Development of an EET Electrical Power and Controls Course

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Abstract

This paper discusses the development of a new course combining topics from a conventional electromechanical energy conversion course with topics from controls and electrical distribution courses. The paper begins with some background of why we developed the new course and the process that was used to develop it. The course topics and laboratory experiments are then described in some detail.

Introduction

Several years ago, our department began an intensive review of our entire curriculum, with an eye toward revising it to more directly meet the needs of employers for the next century. The process began with a so-called ad hoc, radical curriculum review team. The ad hoc team began the process of revising the curriculum by starting with a clean slate and "blue skying" their ideas of what it should look like. Later as the process matured, they expanded it to include the department's specialty area curriculum teams. The development of the new curriculum took approximately two years and consumed several thousand hours of faculty members' time. During the process, members of the Industrial Advisory Board (IAB) and graduates of our program out in industry were consulted to help shape the new plan of study.

For many years, the Purdue EET program prided itself as being one of only a few in the United States with a strong electric power program. The plan of study included a required electric motors course, which was organized in a traditional pattern of magnetics, DC machines, transformers, and AC machines. Electives included a course oriented toward electric utility operations (generation and transmission), an electrical distribution course,[1] and two controls courses. Despite this history, some faculty viewed the required course as a target for elimination, which would allow other topics to be included. Surprisingly, however, there were a few non-power faculty who felt the course should be kept exactly as it was.

Like others,[2] we noticed the change in what was important to industry and how that differed from what was included in most undergraduate energy conversion courses. Our required course, as previously mentioned, covered DC machines before AC machines and generators before motors. Prior to the formation of the curriculum review team, we reversed the order of presentation of AC and DC machines and put more emphasis on motors as opposed to generators. We felt this was appropriate because the vast majority of our graduates will encounter induction motor applications long before they use DC motors or generators of any sort We also added a lecture and laboratory covering variable speed drives since many motors are now connected to them to provide more efficient plant processes. This constituted a good beginning, however, it was very clear to us that to keep a place in the curriculum for a power course, we would have to make even more changes to the course.

Course Development

Based upon our industrial experience, we had some concerns over the emphasis of the material in the course we inherited when we began teaching at Purdue. While a balance of theory and application is desirable so that the students will understand why a device performs the way it does, we felt the course was too heavily weighted toward the analysis of equivalent circuits of machines, rather than the practical application of them. Thus one goal was to reduce the emphasis on equivalent circuit analysis of induction motors and DC machines. We felt we could then include more applications oriented material as well as the basics of motor and power circuit design. An area that we considered essential to emphasize was power quality. Virtually anyone who adds equipment to the system has the potential to cause power quality issues, specifically harmonics.[3] Thus we felt it was important to add power quality considerations throughout the course.

We also found from consultations with IAB members and employers that there was a desire to have some coverage of programmable logic controllers (PLCs) included in the power course, since it is required in the two-year associate program. This became an area of debate within our department. There were several members who saw this as an opportunity to essentially eliminate the power course, by devoting 40 to 60% of the course to PLCs. We did not believe that would allow enough time for coverage of even the basics of power circuits and devices. Fortunately we were found sufficient support from the IAB and other faculty members to limit the PLC material to approximately 2 weeks out of the 15 week semester. From our review and the consultations with others, we developed an outline of course topics and laboratories. After several rounds of negotiations, the version shown in Table 1 was approved by the department faculty members.

Once the course outline was determined, we looked at the texts that were available in energy conversion, controls, and PLCs. We did not find one that covered the variety of topics we wanted, so we began writing our own. The text[4] is currently published locally, but will be published in 1999 by Prentice-Hall.

Course Content

As shown in table 1, the course begins with a review of basic energy concepts and single and three-phase power calculations. While the students learn phasor notation and power calculations in their circuits courses, experience has shown they tend to forget it very quickly between semesters. We also include an overview of the electrical power system, from the generation station through the transmission and distribution subsystems to the end-user. Two laboratory sessions are devoted to single and three-phase power. However, before they are allowed to use the equipment in the power laboratory, we provide the students with a multi-media presentation about electrical safety. This is the first lab that the students routinely use lethal level voltages, so we require them to demonstrate their understanding of electrical safety by passing a quiz after the safety presentation. In the single-phase lab, students can see how changing the reactance in a load from inductive to capacitive causes the current to go from lagging the voltage to leading it.

