Development of a New Course on Smart-grid Communication and Security for Senior Undergraduate and Graduate Students

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Abstract: While the deployment of the smart grid, modernizing the nation's electric power infrastructure, is currently in the public eye with attention paid predominantly to deployment of advanced equipment, technologies and applications, a less prominent but equally vital factor to the smart grid's success is the need for a highly skilled electric power sector workforce. With the current labor force aging, a considerable number of the most knowledgeable workers in the power industry are heading toward retirement. Furthermore, even the most experienced workers often lack the updated skills and training needed to successfully support the advanced systems, tools and devices that make up the smart grid. An important aspect of the smart grid is communication and security. Supported by a grant from the National Science Foundation, and to train our students in the area of smart gird, a new course titled "Smart Grid Communications and Security" was developed and offered to train students with the required skills to succeed in this competitive job market.

This paper presents the development of this new multidisciplinary course at the Department of Electrical and Computer Engineering at the University of the District of Columbia. The course content includes various communication technologies that are essential in the evolution of smart grid, types of cyber-attacks on the grid, privacy and security issues, and their possible solutions. This paper will discuss the course content, the pedagogical approach used to deliver the course and the students' projects and presentations that have resulted from its offering.

I. INTRODUCTION AND BACKGROUND

Almost two decades ago, the US National Academy of Engineering developed a list of the 20 most significant and greatest engineering achievements of the 20th century which have had the most impact on the lives of people. Electrification, as supported by the electrical power grid, was first on the list (compared to the Airplane, Telephone, and Internet which ranked 3rd, 9th, and 13th respectively) [1]. Our century-old power grid is the largest interconnected machine on Earth, so massively complex and inextricably linked to human involvement and endeavor that it has alternatively, and appropriately, been called an ecosystem [2]. The grid consists of more than 9200 electric generating units with more than 1,000,000 megawatts of generating capacity connected to more than 300,000 miles of transmission. The 20th century electrical grid is being stretched to its limit in the 21st century. Since 1982, growth in peak demand for electricity – driven by population growth, bigger houses, bigger TVs, more air conditioners and more computers – has exceeded transmission growth by almost 25% every year and power outages are costing Americans more than 100 billion dollars every year [2]. In addition to the increasing demand for power, other factors driving the need for a modern 21st century smart grid include the increasing availability of local generation of electricity through distributed renewable sources such as solar and wind, customer energy efficiency, and improved reliability and operations. According to the National Institute of Standards and Technology (NIST), a Smart Grid is a complex infrastructure based on a set of seven chief domains [3]: bulk generation, energy distribution, power transmission, operation and control, market, service providers, and customers. Each domain comprises heterogeneous elements that include organizations, buildings, individuals, systems, system resources and other entities. The Smart Grid provides significant benefits in terms of its support for *bidirectional* flow of information both to the appliances and devices inside the customer premise and back to the utility provider using Internet Protocol-based communications. “Smart grid” technologies are made possible by two-way communication technologies, control systems, and computer processing [5]. These advanced technologies include advanced sensors known as Phasor Measurement Units (PMUs) that allow operators to assess grid stability, advanced digital meters that give consumers better information and automatically report outages, relays that sense and recover from faults in the substation automatically, automated feeder switches that re-route power around problems, and batteries that store excess energy and make it available later to the grid to meet customer demand [5].

While the deployment of a smart grid—modernizing the Nation’s electric power infrastructure is currently in the public eye with attention paid predominantly to deployment of advanced equipment, technologies and applications, a less prominent but equally vital factor to the smart grid’s success is the need for a highly skilled electric power sector workforce [6]. With the current labor force aging, a considerable number of the most knowledgeable workers in the power industry are heading toward retirement. Furthermore, even the most experienced workers often lack the updated skills and training needed to successfully support the advanced systems, tools and devices that make up the smart grid. The electricity industry will need a cross-disciplinary power grid workforce that can comprehend, design, and mange cyber-physical systems [7]. The electricity system of the 21st century will require an adaptable and flexible workforce with additional areas of expertise and capabilities than the current workforce. The integration of variable renewable sources, storage systems, smart grid, and demand management will require new training and skillsets [6]. The evolving demands on the electricity industry are causing a number of workforce challenges for the electricity industry, which include large shifts in skills needed and in geographic location of jobs, a skills gap for deploying and operating newer technologies, changes occurring during a period when the industry is facing high levels of retirements, and challenges recruiting and retaining a workforce that reflects the gender and racial diversity of the Nation. At the same time, the evolution of the industry is also creating a number of new workforce opportunities, including jobs in renewable energy, natural gas, and information and communications technology (ICT) [7]. The second edition of the U.S. Energy and Employment Report (USEER) published in January 2017 reported that about 862,000 people are employed in jobs related to electric power generation [8].

In recent years, various efforts [9]- [13] have explored how to incorporate Smart Grid topics into the engineering curricula however many of these proposed curricula have focused on modifications of current electrical engineering courses. Supported by a grant from the National Science Foundation, and to train our students in smart gird, a new course titled “Smart Grid Communications and Security” was developed and offered to train students with the required skills to succeed in this competitive job market.

