AC 2012-3047: DEVELOPMENT OF A NEW POWER SYSTEM COURSE: POWER SYSTEM ANALYSIS USING ADVANCED SOFTWARE

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1. Introduction

Power utilities routinely employ software packages such as Power System Simulator for Engineering (PSS/E) for performing system studies [1-6]. When making hiring decisions, employers in power industry usually prefer students with experiences in widely adopted power software. Regular electrical engineering courses usually focus on theories and the students may not have opportunities to learn the advanced software. Recent ongoing transformation of the national grid into a smart grid spurs the needs of modeling and simulation of power system [7]. A new course titled Power System Analysis Using Advanced Software was developed at the department of electrical and computer engineering the University of Kentucky to provide students in-depth understanding of and hands on experiences in selected software packages. This new course is intended for senior undergraduate and graduate students and has been offered in the past at our university. This class also provides an opportunity for students to appreciate the model of real world utility systems.

This paper discusses the course contents and pedagogical approach employed to deliver the new course. The effectiveness of the class is evaluated through assigned projects and our university's official course evaluation system. Evaluation studies have indicated that the students feel the class is very valuable and the teaching method is well received.

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 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

The contents of this course can be largely divided into six modules as described below. Examples are employed throughout the course to illustrate concepts and methods and utilization of the software.

2.1 Course modules

Module 1: Introduction

This module covers the objective and motivation of the course, and an introduction to North American Electric Reliability Corporation (NERC) Transmission System Planning Performance Requirements [1]. The transformation of the national grid into smart grid demands various modeling and simulation techniques, and software modules to be developed and the entire power system to be thoroughly studied [7].