Table 1: EET 231 Class and Lab Topics

Course Topic	**Class Time**	**Related Laboratory**
Introduction, energy concepts, The Power System	2.0 hours	Lab Introduction and Electrical Safety
Single-phase power review	1.0 hour	Single-phase power
Three-phase power calculations	1.0 hours	Three-phase power
Power quality	1.5 hours	Nonlinear loads and harmonics
Power Factor correction	0.5 hour	
Magnetic fields, magnetomotive force, reluctance, permeability	3.0 hours	
Transformer construction, principles of operation	1.0 hour	Single-phase transformers
Transformer equivalent circuit, loading, voltage reg., efficiency	3.0 hours	
Three phase--transformers and power calculations	2.0 hours	Three-phase transformers
Generator and motor action	2.0 hours	DC generator voltage vs. excitation and speed
DC and AC machine construction and operation	1.0 hours	Power plant tour
Polyphase induction motors: design features, rotating magnetic field, NEMA classes, characteristics, efficiency considerations, life-cycle costing, and selection	5.0 hours	Three-phase induction motor characteristics
Variable frequency operation of induction motors	1.0 hour	3-phase induction motor variable speed operation
Relay construction, motor starters, control ladder diagrams, solid state control	3.0 hours	1. Motor control circuits 2. Reversible motor controllers
Single phase motor characteristics and selection	1.0 hours	Single-phase induction motor characteristics
National Electrical Code calculations, fuses and circuit breakers	3.0 hours	
PLCs	6.0 hours	PLC and AC drive programming project (2 wks)
120/240 volt wiring calculations	1.0 hours	
Grounding	1.0 hour	
Testing	4.0 hours	
Review/summary	1.0 hours	

In the three-phase lab, they observe the 120^{O} separation between phase voltages, 30^{O} angles between line and phase quantities, and that the line currents do in fact add to zero on a balanced Y-connected system. The concept of power factor correction is also presented, since many industrial facilities are required by their electric utility to maintain a minimum power factor.

The first new topic for the students is power quality. During the introduction to power quality, students learn what harmonics are, where they come from, and some of the effects they can have on power system devices and meters. The lecture material is reinforced by a laboratory session[5] devoted to power quality issues. In lab, students observe the difference between average-responding, RMS calibrated and True-RMS meters. They also observe the phase and neutral currents in a nonlinear, single-phase loads are connected in a balanced, Y configuration. They are very surprised to find that the neutral current may exceed the phase current when the total harmonic distortion (THD) is high. Power quality and harmonics are also included when transformers, motors, and variable-speed AC drives are presented in lecture and observed in lab.[6]

Prior to discussing transformers or motors, it is necessary to present the fundamentals of magnetics, including the basic quantities of flux, flux denstity, field intensity, magnetomotive force (mmf), and reluctance, as well as the properties of ferromagnetic materials. Following that, the transformer is presented in considerable detail, including the equivalent circuit and variations thereof. The effects of harmonics on transformers and K-factor ratings are discussed in class. Two labs are devoted to transformers, one for single-phase and one for three-phase connections. In the single-phase lab, students observe the exciting current and conduct open-circuit, short-circuit, and full-load tests, from which they can calculate the equivalent circuit parameters, efficiency, and voltage regulation. In the three-phase lab, they examine several different connections, as well as the third-harmonic component of exciting current and some of the problems it presents for Y-Y three-phase banks.

Following the transformer, there is a transition section to introduce the concepts of motor and generation operation of electric machines. To cover the new topics, something had to be eliminated, and we chose to essentially eliminate coverage of DC machines. During this transition section, the construction and operation of both DC machines and AC synchronous machines are discussed. To reinforce the concepts of magnetic saturation, hysteresis, and generated voltage, one lab period is devoted to examination of a DC generator.

