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Integrating Power Engineering Topics and Applications in Non-Power Courses*

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Abstract – *This paper investigates integrating power engineering material over the breadth of an electrical engineering curriculum. Electrical engineering curriculums have a large number of required courses and many subareas for students to study. By introducing power concepts in a variety of courses, students may be motivated to take additional courses in the power area and are better prepared for the diverse background which will be required of them as practicing power engineers. The important interrelationships between subareas of electrical engineering are better understood by students when cross discipline applications are discussed. This paper describes the introduction of power concepts and applications in courses such as linear systems, digital systems, microprocessors, digital signal processing, electronic system design, and electrical materials.*

Introduction

In light of a perceived shortage of competent engineers with a power engineering background, the National Science Foundation and the Electric Power Research Institute have joined together to help US academic institutions prepare their graduates adequately so they will be able to accept future challenges. At the same time, the recent power industry deregulation has brought a number of issues into the limelight. These are:

- Open access – wholesale and retail competition
- Independent System Operator (ISO) – an unbiased control area operator
- OASIS: Open Access Same Time Information System
- Unbundled services
- Stranded costs
- Ancillary services - scheduling, system control and dispatching service; var and voltage support from generation service; operating reserve-spinning service
- Generation bidding

- Risk management
- Spot Market - competitive generation market controlled and coordinated by the ISO
- Power Quality in a deregulated environment

Aside from issues emanating from industry restructuring, there are also environmental issues related to power plant emissions and associated control alternatives, global warming, renewable energy and energy efficiency.

While graduate students who have a power option can gather a background in these topics, it is more of a challenge to impart the same knowledge to undergraduate students. There is no room in the undergraduate curriculum to discuss specific issues of power engineering. The current emphasis is on an overwhelming amount of analysis, starting from 3-phase and magnetic circuits to power system component modeling. Students often lose interest because of the nature of the material.

The intent at the University of Wyoming is to impart knowledge relevant to the power systems discipline over the breadth of the EE curriculum [1]. This will give students the core background in power along with additional breadth in digital systems, communications, signal processing, power electronics, and control. By this method, basic energy and power concepts can be introduced in some of the required EE courses while more depth can be covered in the senior and graduate level elective courses. The result will be a more goal-oriented program with emphasis on real-world applications.

The challenge in this approach is to be able to offer the breadth in the required courses without losing sight of the main objectives of the individual courses. Therefore, one has to be careful so as to work within the framework of the department's accredited curriculum. A summary of the changes in the non-power courses is shown below followed by a more detailed description in a later section of the paper.

♦ EE 2250 Linear Systems (Sophomore level): Fourier analysis of waveforms in a circuit with non-linear loads, converters, etc., and elimination of the harmonics.

♦ EE 2390 Digital Systems (Sophomore level): Addition of a new lab on stepper motor control logic.

♦ EE 4390 Microprocessors (Senior level): Microprocessor control of stepper motors.

♦ EE 4240 Digital Signal Processing (Senior level): Introduce applications in power system identification of electromechanical modes using ambient data.

♦ EE 4330 Electronic System Design (Senior level): Include introduction to switching power supplies and DC to DC converters.

♦ EE 4340 Materials in EE (Senior level): Description of several devices and sensors related to power engineering were introduced into course syllabus.

Curriculum Changes in Non Power Courses

Linear Systems Analysis

As outlined in the original proposal to NSF a change has been made in the laboratory exercise that examines Fourier analysis and its application. In the past, typical laboratory exercises dealt with topics taken from vehicle dynamics, communication systems and control systems. The new exercise addresses harmonics in electrical power systems and investigates a simple technique to improve power quality.

Students are presented with a waveform file for a 60 Hz line voltage which is heavily contaminated with third and fifth harmonics. They are to establish the number of samples comprising a single period of the waveform and perform a Fourier analysis of that waveform to get the magnitude and phase spectra. The phase spectrum is also to be converted to a time delay spectrum. Based on the magnitude spectrum the students are to propose a highpass filter to pass the higher harmonics, reverse their phase and to add this reversed phase signal to the original waveform to partially cancel the effect of the higher harmonics.

