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New Three-Level Undergraduate Curriculum for Teaching Electrical Energy Subjects

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Abstract
A new approach to an electric power and energy curriculum is presented. Student interests appear in three categories: those who take only one introductory course for breadth, those who want the greatest available depth of study in power and energy topics, and those who will study another area of electrical engineering in depth but find understanding power and energy topics helpful to their anticipated role as a customer. Curriculum structure fits these three categories. Details of topics considered appropriate for each category are discussed, including laboratory program.

Introduction

A carefully designed balance characterizes the structure of an undergraduate electrical engineering curriculum. Giving the student an introduction to the breadth of knowledge that meets the desired outcomes is of primary importance at the undergraduate level. It is also important to provide some depth of study in a particular field that the student may propose to enter. The structure of a good electrical engineering curriculum institutionalizes this balance.

Employers have been clear in their expectation that any electrical engineering graduates that they hire should possess a strong foundation in a broad range of fundamentals. This breadth of fundamental knowledge and skills must be taught well. In the curriculum at hand at the University of Idaho, these fundamentals are defined within five areas of study: analog electronics, power and energy, electromagnetics, digital electronics, and systems. In this fivefold structure, the Electrical and Computer Engineering (ECE) Department organizes its faculty expertise and even its assigned course numbers. To illustrate this structure, the ECE Department's undergraduate course offerings are listed in Table 1, sorted by area of study. At the junior level, students must take one course and one lab in each of the five areas (shown in **boldface** in the Junior Year Courses column in Table 1). This requirement provides an introduction and a foundation of common topics across the available breadth of electrical engineering practice. At the senior level, the ECE Department requires that each student take at least one course in three of the five areas of study. The specific courses designed to provide this breadth are shown in **boldface** in the Senior Year Courses column of Table 1. Most, but not all, areas have a senior-level lab requirement. This structure provides a strong breadth in the fundamental topics that the department offers.

Most students express an interest in obtaining some depth of knowledge in a particular field of study. Certain employers have often requested this as well. To meet this need, the ECE

Department offers a technical electives in each of its five areas. These electives, shown in *italics* in Table 1, provide a greater depth of study in a particular topic. Students are afforded at least three technical electives. Grouping these technical electives in a single area of study does provide the student some degree of depth. Not all students want this depth, so the curriculum allows them to distribute their technical elective opportunities among the five areas and even among certain mathematics, science, and engineering electives. The result is an opportunity for a limited degree of specialization balanced with a strong breadth of knowledge and skills.

Within this structure, faculty in each of the five areas must provide instruction to meet a remarkably broad range of student interest. This paper describes how the faculty who teach power and energy topics have designed their curriculum.

Table 1. ECE Undergraduate Curriculum

Area of Study	Junior Year Courses	Senior Year Courses
Analog Microelectronics	**Fundamentals of Electronics**	**Analog Microelectronics**
		Active Filters
		Communication Circuits
		Analog IC Analysis and Design
		CMOS Analog Microelectronics
		Applications of Linear ICs
		Pulse and Digital Circuits
Power and Energy	**Energy Systems I**	**Energy Systems II**
		Power System Analysis
		Power Electronics and Drives
Electromagnetics	**Electromagnetic Theory**	**Microwave Millimeter Wave Circuits**
		Applications of Electromagnetic Theory
		Numerical Solutions
Digital Electronics	**Microcontrollers**	**Digital Systems Engineering**
		Computer Organization
		Intro to VLSI Design
Systems	**Signals and Systems I**	**Signals and Systems II**
		Communications Systems
		Digital Data Storage Systems
		Information and Coding Theory
		Semiconductor Devices
		Control Systems
		Digital Control Systems
		Digital Filtering
		Digital Process Control

Three categories of students

An important element in establishing the power and energy curriculum was to recognize that the overall curriculum structure tends to define three categories of student interest. With the emphasis on balancing breadth and depth, one would think that there would be only two categories: those students who get only breadth and those who want more depth. However, this is not the case. In fact, defining three categories of student interest leads to a new and perhaps more effective curriculum. Though the power and energy curriculum is the vehicle in this paper for illustrating this structure of the curriculum and identifying categories of students, it is readily apparent from Table 1 that these ideas apply to the curriculum and students of the other areas of study as well.

The first category of student interest consists of students who take a power and energy course solely to meet breadth requirements. These students appear in only the one junior-level power and energy course, taking all their other courses in other areas. There is but this one opportunity to provide these students with an introduction and appropriate breadth of study in power and energy.

As might be expected, another category of students wants depth of study in power and energy topics. These students expect to seek and gain employment within industries that expect a significant degree of specialized preparation. For example, these include the electric utilities, manufacturing and process industries, and certain government agencies. These students want the greatest depth that limited time and resources can provide. Their employers expect it and say so.

