED IN IEEE TRANSACTIONS ON POWER SYSTEMS IN THE PAST 10 YEARS

Year	No. of papers
2004	21
2005	5
2006	1
2007	1
2008	2
2009	2
2010	2
2011	2
2012	1
2013	0

Momoh presents the outcome of a summer enrichment program to promote and expose precollege students to electrical engineering concepts with an emphasis on power and energy, and STEM topics with the help of hands-on research projects. A 6-week program is attended by underrepresented U. S. high school students and international students and is supported by the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). The main goal of the program is to expose and attract underrepresented groups to electric power and energy. Hands-on experiments include fuzzy logic controlled PV powered billboard display, runway lighting power system protection system, residential intelligent control of electricity usage, and economic dispatch considering wind energy conversion systems. The author describes various educational outcomes of the program and related activities. Finally, results of tracking 330 students since the inception of the program are presented.

In the paper by Holbert, Grable, Overbay, and Nzekwe, three outreach components of the NSF-supported Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Engineering Research Center (ERC) which involve STEM teachers, and high school and middle school students are presented. The paper discusses the various aspects of each program at the five center institutions and an overview of an extensive assessment plan utilizing several established instruments aimed at measuring gains in knowledge, skills, attitudes, and behavior of its precollege and teacher participants. Further, the impact of the programs on its participants and broader pre-college community of students and teachers as well as a brief analysis of the return on investment of each component are presented.

B. Course and Curriculum Development

Mohan, Robins, and Wollenberg describe a new curriculum and pedagogy for electric energy systems education for undergraduate and graduate students. The curriculum focuses on providing a broad-based education with power systems, power electronics, and electric drives at the core. These courses are complemented by courses in control, embedded systems, digital signal processing, programming, thermodynamics, heat

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transfer, etc. The paper describes various innovative laboratory experiments that have been integrated into the curriculum. Data given in the paper shows that the approach used by the authors at the University of Minnesota has attracted a large number of students to the curriculum. For wider dissemination of the approach, the authors have built a consortium called Consortium of Universities for Sustainable Power (CUSP™). The consortium conducts an annual workshop to train faculty members for the new curriculum.

The Professional Science Masters (PSM) Program is the model for a new MS in Electrical and Power Systems Engineering (MS-EPSE) program discussed by Baran, Carpenter, Borbye, Lubkeman, Ligett, and Covington. The program includes integrated courses and experiences in power engineering topics, cross-disciplinary technical topics, hands-on experiences in smart grid applications, and professional skills to prepare students for a successful career in the power industry. The paper discusses the unique aspects of this new type of professional masters program in engineering including the program outcomes, experiences in creating the courses, and results of assessment of the industry on the appropriateness of the program components in meeting industry needs and regular formative assessment of the students about their experiences. The MS-EPSE program has been well-received by the students and industry.

Quintero, Zhang, Chakhchoukh, Vittal, and Heydt present models, tools, and educational opportunities for transmission expansion planning for the future systems. The paper provides details of the next-generation transmission expansion planning process including optimization and verification of the plans. Mathematical models include cost equations, and validation of the plans is performed based on the system stability. A summary of various software tools available and their capabilities are listed. A case study of security assessment of bulk power system is presented. This is followed by a summary of experiences and student feedback on a class on transmission planning at Arizona State University. Finally, the paper provides guidance on developing a curriculum related to transmission planning.

Nordström, Zhu, and Wu discuss a portfolio for a multidisciplinary computer applications to power systems (CAPS) course and several smaller course modules which addresses properties of underlying information communications technology infrastructures for automation, operation, and control for active distribution grids and transmission system operation. The portfolio complements several masters programs and uses a problem-based learning approach to prepare students for work in the field. The paper focuses primarily on the CAPS course including its context within the portfolio, and additionally presents student assessment results, examples of student experiences, and how the course scope aligns with future workforce needs.