A VisSim simulation is employed to perform a Fourier synthesis of the original waveform based on the spectral analysis and to assess the effectiveness of the scheme.

The new laboratory exercise was first employed in the fall of 1998 and is being modified to improve it for the spring of 1999. The modifications will be such as to make it more realistic and a better learning experience. Contemplated changes involve using a voltage waveform taken from a real power device, increasing the order of the highpass filter and examination of spectra at various points in the system.

Exposure to Power Engineering in the Digital Areas

The areas of digital electronics and digital systems design are very popular in our curriculum. This may be because many of the students who are attracted to Electrical Engineering have been exposed to computers in their high school careers. Of course, we always try to design our laboratory assignments to provide a meaningful experience to the student, but perhaps we can do this better in the digital area than other areas. For example, with the advent of the ability to generate rather complicated circuits within FPGAs using Hardware Descriptive Languages (HDLs), it now is possible to specify, design, and test a complex digital design in a relatively short time period. Also, in our microprocessor class, the students can implement a control algorithm that runs in real time by using code developed in a high level programming language such as C. Because the microprocessor we use in this class (the HC11) can be used as a microcontroller, the students are aware that their implementation could be operated in a stand-alone mode.

We try to have laboratory exercises in the digital area that stimulate the student. Some of our labs are indeed design labs in that we ask the student to design a controller that implements some algorithm. One such group of laboratory exercises involves the use of stepper motors. These are very popular because the students like to see some mechanical system respond to the digital system they designed. Likewise, the stepper motor seems like an ideal application for digital systems since it is a digital device where precise movement can be obtained.

In the two semesters of this current academic year, several laboratory exercises that involved the use of stepper motors were designed. These are:

- Digital Electronics Course (Sophomore level)
  Lab 11. State Machine Design (Stepper Motor Controller). In this lab, the students design a simple controller for a stepper motor. The controller has two inputs CW and CCW that when active, drive the motor with the appropriate gray code to move the motor in the desired direction.

- Microprocessor Course (Senior level)
  Lab 6. Stepper Motor Controller. In the first part of this lab, the students design a controller that drives a simple motor in the CW or CCW direction depending upon switch inputs. In the second part, the motors in an X-Y plotter are controlled under the student program to generate a variety of plots, such as a square wave, a sine wave or even a circle. To support this, we use a C compiler for the HC11 microprocessor that has floating point support.
  Lab 7. Etch-a-Sketch Controller. In this exercise, the student develops a program (using C) that reads the analog voltages on a two dimensional joy stick and use these values to drive the stepper motors of

a X-Y plotter to simulate the childhood toy called an Etch-a-Sketch. The control is done interrupt driven, and the speed of the motors had to follow a well defined specification.

In the near future, we propose to enhance the exposure our students have in the power area. We do not have a great deal of time in the lecture for this, but again it is felt that the laboratory will be the primary method to implement these additions. These additional activities include:

- Internal Structure of Stepper Motors
  Currently we have the students control the stepper motors with little explanation of their internal construction. We expect we will give more complete information on the various types and modes of operation of stepper motors.
- Implementation of Control Algorithms to Power Systems
  We would like to implement some control algorithm that has a power application in either our microprocessor course, or if speed is important, in an FPGA programmed with an HDL. A real time implementation of relaying algorithm seems like a good project to attempt. This is an important, real world problem, and our students could gain some exposure to this power related subject.

Digital Signal Processing

Spectral estimation is frequently performed in power system analysis. These applications can be used as an example of spectral estimation in a Digital Signal Processing course. Students appreciate the use of real data from actual engineering problems. Such applications show the diversity in the power field and may motivate some students to learn more about power engineering. An example power application problem, which can be used as a computer based assignment or laboratory in a DSP course, is estimation of the electromechanical modes of oscillation in a power system. Inter-area electromechanical modes involve generators or groups of generators, separated by large distances, participating in low frequency oscillations in the range of 0.2 to 0.6 Hz. Accurate estimation of these modes is a critical part of analyzing, controlling, and operating a power system.