This paper presents the development of this new course at the Department of Electrical and Computer Engineering at the University of the District of Columbia. The course was offered to our senior undergraduate and graduate students in the Spring 2017 at the Department of Electrical and Computer Engineering at the University of the District of Columbia and in Fall 2017 at the Department of Electrical and Computer Engineering at Rutgers University where the author is spending his Sabbatical leave. The course content includes an introduction to smart grid and its elements, various communication technologies that are essential in the evolution of smart grid, types of cyber-attacks on the grid, privacy and security issues, and their possible solutions.

The rest of this paper is organized as follows. In Section II, the course content is introduced and the main references in teaching the course are identified. In Section III, some of the student projects that were completed as part of this class are summarized. Finally, some conclusions are given in Section IV and future courses under development are introduced.

II. SMART GRID COMMUNICATION AND SECURITY COURSE INFROMATION

In this section we provide the catalog description for the course, the prerequisites and detailed information on the topics covered as part of the course. Sample projects completed by students in this class are presented in the next section.

Catalog Description

This senior level course informs the students of the various communication technologies that are essential in the evolution of a Smart Grid and will train the students about the types of cyber-attacks on the Smart Grid, privacy and security issues and their possible solutions. Through this course the students are expected to gain an in-depth knowledge about the communication and security aspects of a Smart Grid. Students are expected to finish a course project and make presentations in class.

Prerequisites

Undergraduate students must be in their fourth year of studies (senior standing) and have taken a course in digital and analog communications. Knowledge of Wireless Communications is a plus. In rare cases, students would be allowed to register for the course, if they register for a course in communication systems at the same time of registering for this class. Graduate students may register for the course with the permission of the instructor if they have not previously taken a class in communication systems.

Textbook

Smart Grid Communications and Networking, Hossain, Ekram Han, Zhu Poor, H. Vincent, Published: June 2012, ISBN: 9781107014138

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1. *Smart Grid Applications, Communications, and Security*, Lars T. Berger, Krzysztof Iniewski ISBN: 978-1-118-00439-5.
2. *Smart Grid Handbook*, Chen-Ching Liu (Editor-in-Chief), Stephen McArthur (Editor-in-Chief), Seung-Jae Lee (Editor-in-Chief), ISBN: 978-1-118-75548-8.
3. *IEEE* Papers specifically papers from the *IEEE Transactions on Smart Grid* and *IEEE Smart Grid Conference Proceedings.*

Topics Covered

The following topics were covered in the course. In addition to the textbook and references listed above, material was also collected from recent IEEE papers [14]- [25] and software tools [26].

1. An overview of power systems was given and a quick review of complex power, power factor, and real and reactive power was provided. The main elements of power system including power production and generation, power transmission, power distribution and power consumption (load) were then examined and an introduction to the economic dispatch problems was formulated.

2. Smart grid systems were introduced. Application and benefits of smart grid technology were discussed. The current status of smart grid in the United States was presented including the major government bodies and companies involved. The role of the government (specifically the Department of Energy and the National Institutes of Standard and Technology and various industries on the current/future projects on smart grid were examined. Smart grid standards were introduced and some of the current effort in modernizing the grid and the different types of projects completed were presented.

3. Communication technologies and network architectures that are used in smart grid were discussed. Specifically, Wireless Mesh Networks (WMNs) for smart grid communications was covered. WMN challenges and potentials for smart grid applications were presented. The IEC 61580, which is a communication standard for smart grid communications, and is focused on the communications across intelligent electronic devices and substations was presented. A

brief introduction to Power line communication (PLC), including broadband PLC and narrowband PLC was provided. The ZigBee protocol and its deployment for Smart Grid applications was presented in detail. Interference of ZigBee and WiFi was discussed. Applications of wireless sensor networks in the Smart Grid were furnished. The role of communication in building a smart home was covered.

4. Cyber security attacks that target the generation, distribution and control, and the consumption sectors of the Smart Grid were discussed. Load altering attacks and false data injection attacks that target smart meters and data centers and their effect on the demand response, situational awareness and system stability in the Smart Grid were presented. Defense mechanisms that can be used to block cyber-attacks or to minimize the damage caused by such attacks were discussed.

Course Outcomes

1. Students will have a basic understanding of power systems including production and generation and power flow analysis**.**

2. Students will understand the elements of a smart Grid System, including the two-way communication paradigm of the smart grid. Students will also learn about the integration of renewable energy sources such as wind and solar power into a smart grid system.

3. Students will learn about the various communication technologies used in smart grid, including powerline communication, Wireless Mesh Networks, ZigBee protocol and application of wireless sensor networks in the smart grid.

4. Students will learn about the cyber security attacks that target generation, distribution and control, and the consumption sectors of the smart grid.

5. Students will learn about privacy issues related to Smart Grid technology and methods to protect consumer electric consumption data.

