AC 2012-3042: DEVELOPMENT OF A NEW MULTIDISCIPLINARY COURSE: SMART GRID

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Development of a New Multidisciplinary Course: Smart Grid

1. Introduction

The future power grid will be a comprehensive cyber-physical (hybrid) system, where the power grid should be able to deliver high quality, clean, reliable, efficient, and affordable electricity to consumers^{1,2}. Importantly, consumers will have more freedom in monitoring and managing their usage of power. More smart appliances and electric vehicles will emerge that interact with the grid. There will be a greater diversity of generation including thermal, wind, solar, hydraulic, biomass, etc. and all will be more easily integrated into the grid. Though power transfer over long distance will still be needed, centralized generation and distributed generators will coexist. Energy related information will flow among consumers, utilities and controllers over communication networks. The security of the system and customer privacy becomes more of an issue with increasing deployment of intelligent controllers and monitors. Advanced computer, communication, and network techniques must be invented to safeguard security. In addition, appropriate policies need to be in place to encourage generation of renewable energies, and deployment of advanced smart grid technologies¹.

For a student to gain a solid understanding of the smart grid, a multidisciplinary course covering various aspects is essential. We have developed a new course on smart grid. This class covers various aspects of the smart grid including engineering, economic, societal and regulatory aspects. Topics covered include automation and control, optimization, economic analysis, cyber security, standards and regulatory issues¹⁻⁴. Upon completion of this course the students will gain an understanding of a broad range of smart grid related concepts and various issues related to smart grid technology deployment, real time electricity pricing, and key technologies in both transmission and distribution systems required to realize the smart grid.

This paper presents the development of a new multidisciplinary course titled *Smart Grid - Automation and Control of Power Systems* at the department of Electrical and Computer Engineering (ECE) at the University of Kentucky. There is a pressing demand for smart grid savvy power engineers with skills in multiple disciplines. This new course aims to meet such a demand by training the next generation of power engineers to have the required skills to succeed in the competitive labor market, and was supported through a grant from the US Department of Energy. Another new class *Smart Grid – Communication and Network Perspectives* focusing on the cyber aspects of the smart grid has been developed and offered within the Department of Computer Science at the University of Kentucky.

The course is targeted at senior undergraduate and graduate students at ECE, but students from other engineering departments can also take this class. The course was first offered in the spring semester of 2011 at our university. Continuous improvements will be made to this class in future offerings.

The remaining paper is organized as follows. The course contents and pedagogical approach employed to successfully deliver the new course are presented in Section 2. Assigned projects

and presentations are described in Section 3. Evaluation of the effectiveness of the class is described in Section 4, followed by the conclusion.

2. Course contents and teaching methodology

According to the US Department of Energy (DOE), “Smart grid is the electric delivery network from electrical generation to end-use customer, integrated with the latest advances in digital communications and information technology for enhanced grid operations, customer services, and environmental benefits¹.” The objective of smart grid is to make the future grid intelligent, efficient, accommodating, motivating, quality-based, resilient, responsive, and green. The scope of the smart grid is quite broad and covers the delivery infrastructure, the end-use systems and related distributed energy resources, management of the generation and delivery infrastructure at various levels of control centers, information networks, and the financial and regulatory environment.

From the perspective of fundamental technologies, the DOE classified the key technologies that enable the smart grid into five areas: A) integrated communications, B) sensing and measurement, C) advanced components, D) advanced control methods, and E) improved interfaces and decision support. In terms of functionality, the smart grid technologies fall into general categories of generation automation, transmission automation, distribution automation, and power utilization automation.

On the other hand, implementation of smart grid projects and deployment of smart grid technologies will involve and affect various stakeholders such as utilities, customers, regulators, environmentalists, etc.¹ With more electric vehicles coming into being, smart grid may also affect and be affected by electric vehicle technologies.

Successful implementation of smart grid projects will require not only the right choice of technologies, but also customer acceptance and regulatory support. So, smart grid has a comprehensive range of relevant topics. The developed course focuses on automation and control of power systems and also covers some security and regulatory issues. The contents of this class can be largely divided into four modules as described below.

2.1 Course modules

Module 1: Introduction to Smart Grid

This module first teaches Supervisory Control and Data Acquisition (SCADA), Energy Management System (EMS), and Distribution Management System (DMS), which are already deployed in power systems. Key functions including power flow, resource scheduling, state estimation, fault analysis, and stability analysis are discussed. Then, the concepts of smart grid are introduced. An overview of the key technologies, vision, scope, and benefits of smart grid is given. In addition, standards relevant to smart grid development and deployment are briefly introduced. National Institute of Standards and Technology (NIST), North American Electric Reliability Corporation (NERC), International Electrotechnical Commission (IEC), and Institute of Electrical and Electronics Engineers (IEEE) are the major organizations responsible for

developing such standards. Example standards include IEC 61968 – application integration at electric utilities, IEC 61850-communication networks and systems for power substation automation, IEC 62351 – information security for power system control operations, and NIST Framework and Roadmap for Smart Grid Interoperability Standards.