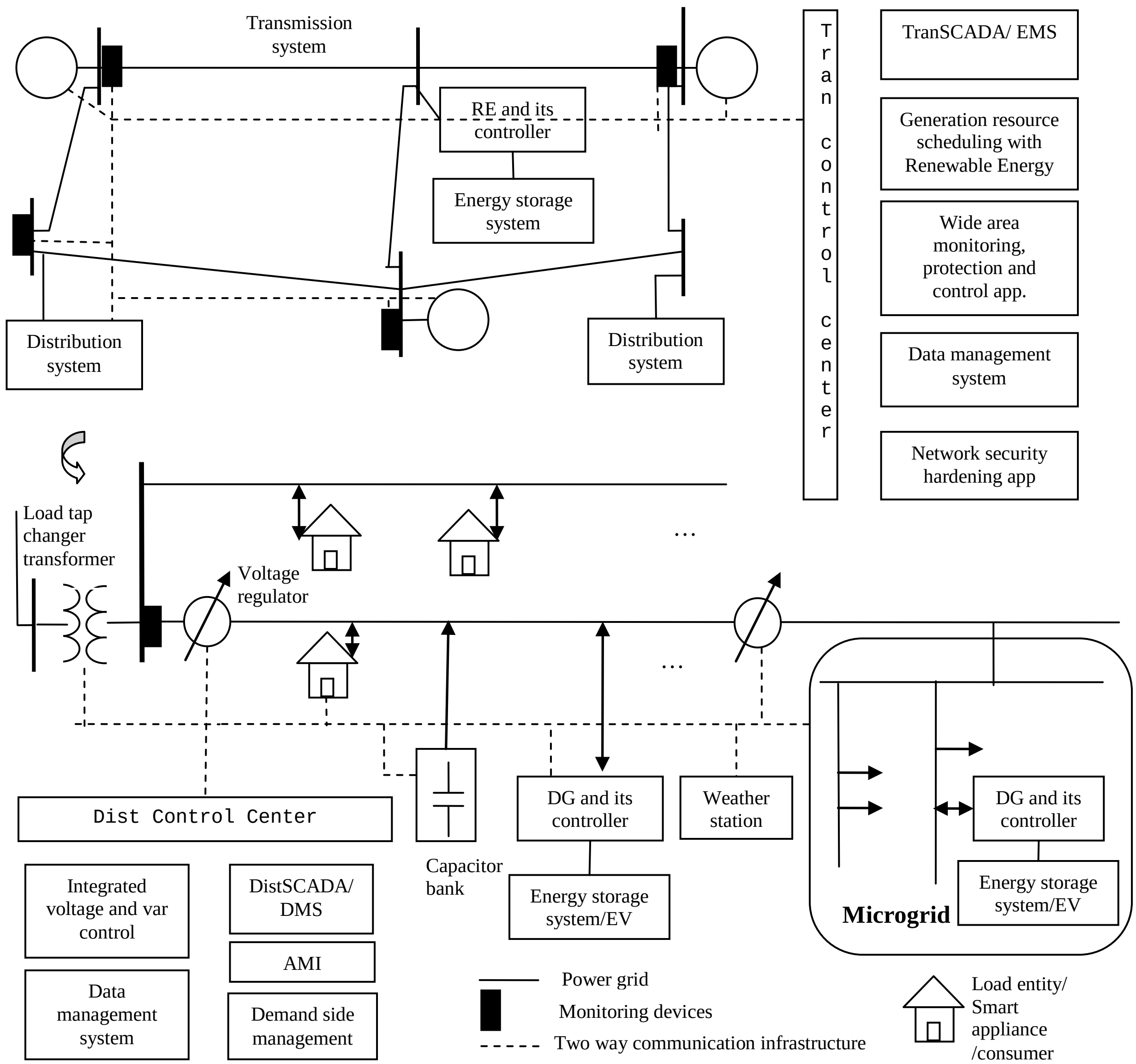

Figure 1. The future smart grid

The national electric power grid is being transformed into a *smart grid*[7]. Figure 1 depicts such a smart grid, which can be largely divided into generation, high voltage transmission, and lower voltage distribution systems. Smart appliances, Distributed Generations (DG), energy storage systems, and electric vehicles (EV) will emerge that interact with the grid. More intermittent Renewable Energy (RE) sources including wind and solar power will be integrated into the grid. Centralized and distributed generation will coexist. More MicroGrids will emerge capable of operating in off-grid or on-grid mode. Energy related information will flow among consumers, utilities and controllers over Advanced Metering Infrastructure (AMI). The transmission and distribution system Supervisory Control and Data Acquisition system (SCADA) collects real-time measurements from the grid and transfers them to the control center. There will be an increasing deployment of intelligent controllers and monitors such as Phasor Measurement Units (PMU). There are also protective relays at substations that respond to disturbances such as faults in milliseconds to protect the system. The Energy Management System (EMS) and Distribution

Management System (DMS) include essential software applications for controlling the grid. The integrated voltage and var control aims to minimize power losses or demand while maintaining the required voltage profile through adjusting the settings of load tap changer transformers, voltage regulators and switchable capacitor banks. Generation resource scheduling, including unit commitment and economic dispatch, is to calculate the optimal scheduling and dispatch of generation resources including renewable resources. Wide area monitoring, protection and control applications intend to monitor, protect and control the grid based on wide area measurements such as synchrophasors collected by PMUs for improved reliability and resilience to disturbances. Demand Side Management (DSM) is a program to reduce energy consumption, shift load usage to different time (normally non-peak time), or reduce/shed load (normally at peak load time). One example of DSM is demand response, where the consumer's energy consumption is adjusted in real time corresponding to prevailing conditions such as dynamic pricing signals. Weather station provides real time weather data such as solar irradiance, relative humidity, temperature, wind speed and direction, barometric pressure, and cloud cover images. The weather data can be transferred to distributed controllers or the control center for real time operation and control, or be archived for more analysis. Data management system performs data archiving and data mining functions. Security hardening applications utilize advanced algorithms to ensure cyber security and privacy. Hence, the future grid will be a complex cyber-physical system that consists of physical power components, protective relays, monitors, controllers, communication networks, data management systems, and advanced software application and control algorithms, distributed across large geographical areas. The chief goals of smart grid are to make the grid more efficient and reliable, accommodate generation from diverse sources, enable customer participation, and achieve environmental improvement [7].

To design and operate such a complex system and realize the goals of smart grid, accurate modeling and simulation of the system will play an essential role. The future grid will not only involves numerous physical and cyber components, but also encourage customer participation in demand response programs. Understanding the grid characteristics under potential normal and abnormal operating scenarios and complex customer behaviors is essential for designing a reliable, efficient and secure system. Simulation methods and software that can simulate the future grid including power system, cyber system and consumer behaviors are entailed. Methods for modeling communication link performance like bandwidth and reliability, smart appliances, electric vehicles, and consumer behaviors under different incentive schemes will need to be developed. Differential equation or phasor based methods may be adopted depending on the time resolution of simulated phenomena. Impacts on grid protection and operation of diverse contingencies such as transmission line failure, communication link delay or failure, protective relay failure, and software defects, and of high penetration of intermittent renewable generations need to be studied. Monte Carlo simulation methods may be utilized to consider uncertainties of diverse input data. To verify the developed model and methods, it is necessary to test them in a realistic testing environment. Advanced protection and control algorithms may be tested by employing a Real Time Digital Simulator (such as RTDS and Opal-RT), which is capable of hardware-in-the loop simulation and testing of various controllers and protection devices.