Following the introduction to motor/generator operation, the induction motor is covered. While the equivalent circuit of the induction motor is introduced, it is used primarily as a tool to understand where the losses are in the motor. Instead of analyzing the equivalent circuit in detail, time is devoted to discussion of different types of loads, the differences between and application of NEMA Design A, B, C, and D motors, energy efficient machines, and life-cycle costing. Students are expected to utilize motor nameplate data to calculate real and reactive power requirements for the motor when operating at rated conditions. In lab, the students measure torque, speed, real power, reactive power, apparent power, and line current as a function of load on the motor. From there measurements and calculations, they observe that efficiency tends to be fairly flat from 50% to 100% of rated load, while power factor drops as the load is reduced. Looking at their power measurements they find that the reactive power is virtually constant, indicating that it only takes a certain amount to magnetize the motor regardless of the load. One lecture and lab are devoted to variable-frequency operation of the induction motor. The effects on power quality are emphasized when the variable-frequency drive is studied in lab.

Single-phase induction motors are covered very quickly, in order to allow time for the other course topics. Construction features, operating principles, and the torque-speed characteristic are discussed for the split-phase, capacitor start, permanent split capacitor, two capacitor, and shaded pole motors. A lab exercise, which is very similar to the three-phase lab, is used to allow students to measure the characteristics of single-phase motors and to observe the difference between the run and start windings. In particular, by measuring the impedances of the main and start windings, they see how a phase angle is created between the winding currents. The remainder of the course is devoted to controls (both relay and PLCs) and power circuit calculations.

In the previous course, less than one lecture was allocated to controls. This was increased to three lectures to allow discussion of the principles of designing ladder diagrams. Motor control circuits including reversible starters and Delta-Wye reduced voltage starters are covered during this time as well. In the two controls lab sessions, students wire, troubleshoot, and operate several circuits provided to them. They also design one control circuit to a set of given specifications.

Since many students wind up working for small firms where they may be the primary person for all electrical matters, it is important to include at least the basics of how to design motor and power circuits to comply with the National Electric Code. Thus several lectures are used to discuss wire sizes, resistance, and insulation; the NEC ampacity tables; voltage drop calculations; and the various tables in Article 430, relating to motors and motor protection. With this background, they should be able to at least perform a sanity check when new equipment is installed in their place of employment. Since 120/240 Volt systems are common, one hour is devoted to discussion of these types of systems.

The final major topic of the course is the PLC. Two weeks was allocated for PLCs, so clearly the students are not expected to become experts. Since the Allen Bradley PLC 5/30s is used in lab, the material is oriented toward them. The lectures include material covering the history of PLCs, their advantages over hard-wired relay controls, the hardware components in a PLC, the PLC scan cycle, the most common programming commands, addressing schemes, and special considerations for converting relay ladder logic to a PLC ladder program. One lecture is typically used to demonstrate the PLC and the programming software before the students go into the laboratory. The two labs consist of programming the PLC to interface to a variable speed AC motor drive. The first program is given to them and they essentially use it to learn how to create a program with the software. Once they have the first program running, they are tasked to design modifications to it in the second lab period.

Conclusion

Since the new course was part of a new curriculum, it was scheduled to be phased-in in the spring semester of 1996 as the class that began in the fall of 1994 reached their fourth semester. The other Purdue Technology locations around the state were scheduled to start a year later, with their first offering in the spring of 1997. We actually started the course one semester early in the fall of 1995 and have taught it for two years at West Lafayette. The other locations have taught it once. The students particularly enjoy the controls and PLC portions of the course where they actually get to build things that work rather than just taking data in lab. For those interested in more detail, the actual class lecture notes are available on the world wide web at http://www.tech.purdue.edu/eet/courses/eet231/eet231.htm

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Biography

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William DeWitt is an Associate Professor of EET at Purdue University. He has a BSEE and MSEE from the University of Tennessee. Prior to joining Purdue in 1993 he was a self-employed consultant, and he has held several teaching appointments and government positions. He is a senior member of IEEE, and a member of NFPA, NAFE, and NSPE.