In addition, deployment of smart grid technologies such as Advanced Metering Infrastructure (AMI) enables utilities to collect real time customer load, and may cause concerns on customer privacy. So, appropriate regulatory rules need to be in place to ensure customer privacy and promote customer acceptance of new technologies. Successful realization of smart grid will require approval of proper electricity rate structures such as time of use pricing and real time pricing. Again, regulatory bodies such as public service commissions need to stipulate necessary laws to encourage adoption of smart grid technologies, while recognizing that the cost to deploy smart grid technologies will ultimately be collected from rate payers. Utility motivations for deploying smart grid technologies will be explored. Smart grid promotes utilization of clean energy sources including wind, hydro and solar power. This will inevitably affect people who work in the coal industry. How to make up a proper renewable energy portfolio for utilities will require considerations of various factors.

By taking this module, students will learn that in order to successfully implement smart grid projects, we not only need to consider appropriate technologies, but also need to consider various societal and regulatory factors.

Module 2: Power Market and Real-time Price Calculation

In this module, we cover the power market structure and calculation of time of day, time of use, and real time electricity pricing based on microeconomics theory and linear programming optimization theory. When first taught, topics covered included the market structure, formulation of market clearing process as a mixed integer linear programming problem, solution to the problem by optimization tools including Matlab optimization toolbox and IBM ILOG optimization suite, and interpretation of the results^{5,6}. Economics concepts including shadow price, incremental or marginal cost, and sensitivity of production cost versus variable perturbations are discussed. The Locational Marginal Price (LMP) is defined as the cost for supplying the next MWh power to a load at a specific location. LMP consists of three components: Energy, loss and congestion cost. This module allows the students to understand the power market mechanism, and learns skills in power system, optimization and economy areas. Students will learn the ability to solve an engineering problem considering not only technical constraints, but also economical constraints.

Module 3: Transmission Technologies

Selected transmission technologies including Flexible AC Transmission System (FACTS), Phasor Measurement Units (PMU), and wide area monitoring, protection, and control are covered in this module. Synchrophasor data collected from PMUs across the power grid are directly compared and analyzed. Such synchrophasors provide great opportunities for wide area monitoring, protection and control. Application examples like dynamic thermal condition monitoring and rating, fault location, and dynamic stability monitoring are discussed^{3,7}.

Especially discussed in detail is how to estimate the conductor temperature utilizing real-time loading (current flow) and data collected from weather stations deployed at strategic locations based on the methods described in IEEE guide⁸. We also explain how to utilize PMU measurements to estimate the average line temperature in real-time for dynamic thermal rating purposes, where no weather information is entailed.

Module 4: Distribution Technologies

Selected distribution technologies that enable smart grid including smart metering, demand side management, voltage regulation and reactive power optimization are covered in this module. Power distribution systems are equipped with diverse types of voltage regulation and reactive power compensation devices for the purpose of maintaining system voltages within specified limits, correcting power factor, and reducing losses. How to optimize the voltage regulator and switchable capacitor settings is discussed. The objective function is either minimization of demand or loss. The constraints include voltage limits, harmonic limits, cable thermal ratings, regulator and capacitor bank setting limits, and power flow equations. The unbalanced distribution power flow algorithm that provides the basis for solving the problem is also covered in the class. We also introduce the problem of optimal placement of capacitor banks considering specified constraints. Potential benefits of harnessing real-time operational data and customer load data brought about by future advanced distribution SCADA and AMI for real time power flow and optimization analysis are discussed. Through this module, students will learn knowledge in electrical engineering and optimization methods.

2.2 Course outcomes

Upon completion of this course the students should be able to:

- Understand concepts of smart grid and various issues related to smart grid technology deployment
- Perform real-time electricity pricing calculation
- Understand key technologies in distribution systems that enable smart grid
- Understand key technologies in transmission systems that enable smart grid

2.3 Pedagogical method

This course intends to be delivered through classroom lectures. Both traditional blackboard method and power point presentation methods are utilized. Students are required to present some of their project results in the class, from which students can also learn from their peers' work. We utilize various software packages in the class including Matlab simpowersystem and optimization toolboxes, and IBM ILOG optimization suite. Students will further enforce what they learned by independently completing assigned projects described in Section 3 utilizing their own after-class time.

3. Course assignments

There are four projects at 25 points each for undergraduate students, and five projects at 20 points each for graduate students.

Project 1: Introduction to Smart Grid

Write a report on what the smart grid is, benefits, risks, and regulatory issues related to smart grid technology deployment.

Project 2: Real-time Pricing

Numerically solve real time pricing problems using sample power systems considering unit generation costs, unit capacity constraints, and transmission constraints. Students are required to present the results to the class.

Project 3: Distribution System Technology

Choose a paper in one of the following areas: voltage and reactive power optimization, microgrid, intelligent islanding, energy storage, issues related to distributed resource integration, and smart metering. Read the paper and write a report on the content.