Therefore, there is a strong need for a course that covers modeling and simulation techniques and prevailing software for analyzing the power grid.

In power industry, NERC requirements provide the types of studies a utility need to perform for compliance. PSS/E software package is a widely employed tool for carrying out such required studies [2,3,4,5,6]. Both steady state and stability performance are evaluated. This module also comprises basic concepts including phasor, power, per unit system, and bus admittance matrix are also explained to make sure every student has the necessary foundation for the next modules. Considering the ongoing advancements in smart grid, the requirements may change in the future as well. But the knowledge learned in this class should provide the foundation for performing required studies according to new requirements that may occur in the future.

Module 2: Power flow and contingency analysis

Various methods such as Gauss Seidel method, Newton-Raphson method, decoupled, and fast decoupled method for solving power flow problems are covered. The concept of contingency analysis is explained. Once the theory is covered, PSS/E software is then demonstrated and explained to solve example problems. Differences between various types of solution techniques are illustrated so that students know why there are needs of different techniques, and understand better the results yielded by the software. For the same solution technique such as Newton-Raphson, different solution settings such as acceleration factor, largest mismatch in MW and Mvar, and iteration limit may also have an impact on convergence characteristics. The theoretical methods covered in the lecture provide students a solid foundation to understand the diverse features contained in the software.

So, students will learn the theory on power flow and contingency analysis, and the skills of solving problems using PSS/E software.

Module 3: Fault analysis

This module covers the theoretical basis of symmetrical and unbalanced fault analysis, and how to carry out fault analysis using PSS/E. The fault analysis software package Computer Aided Protection Engineering (CAPE) is also introduced and demonstrated. Single line to ground faults, double line to ground faults, double line faults and three phase faults are covered [8]. Simulation of simultaneous faults in PSS/E is also covered. The skills learned in this module will be essential for students to learn module 5 since system stability performance will be evaluated under fault conditions.

Module 4: Transient analysis

The electromagnetic transient phenomenon is introduced. Time-domain software packages including Matlab simpowersystem [9], Electromagnetic transients program (EMTP) and Omicron transient analysis module are introduced and demonstrated. Omicron transient analyzer works with the hardware including the voltage and current amplifiers and can be utilized for relay testing purposes. Hence, relay testing using Omicron is introduced and the mho characteristics of a distance relay is explained so that students can understand the outputs of Omicron software. Power quality phenomena including switching transient, impulse, voltage sag, harmonic, notch, flicker, and so on are also introduced.

Module 5: Power system stability analysis

Power angle stability phenomenon and equal area criterion are introduced. The concept of critical clearing time is covered; how to practically obtain this parameter for a system under a specific disturbance by gradually changing the tripping time of the protection system is illustrated. Models of round-rotor and salient-pole generator, generator governor, excitation system, and power system stabilizer are discussed. How to represent all these components in PSS/E and perform stability analysis under fault conditions is illustrated. The excitation model (EXST1), speed governor model (IEEEG1), power system stabilizer model (PSS2A), and round rotor generator model (GENROU) are illustrated in detail and utilized in labs.

Module 6: Python programming and application of Python for automating PSS/E tasks

Python programming is introduced, where basic data types, control flow statements, file operations, and modules are covered [10]. Common Python programming interfaces used to call PSS/E functions are elucidated. Using Python programming to automate power system studies (load case, modify case, impose disturbances, run simulations, clear disturbances, run simulations, write results to a file, etc.) is illustrated. PSS/E provides a comprehensive set of programming interfaces between Python environment and PSS/E functions. Selected sets of essential functions for case preparation, power flow, fault analysis, stability analysis, and results retrieval are covered, such as psspy.fnsl, fdns, natono, case, seqd, scmu, scinit, scdone, abusreal, busdat, scbus2, scbrn2, etc [3]. The PSS/E Application Program Interface reference book [3] is introduced to students so that students can find the required functions on their own when needed.