Course Project

An important element of this course was a course project. At the beginning of the semester, the instructor provided the students guideline for course project. For the course project, students were encouraged to work in groups of 2 (for graduate students) or 3 (for undergraduate students). The students were provided with a list of possible research topics and were given guidelines to find 5 to 10 recent articles published in IEEE journals and conference proceedings and write a review paper. Alternatively, students were allowed to work on a hands-on project. A list of possible research topics that were provided to students is as follows:

1. Communication Security in SCADA
2. Substation Communication Standards and issues
3. Electric Vehicle Integration into the Smart Grid
4. Microgrid Technologies including DC and AC Microgrids
5. Home Area Networks for Smart Grid
6. Interoperability of Various Communication Protocols
7. Integration of Renewable Energy in Smart Grid
8. Internet of Things for Smart Grid and Internet of Energy
9. Security and Privacy issues in Smart Grid
10. Phasor Measurement Units and their Role in Smart Grid

A list of sample projects that students have attempted in the past is provided in the next Section.

<u>Course Evaluation</u>

Course evaluation was based on assignment, student presentations in class and a final project. Each student was asked to make a presentation on at least one IEEE research paper. Papers were selected by the instructor to make sure it fits the background of the students. If the paper required some background, this was covered by the instructor in class before the presentation by the student. Other components of course evaluation included a midterm project report and final project report presentations. The instructor worked with each group to help them select a project within the first 6 weeks of class. To expose students to research areas within Smart Grid, many review papers were uploaded to the course website for students to study. Each week, one recent IEEE paper was presented by a student in class. A feedback form was distributed among students for every presentation to rate the presenter. Feedback from the students were provided to the presenter at the end of the class by the instructor. The student took the time to provide written feedback to their peers which improved their skills in subsequent presentations. Figure 1, below, shows the feedback form used in the class.

Today's Date:________________________ **Presenter's Name:** ____________________________________

LECTURE CONTENT: Circle one number for each item.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I found the topic important to Smart Grid	5	4	3	2	1
The speaker was well prepared	5	4	3	2	1
In presentation simulated my interest in the subject matter.	5	4	3	2	1
Overall this was a good presentation	5	4	3	2	1

Please share any comments you have with the presenter or about the presentation topic below:

Figure 1: Feedback form for students to complete after each presentation.

III. SAMPLE STUDENT PROJECTS

Students all completed a course project. For the project students made two presentations, a midterm report presentation and a final project presentation. For the midterm report, the students wrote a two-page summary of what their intention was to do for their project and provided a list of references. If the project was hands-on the midterm project report gave an overview of what was to be done and the schematic of the design. For the final project report, each group presented their work in an IEEE style paper. For group projects each student identified the sections of the report that they had worked on. Below are a few sample projects that the students have completed in this class.

Project 1: A review of the application of Internet of Things (IoT) in Smart Grid

Brief Description of the Project: This project was done by an undergraduate student where she did a detailed study on the integration of IoT into the smart grid. IoT helps Smart Grid systems to support various network functions throughout the generation, transmission, distribution and consumption of energy by incorporating IoT devices (such as sensors, actuators and smart meters), as well as by providing the connectivity, automation and tracking for such devices.

Project 2: The Design of a Smart Switch Outlet Adaptor

Brief Description of the Project: In this project, a graduate student worked on the development of a Wi-Fi smart plug capable of remotely switching a load on or off. He designed a switch that monitors energy consumption and collects data from the plug, sending the data to a server that can communicate the data in real time to a website accessible on a user's smartphone. The student completed this project successfully over the course of one semester and demonstrated his design as part of the final class project.

Project 3: To Submeter or not to Submeter: How to make profit on Commercial and Residential Buildings

Brief Description of the Project: This project served to display how smart meters can be used from the owners/ landlord (commercial or residential) perspective to make profit through submetering. A submetering model, including hardware, software and billing was introduced. For the project a graduate student completed the project and introduced the type of meters developed by the company he is working for, and how companies and buildings can benefit from submetering, the issues with submetering, and possible solutions.

Project 4: Vehicle to Grid (V2G) Technology and its Integration into the Smart Grid

Brief Description of the Project: In this project, a group of 3 undergraduate students reviewed recent papers on V2G technology, provided an overview of power and frequency regulations in V2G, integration of renewable energy for V2G and finally battery wear and revenue models in V2G technologies.

IV. CONCLUSIONS AND FUTURE COURSES

To operate today's modern grid, a skilled workforce is needed. This paper presented our efforts to establish a new course on Smart Grid Communications and Security where students are trained on the various communication technologies used in smart grid and privacy and security issues of the modern grid system.

As microgrids are an essential part of the Smart grid of tomorrow, the author is currently developing a course on microgrids and distributed energy technologies where topics will include distributed energy resources (solar and wind), energy storage systems (batteries, fuel cells, flywheels, etc.) and the design and operation of microgrids. For this class students will be introduced to DER-CAM (Distributed Energy Resources Customer Adoption Model), an economic and environmental model of customer distributed energy resource adoption, which is developed by Berkeley Lab and would be required to complete a course project employing the tool.

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