C. Laboratory Development

Leeb, Kirtley, Jr., and Muller present new pedagogy for teaching electric machines by focusing on experiments that relate to real life. They give undergraduate students a "hands-on" exposure for motor sizing rules, electrical terminal models, drive efficiency, and role of power electronic drives. The flexible kits designed by the authors for the laboratory portion allow students to build electromagnetic actuators and sensors. The focus of the class is to discuss different motor designs in relation to commercial products for inspiring students to compete in design contests.

Leeb, Alvira, Cox, Cooley, Kirtley, Jr., and Shaw present a hands-on kit built by them for prototyping power electronics. The kit allows students to design and build power circuits based on a flexible approach instead of a "cookbook" approach based on laboratory assignments. The goal is to expose students to real-world operating conditions to prepare them as well as excite them by providing opportunities to build relevant products. The class is of one-term focused on junior and senior students.

Designing and integrating wind power lab experiments into power and energy systems courses is the subject of a paper authored by Santoso, Lwin, Ramos, Singh, Muljadi, and Jonkman. Both simulation-based and hands-on experiments for undergraduate and graduate level students are discussed. The experiments have been implemented at the University of Texas at Austin and the University of Texas Pan American. A wide range of topics, such as operation of induction machines, modeling of aerodynamics, and electrical components of wind turbines, are included. Some of the experiments are integrated in an available power and energy course, whereas the advanced topics are included as part of a standalone wind energy course. Student feedback on the experiments is reported to be highly positive.

Rasheduzzaman, Chowdhury, and Bhaskara discuss their experience in remodeling an old machines lab to build a microgrid, which can be operated in both grid-connected and islanded modes. Six synchronous machines in the lab were converted to represent distributed generating units within a laboratory-based microgrid. Experiments include voltage control and power sharing between the generators in the islanded mode. Details of a Laboratory Grid Central Controller (LGCC) to coordinate operation of the microgrid are presented. A one-credit-hour lab course based on this laboratory was offered for the first time during the fall semester of 2012 at Missouri S&T University. Results of a survey of students show very positive impacts of the class.

Development of a hands-on laboratory-based curriculum in compliance with the Bologna Declaration is the topic of a paper by Kuzle, Juraj Havelka, Hrvoje Pandžíc, and Capuder. The course focuses on power system simulations, computer simulations, and high voltage. A miniature power system, which can be synchronized to the grid, is built for power system simulations. Various high voltage experiments for familiarization of students to high voltage phenomena are described. Results of feedback from students about the class show that the class has been successful with continuous improvements over the years.

D. Software Tools

Georgilakis, Orfanos, and Hatziargyriou propose an interactive approach for teaching and learning the concepts of transmission pricing. Pricing transmission services in competitive, interconnected electricity markets is an integrated component of economical operation of such systems. This paper mainly discusses the software tool that is built to study alternative transmission pricing schemes and their characteristics through modeling and simulation of small and large power systems. The approach has been experimented at the National Technical University of Athens. Student evaluation results provided in the paper show that the proposed approach has been a useful tool in enhancing students' learning experience.

A tool for teaching phasor measurement units is proposed by Dotta, Chow, and Bertagnolli. Phasor measurement units are becoming increasingly popular for wide area monitoring and control of power systems. The paper discusses a MATLAB©-based tool that is intended to provide a flexible environment for teaching phasor measurement and frequency estimation to undergraduate and graduate students. The evaluation results reported in the paper show that the tool has helped students better understand the concepts of phasor measurement units at the Federal Institute of Santa Catarina (IFSC) and the University of Sao Paulo (USP-SC), Brazil.

A paper by Strasser, Stifter, Andŕen, and Palensky proposes a simulation platform for ongoing training and education of power professionals and students. The motivation comes from the continuous changes happening in power systems around the world. With the growing interests towards making the power grid smarter, the complexity of power and energy systems grows. The focus of the paper is on interconnection of several engineering domains in the future smart grids. Modeling of grid components, monitoring and measurement systems, control aspects, communication platforms, and power system analysis tools are discussed. The platform has been implemented at the University of Applied Sciences Technikum Vienna, Austria, at the graduate level.

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