PSS/E also provides a convenient way of automating tasks through its recording functionality, where a series of steps embodied in proper functions and codes for performing specific tasks are recorded in a response file (.idv) or python file (.py). One can easily discover the needed python functions for a specific task by taking advantage of this method and examining the files.

2.2 Course outcomes

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

1. Understand essential concepts: phasor, power, per unit system, bus admittance matrix
2. Use PSS/E to perform power system analysis, including building a case (i.e. adding generators, loads, lines, transformers, etc.), imposing disturbances, running simulations and interpreting the results.
3. Develop computer programs to perform power system studies using Python programming language.
4. Perform transient simulation.

2.3 Pedagogical method

This course intends to be delivered through both regular classroom lectures and labs. For the regular classroom lectures, both traditional blackboard method and power point presentation method are utilized. Students are required to present some of their projects in the class, from which students can also learn from their peers' work. The classroom lectures cover the theories of power system analysis.

For the labs, the instructor usually first provides demonstrations of the software. Then the students will work on lab exercises gave out to them to gain hands-on-experiences of the software. Usually each regular lecture is followed by a lab. Lab exercises are prepared in advance and distributed to the students at lab time.

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 five projects at 20 points each.

Project 1: system analysis based on bus admittance matrix

In this project, students are required to analyze a three phase unbalanced power system utilizing bus admittance matrix techniques. Students will develop a program in any programming language such as Matlab. This project will assess how well the students understand the concepts of phasors, power, per unit system and bus admittance matrix. The concepts are basis for more complex analysis of power systems. Students are asked to present the results to the class.

Project 2: create a power flow case in PSS/E and perform basic power flow studies

A sample power system is provided to students. In part 1, students will develop a computer program in Matlab or any other language of their choice to solve the power flow problem using the Gauss-Seidel method. In part 2, students are asked to create a power flow case based on provided case data in PSS/E and perform basic power flow studies. Students will become familiar with the user interface of PSS/E, basic functionalities of PSS/E, and solution choices. The results obtained in part 1 and part 2 are compared to corroborate each other.

Project 3: perform contingency studies and perform stability analysis (under faults)

Students are asked to perform contingency studies by setting specified components out of service, and carry out stability analysis under various types of faults. Models of various controllers need to be included. Critical clearing time for sustaining system stability for specified events needs to be identified.

Project 4: use Python programming technique to automate a work flow

Students are first asked to develop Python programs to solve several basic problems including file editing and copying, and array sorting. Then, students are required to automate a series of power system studies based on Python programming. Students will need to develop Python programs to call required PSS/E functions and also handle file operations for inputs and outputs.

Project 5: perform transient analysis

Students are asked to perform transient analysis utilizing Matlab Simpowersystem and Omicron transient analysis package. Voltage and current waveforms and apparent impedances seen by relays are to be recorded and results analyzed. Students are also asked to model and simulate selected power quality phenomena such as voltage sag, swell, harmonic, and switching transient, and propose suitable methods for problem mitigation. Students are asked to present the results to the class.

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 feel the value and quality of teaching of this course on a scale of 4.0. In Table 1, column 3 gives the assessment by instructor based on the grades of student projects, and column 4 provides 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 essential concepts: phasor, power, per unit system, bus admittance matrix	4.8	4.7	Project 1
2. Use PSS/E to perform power system analysis, including building a case, imposing disturbances**,** running simulations and interpreting the results.	4.6	4.6	Project 2, 3
3. Develop computer programs to perform power system studies using Python programming language	4.5	4.5	Project 4
4. Perform transient simulation.	4.8	4.5	Project 5

Table 2. Student General Learning Outcomes Scaled to 4.0

General Learning Outcomes	Student's assessment from TCE
1. Learned to respect different viewpoints	3.5
2. Increase the ability to analyze and evaluate	3.8
3. Course helped ability to solve problem	3.9
4. Gained understanding of concepts and principles	3.8
5. Course stimulated me to read further	3.8

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. Recent research findings in education may be harnessed to further improve the class [11]. New advancements in smart grid modeling and simulation and software development will be incorporated into future courses.

5. Conclusion

This paper outlines the development of a new course on Power System Analysis Using Advanced Software at the department of electrical and computer engineering at the University of Kentucky. This course covers the theories of essential power system analyses and how to utilize prevailing software packages for performing such analyses. The focus is to teach application of PSS/E software while CAPE, EMTP and Matlab simpowersystem are also introduced. Past offerings indicate that the course has been valued and well received by our students. We plan to continue improving and offering this class in future semesters.

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