A third category of students recognizes a need for more skill in using power and energy. They intend to specialize in another area, so extensive depth of study is not practical. However, they do recognize the importance of being able to understand energy topics better and to relate more effectively to those who provide energy to them. Identifying this third category of students provides an insight into structuring the curriculum more effectively, meeting their needs of both depth and breadth in a balanced fashion.

Level 1: Breadth

Every electrical engineer will likely encounter a certain range of energy topics, such as household and commercial distribution and wiring, power quality problems with harmonics, transformers, small dc motors, dc to dc conversion, and switch mode power supplies. The first course addresses these topics at the junior level. Also included are topics that form a basis for an advanced study of alternating current phenomena; these are important to those students who intend to study further while retaining interest in those students who want only breadth.

There are actually two places to introduce these topics in the curriculum. Traditionally, some of these topics appear in a circuits course, for example, steady state alternating current circuit analysis, definition and calculation of power and energy quantities, and the significance of root mean square (rms) quantities. The other place for these topics is the junior-level power and energy course that all students take.

In the junior-level power and energy course, an introduction to a number of common topics appears. Two common threads are, as described already, the likeliness that most electrical engineers will encounter these topics and the intent of providing some preparation for more depth of study. The study of dc power supplies provides an example of how these threads are balanced. Most electrical engineers will encounter electronic equipment that draws alternating current but converts the energy to a direct current form for use in most of its circuitry. Therefore, in the universal junior-level power and energy course, every student studies single-phase ac power, household and commercial wiring practices, transformers, rectifiers, and dc to dc converters. Rectifiers also appear in the common junior-level analog electronics course. To develop some understanding, the student must review and solidify the appropriate math and physics concepts. The student must make the connection to other areas within electrical engineering, for example, analog electronics, to understand rectifier and load. In preparation for more advanced study, transformer models and power electronic converter fundamentals are introduced. A list of the topics is shown in Table 2.

Table 2.
Course Content, Junior-level course

ECE 320 Energy Systems I (3 credits)

1. Single-phase AC	1
2. Instantaneous and average power	1
3. Reactive and complex power	3
4. Single-phase power calculations	2
5. Household wiring	1
6. Ferromagnetics	5
7. Magnetic circuits	2
8. Transformers	3
9. Per unit normalization	3
10. Linear DC machines	3
11. Volt-sec balance	1
12. Current-sec balance	1
13. Energy balance	1
14. Single-phase rectifier	3
15. Buck converter	3
16. Boost converter	1
17. Buck-boost converter	1
18. Flyback converter	2
19. Forward converter	2
20. Ybus	2
21. Power flow	4
Total number of lessons	45

Table 3.
Content of Junior-level lab course

ECE 321 Energy Systems Lab
(1 credit lab)

1. AC Measurements	1
2. Transformers	2
3. DC Machines	2
4. DC-DC Converters	2
5. Lab proficiency exam	1
Total number of lessons	8

A laboratory requirement emphasizes applications of these introductory topics in power and energy. For the students who will take no other power and energy courses, this is normally their only laboratory experience with voltage levels commonly considered to be dangerous. Every student continues to learn electrical safety with every lab exercise in this course. The first lab exercise builds on circuits and physics lab work to review and teach electrical safety while making alternating current measurements. In the two transformer labs, students first use appropriate tests to find parameters for a circuit model, then verify the model on a transformer under load. The same concept, completing and verifying a model, is repeated in the dc machines labs and the dc to dc converters labs. In this manner, students are introduced to equipment that they are likely to encounter and are taught the common methods for its safe use and analysis. A concise list of the topics for this lab is shown in Table 3.

Level 2: Greater depth and preparation

For depth of study in power and energy, the department tends to broadly emphasize power transmission and distribution topics. A majority of this program's graduates who gain employment in what could be considered to be a power and energy position will find themselves working day-to-day somewhere in transmission or distribution, either in the public utility or as the customer's interface to the utility. These courses address how electric power is generated, transmitted, distributed, and used. For those students who seek more depth but will probably not seek such employment, as discovered above, these topics are appropriate for their most likely contact: industrial and commercial power systems. Therefore, the second course, a senior-level course, addresses primarily these topics. The topics include three phase systems and methods of analysis, introduction to synchronous machines, and power transmission.

Unlike many traditional curricula, a single introductory course does not contain a concentrated study of electric machines. Rather, this curriculum introduces the major machine types one-by-one at each of the three levels: dc machines as a topic for all students, synchronous machines for those who want some greater understanding of power and energy, and induction machines for students seeking depth.

Table 4.
Content of Senior-level Course

ECE 420 Energy Systems II (2.75 credit lecture & 0.25 credit lab)

1. Three-phase systems, one-line (lab)	5	8. Synchronous generators	7
2. Three-phase transformers	6	9. Synchronous Generators (lab)	2
3. Three-phase transformers (lab)	1	10. Short and medium line models	2
4. Three-phase per unit	2	11. Ybus	4
5. Regulating transformers	2	12. Three-phase power flow	6
6. Winding Theory	5	13. Power flow (lab)	1
7. Rotating waves	2	Total number of lessons	45

Laboratory work reinforces learning in this senior-level course. Each lab exercise addresses a major topic area: three phase systems, transformers, synchronous generators, and power flow. Laboratory resources are quite strong to support all these topic areas. The power flow laboratory work uses commercial power flow software and a five-bus model power system.[1] Table 4 contains a more detailed list of topics for this course.