The developed exercise has students estimate the frequencies of the electromechanical modes of oscillation from actual ambient power system data. The data used is the real power data from the monitors at BC Hydro's Boundary location. The data has been preprocessed to remove the mean and has been carefully downsampled to a rate of 4 samples per second. The exercise discusses the interconnected power system in the Western United States and gives a brief background on the significance of the electromechanical modes to the stability of the system.

The DSP course covers the simple and averaged periodogram methods of spectral estimation and the students write programs to implement these methods. The students plot the first minute of data as shown in Figure 1, where the well-known 0.3 Hz mode is clearly identifiable. They then compute a simple periodogram, as shown in Figure 2, which is a poor estimate of the spectrum. An averaged periodogram is then used to estimate the spectrum, as shown in Figure 3. The modes of oscillation are very clearly revealed at 0.45 and 0.6 Hz as well as the dominant mode at 0.3 Hz.

This type of problem may be of particular interest to the students, because of their familiarities with large area blackouts such as the August 10, 1996 event. During that event the 0.3 Hz mode went unstable resulting in growing oscillations in the power system and the eventual failure of the system. Motivationally, these current events can be discussed in class, leading to increased interest in power systems.

Electronic System Design

One of the goals in reorganizing two senior elective courses, Electronic Systems Design (EE 4330) and Power Electronics (EE 4560), was to move some topics from the EE 4560 to the EE 4330. The EE 4560 course is the first
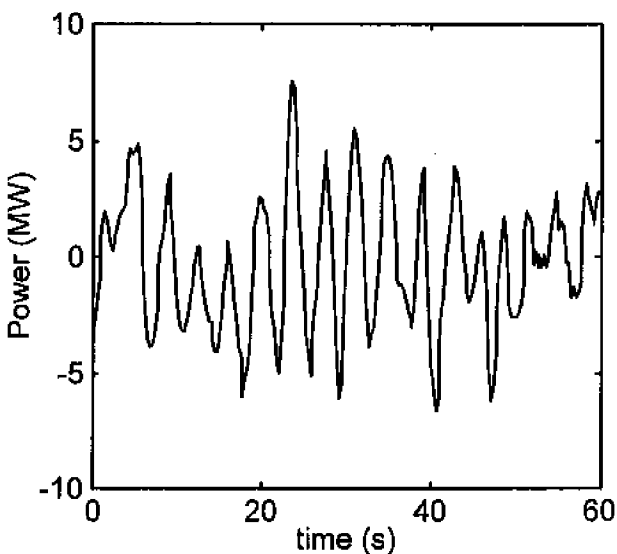

Figure 1. One minute of the power signal at BC Hydro Boundary from July 11, 1995, where the average value has been removed.
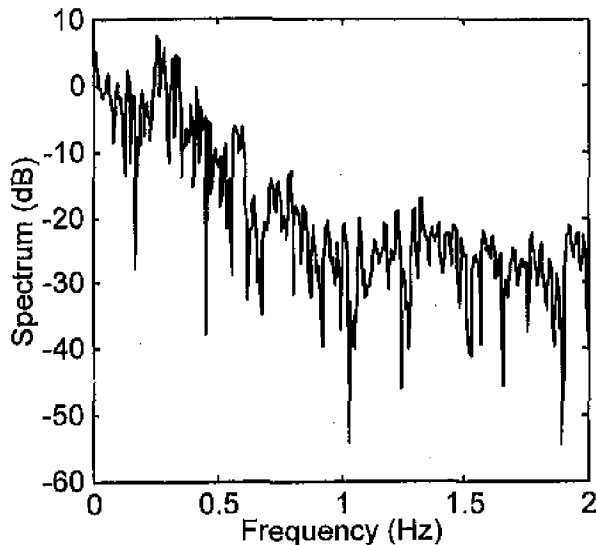
Figure 2. A simple periodogram estimate of the spectrum for the power signal at BC Hydro Boundary where the average value was first removed. The periodogram used the FFT with a Hamming window with a size of 128 seconds.
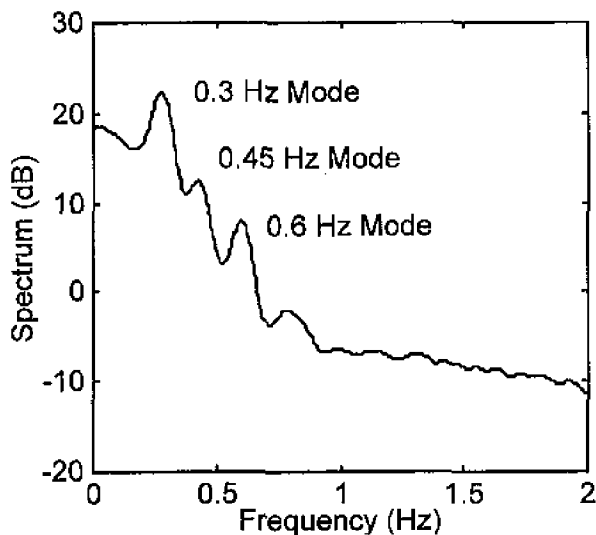