The first time the course was offered, students chose the following topics for their projects: Energy storage systems for smart grid applications, voltage regulation for systems with distributed generation, reliability study of a microgrid power system, demand side measurement technology, smart metering - technology, benefits and issues, seeker optimization algorithm for optimal reactive power management, intelligent islanding technique applied to distribution system, and novel harmonic assessment method for a microgrid. These topics represent a comprehensive range of smart grid technologies in distribution systems.

Project 4: Transmission System Technology

Choose a paper in one of the following areas: Application of phasor measurement units for wide area monitoring, protection and control, fault detection, isolation and system restoration, and energy storage. Read the paper and write a report on the content. Students are required to present what they learned and their findings to the class.

The first time the course was offered, topics chosen by students included potential challenges for integrating intermittent renewable energy with smart grid, risk-based optimal maintenance scheduling for transmission system, voltage stability enhancement using PMU technology, advancement of energy storage devices and applications in power systems, wide-area monitoring, protection and control of future electric power networks, smart grid restoration concepts, and a robust control scheme for grid-connected voltage-source inverters.

Project 5: Reactive Power Optimization (for graduate students only)

Students are to numerically solve the problem of optimizing capacitor placement and voltage regulator settings in a distribution system.

In the future offering of this course, we plan to modify project 3 and 4 so that students will not only read and understand the selected technology presented in a paper, but also need to perform required modeling and simulation studies to verify the results.

It is worth mentioning that another new course *Smart Grid – Communication and Network Perspectives* has been developed within the Department of Computer Science at our university,

which focuses on communication and computer network perspectives.

4. Evaluation of Course Outcomes

Tables 1-3 show the course outcome assessment results based on our University's official Teacher and Course Evaluation (TCE) system. Table 1 shows the assessment results of the four specific outcomes of the course on a scale of 5.0. Table 2 lists the assessment results of the general educational outcomes on a scale of 4.0. Table 3 shows how the students value the course and rate the quality of teaching on a scale of 4.0. Table 1, column 3 gives the instructor's assessment based on student projects grades, and column 4 lists the assessment sources utilized by the instructor.

Table 1. Student Specific Learning Outcome Assessment Scaled to 5.0

Student Learning Outcomes	Student's Assessment from TCE	Instructor Assessment	Assessment Source
1. Understand concepts of smart grid and various issues related to smart grid technology deployment	4.8	4.7	Project 1
2. Perform real time electricity pricing calculation	4.8	4.8	Project 1
3. Understand key technologies in distribution systems that enable smart grid	4.5	4.6	Project 3, 5
4. Understand key technologies in transmission systems that enable smart grid	4.8	4.6	Project 4

Table 2. Student General Learning Outcomes Scaled to 4.0

General Learning Outcomes	Student's assessment from TCE
1. Learned to respect different viewpoints	3.6
2. Increase the ability to analyze and evaluate	3.9
3. Course helped ability to solve problem	3.9
4. Gained understanding of concepts and principles	3.9
5. Course stimulated me to read further	3.6

Table 3. Student Evaluation of the Course Scaled to 4.0

General Learning Outcomes	Student's assessment from TCE
1. Overall value of the course	3.9
2. Overall quality of teaching	3.9

These results indicate that the course is valued and well received by the students, and the delivery of the class has fulfilled the expected outcomes. Future improvements may be made based on research findings about multidisciplinary class of other educators ^{9, 10}.

5. Conclusion

This paper outlines the development of a new course on Smart Grid at the department of electrical and computer engineering at the University of Kentucky. This course focuses on power system aspects of smart grid. Key technologies in transmission and distribution systems that enable smart grid are covered in the class. Appropriate software tools are utilized to solve optimization problems. Students will learn knowledge in power system, optimization, economics, and also become aware of social and regulatory issues related to smart grid deployment. Initial offering of the class appears to be well received by students. We plan to continue improving and offering this class in future semesters. Another new course on Smart Grid focusing on the communication and computer network aspects of smart grid is developed and offered at the department of computer science at our university. These two new courses will enable students to have a good understanding of various aspects of smart grid.

6. Bibliography

1. US Department of Energy, Smart Grid, 2009.
2. US Department of Energy smart grid web site: <http://energy.gov/oe/technology-development/smart-grid>.
3. C37.118 Synchrophasor Standard, 2005.
4. IEEE 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, 2003.
5. Matlab Help Manual, The Mathworks, Inc., 2009.
6. IBM, IBM ILOG CPLEX manuals, 2009.
7. J. L. Blackburn, Protective Relaying – Principles and Applications, Marcel Dekker, Inc., 1998.
8. IEEE Std. 738-1993, IEEE Standard for Calculating the Current- Temperature Relationship of Bare Overhead Conductors, 1993.
9. S. Northrup, “A Multidisciplinary Senior Design Project: Redesigned to Increase Interdisciplinary Interaction,” the 2011 ASEE Annual Conference and Exposition, Vancouver, Canada, June 2011.
10. S.M. Batill, “Teaching Engineering Decision Making Using a Multidisciplinary Design Paradigm,” the 2000 ASEE Annual Conference and Exposition, St. Louis, Missouri, USA, June 2000.