Level 3: Depth of study

Power and energy topics can be grouped into three somewhat interrelated categories: power systems, electric machines, and power electronics. Topics that every student would be likely to encounter in each of these categories appear in the junior-level course. The senior-level course addresses primarily power systems, even in its treatment of synchronous generators. One of the two technical electives provides depth of study in power systems. The other technical elective provides depth in power electronics with the lion's share of the emphasis in motor drives.

Dynamic behavior of power systems is the main thrust of the power systems technical elective. Topics include line modeling, traveling waves on lines, generator transient behavior, unbalanced three phase systems, fault analysis, and stability analysis. Most of these topics appeared in the past in an Advanced Power Systems technical elective. They provide the strong background that employers strongly desire in the student who plans to seek employment in the electric utilities or in industries with a strong, direct interface to those utilities. These topics also prepare the student for graduate work in power systems, the primary focus of our graduate program.

An in-depth study of power electronics and machine drives is the subject of the other technical elective. The junior-level course uses dc to dc converters and switch mode power supplies to teach the fundamentals and to give some depth in an application. Industrial power converters and motor drives are the subject of this technical elective, for example, three-phase rectifiers, inverters, drives, and methods of protection. Here the induction machine finally appears, followed by power electronic methods to drive it. Ned Mohan from the University of Minnesota has done a great deal of pioneering work in establishing such a course; this course draws from his experience and recommendations.[2,3]

Table 5.
Content of Technical Electives

ECE 423 Power System Analysis (3 credits)

1.	Line models	4
2.	Traveling waves	5
3.	Zbus	4
4.	Transient Synchronous Generators	7
5.	Symmetrical Components	3
6.	Balanced Faults	5
7.	Shunt Fault Analysis	7
8.	Stability Analysis	7
9.	National Electrical Code (NEC)	3
Total number of lessons		45

ECE 427 Power Electronics and Drives (3 credits)

1.	Uncontrolled 3-phase rectifiers	3
2.	Controlled 3-phase rectifiers	5
3.	DC drives	4
4.	Single-phase inverters	5
5.	Three-phase inverters	9
6.	Induction machines	9
7.	AC drives	6
8.	Protection and NEC	4
Total number of lessons		45

A formal laboratory requirement for the technical electives may seem absent from the list of topics is shown in Table 5. Nonetheless, it is in there. For example, the power and energy group has a research program in protection, a scaled five-bus model power system designed for teaching, and a large local industry sponsor. As a result, laboratory work is integrated throughout the technical elective course and extends strongly into the capstone design program.

Conclusions

The University of Idaho new undergraduate curriculum in electrical energy subjects is designed to meet observed needs and interests of the students effectively. The key to this new three-level approach to the electric power and energy curriculum is understanding that student interests can be grouped into three categories: taking only a single course for breadth, expressing a secondary interest in power and energy systems that includes understanding how to interface and work with these systems as a customer, or interface, and planning to seek employment as power and energy specialists. Recognizing that these three categories exist led to development of a curriculum that balances breadth and depth of study within an established electrical engineering department's framework.

The junior-level course addresses topics that all electrical engineers are likely to see, such as household and commercial distribution and wiring, power quality problems with harmonics, transformers, small dc motors, dc to dc conversion, and switch mode power supplies. It also introduces topics that form a basis for more advanced study, such as transformer models and power electronic converter fundamentals. The next course, a senior-level course, addresses topics in power systems, such as three phase systems, synchronous generators, and power flow. These topics are most likely to concern students who will study something other than power and energy in depth, but will find it helpful in their respective industries to have some understanding of industrial and commercial power systems. There is also appropriate preparation in this course for those interested in more advanced study. Both of these first two courses have a supporting laboratory component.

For undergraduates seeking further depth, two technical electives are available: advanced power systems and power electronics and drives. Dynamic behavior of power systems is the main thrust of the power systems technical elective. Industrial power converters and motor drives are the subject of the other. Electric machine theory appears in separate modules at each level, rather than grouped in a single course. The first two courses have been taught for a year and the technical electives are being modified from their present form for introduction next year. Assessment will be the subject of a future paper.

References

[1] Johnson, B., and H. Hess, "Undergraduate Research and Teaching Opportunities from aTransient Network Analyzer," ASEE Annual Conference, June 2002, Session 1333.
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[3] Mohan, N., (2004), NSF-Sponsored Developments in Teaching of Power Electronics and Electric Drives, http://www.ece.umn.edu/groups/PowerElectronics_Drives/, (6 March 2004).

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