Figure 3. An averaged periodogram estimate of the spectrum for the power signal at BC Hydro Boundary. The periodogram was computed using 50 minutes of data. The data was broken into 24 second segments overlapping by 50 percent. The FFT was computed for each segment using a Hamming window, and the FFT magnitudes were averaged.

course in power electronics and for the undergraduate student the only one in this area that is offered, hence the contents of this course must be very carefully determined. It was possible to make modest changes in the contents of the EE 4330, because some topics may be moved from this course to the EE 5330, Advanced Electronic Systems Design. Switching voltage regulators and switching power supplies were eliminated from the EE 4560 course and moved to EE 4330. The textbook used for EE 4330 is [2], which covers some of the topologies of dc to dc converters making it very natural to include these topics in the EE 4330 course. EE 4330 is a well structured course and includes an extensive laboratory. Addition of a new topic involves design of a new laboratory experiment.

The new laboratory experiment, Switching Voltage Regulators and Power Supplies, has been planned and partially designed. The purpose of this experiment is to show operation and parameters of main kinds of integrated circuits dedicated for switching power supplies and dc to dc converters. These circuits cannot operate properly when assembled on a breadboard, therefore appropriate circuits have been designed in a form of printed circuit boards and include testing points where necessary. Three integrated circuits from the National Semiconductor company were selected for this laboratory, the LM 2574 (step-down regulator), LM2577 (step-up or flyback regulator), and LM2578 (step-up, step-down, flyback, or inverter type regulator). In addition to the three printed boards that demonstrate applications of integrated circuits, a fully equipped, commercially available module of a switching power supply is used in this laboratory. This switching power supply module is a good illustration of auxiliary circuitry usually incorporated in switching power supplies.

Physical Electronics

The course, Materials in Electrical Engineering (EE 4340), covers materials and devices, which are used in electrical engineering. Several new topics were introduced and other topics were significantly modified. To emphasize power engineering, the following topics were modified: (1) capacitors and dielectrics; (2) properties of magnetic materials, magnetic cores, magnetic circuit design, relays, and reed switches; (3) force and strain transducers including piezoelectricity and piezoresistivity; (4) optoelectronic devices such as fiber optics, infrared sources and detectors, including their applications in control and measurement of power systems.

The following topics were introduced into the course: (1) magnetic sensors such as Hall effect devices and magnetoresistors; (2) temperature sensors such as integrated sensors, PTC and NTC thermistors; (3) power transistors including BJT, MOS, and IGBT; (4) power switching devices such as power diodes, SCR, TRIAC, and CMT; (5) negative resistance devices such as DIAC and PUT which are used to control switching circuitry. Description of most of

these devices and sensors were accompanied with examples of application circuits.

Conclusions

Student reaction to the use of realistic problems with a power application has been quite positive. Most of them realize that breadth in their education is a positive attribute. Although only a fraction anticipate a career in the power industry they see the value in a diverse education which opens their eyes to a wider spectrum of applications of engineering principles.

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