AC 2007-336: AN ELECTRICAL SYSTEMS COURSE IN A GENERAL ENGINEERING PROGRAM

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An Electrical Systems Course in a General Engineering Program: Experience and Lessons

Abstract

General engineering programs, by their nature, require a curriculum covering a broad range of material from multiple engineering disciplines. Individual courses must support the outcomes of the program and sufficient coverage of topics is critical for the success of the program and the students. The challenge in key topical areas is to balance the conflict between the limited available time and the breadth and depth of topics. One topical area is electrical systems, which encompasses electrical engineering concepts for the general engineer. Required topics for an electrical systems course could include basic circuit concepts, electronic devices, digital logic, power, electric machines, and often instrumentation and controls. The decision for which topics will be chosen and developed for a compact electrical engineering course in a general engineering program requires thorough understanding of the program and careful planning. This paper describes the planning and initial delivery experiences of a circuit analysis course in a newly-established general engineering program. The paper relates the program mission with the curriculum structure and how the circuits course builds a foundation for advanced topics and concentration areas such as bioprocess engineering. The paper also examines the valuable lessons learned from the impact of prerequisite knowledge on topic selection, math/science requirement, and laboratory activities. Encountered difficulties and opportunities are identified and improvement plans are described.

I. INTRODUCTION

Some universities offer general engineering programs to help students who are "fundamentally interested in becoming engineers but are not ready to select one of the engineering degree programs". [1] After finishing the required courses by the program, students choose an engineering discipline to continue their degree program. A few universities offer a Bachelor's degree in General Engineering. However, the definitions of "General Engineering" in such programs are vague and vary. The following two definition statements attempt to explain the term:

> Definition 1: *"General Engineering is unique because it includes a variety of engineering fields. This field of study helps make a well-rounded engineer and gives opportunities to become a strong leader and decision maker with practical engineering abilities."[1]*
>
> Definition 2: "*A professional in general engineering uses the principles of math and science to solve technical problems. For example, a professional with a general engineering degree may be involved in the design of computers, helicopters, toys, and robots used in manufacturing. Knowledge of general engineering is also required to build viable structures like the Golden Gate Bridge in San Francisco, and used to determine the safest slope of an exit ramp from a highway."[2]*

It is apparent that the lack of a consistent definition makes general engineering curriculum development challenging. The curricula have an "arbitrary" quality since no commonly-accepted logic and guidelines exist. Faculty creating general engineering programs have to extensively rely on personal understandings and experiences. This challenge is particularly true for the newly-established engineering department at East Carolina University (ECU). The growing pains of a new program stem from an evolving curriculum requiring the focus of individual courses to change in order to support the program. One such course or series of courses for a general engineering program is electrical systems. This topic complements other engineering courses focused on applied physical sciences and plays a significant role in an engineering student's academic career.

In general, circuits and electrical systems are good models for the study of energy systems and the applied math required to analyze and design circuits and systems are invaluable to an engineer, specifically a general engineer. With the concept of "systems" in mind, this article describes the planning, rationale, development, and delivery an electrical engineering course in the ECU general engineering program. It provides a brief review of peer programs and outlines several observations from the first experience and presents opportunities and suggestions for improvement.

II. BACKGROUND

The General Engineering program at East Carolina University started in 2004 and the Department of Engineering was founded in 2006. The philosophy governing the program is to introduce the students to key engineering concepts and applications in the first semester of their freshmen year; these concepts are then integrated throughout the courses in the core curriculum and extend into the respective concentrations leading up to the capstone design project. The subsequent courses build upon these concepts allowing the students to make insightful connections at each phase and follow the development of these concepts to a professional level. The program is established with the following mission statement and educational objectives [3].

Mission:
Our program provides a theory based, application oriented general engineering education that serves as a basis for career success and lifelong learning. Our graduates possess and demonstrate the engineering and scientific knowledge required for analysis, design, improvement, and evaluation of integrated technology based systems. Our program equips graduates to be applied problem solvers who develop solutions that consider system interrelationships and meet or exceed customer needs.

Program Objectives
Graduates of the BS Engineering program are:

1. *Prepared for professional practice as licensed engineers with a broad knowledge of general systems and problem solving methodologies.*
2. *Demonstrate capabilities to pursue advanced studies and are committed to lifelong learning.*
3. *Aware of and capable of analyzing the technical, environmental, and social implications of technology driven systems.*
4. *Capable of being an effective team member or leader including skills in written communications and an appreciation for diversity in the workplace.*
5. *Committed to honesty, ethics, social responsibility, and professionalism as representatives of the engineering profession.*

The BS in Engineering curriculum is structured with a common engineering core and courses in four concentrations. While the core courses aim to develop fundamental engineering skills, courses in the four concentrations including, Systems Engineering (SE), Engineering Management (EM), Bioprocess Engineering (BioPro), and soon to be offered Biomedical Engineering (BME), build specialized knowledge to satisfy students' more specific career needs as outlined below.

- *Systems engineering:* *Systems engineering focuses on inter disciplinary tools to analyze the intricate relationships of "systems." Systems Engineers focus on defining component interrelationships, customer needs and required system capabilities as an integrated problem.*
- *Engineering Management:* *Technology driven organizations must have management systems that assure optimal performance. Engineering management graduates are skilled in critical technology management systems such as project management, production, and logistics.*
- *Bioprocess Engineering:* *One of the fastest growing segments of the economy involves the engineering and operation of bioprocessing and pharmaceutical processing systems. Bioprocess engineers have the skills to support, operate, and improve these biomanufacturing systems.*[4]

To expose students to electrical engineering knowledge, one dedicated four-hour course, Circuit Analysis, was included in the curriculum. This course followed a six-hour Introduction to Engineering course, which integrates Electrical, Mechanical, Professional Practice, and Graphics, offered in the freshman year to provide students some engineering background. It is essential to note that the first iteration of this course was designed to fulfill the prerequisite requirement for the students in the Systems Engineering concentration who are scheduled to take a controls systems course.

III. METHODS

A. Electrical Engineering Courses Offered in Systems Engineering Programs

To understand how electrical engineering courses are offered in similar programs, a website search was conducted for Systems Engineering, a typical major in General Engineering programs. Results from this research (presented in Table 1) show the diversity of coverage of electrical engineering topics in both the number of courses offered and the covered topical areas in different institutions.

The numbers of courses that cover electrical-related topics vary from 0 to 7. While all institutions cover Controls in their curricula (although the depth varies), ten other topic areas (circuit analysis, electronics, power, electrical machines, microcontrollers/ microprocessors, digital control, sensors and instrumentation, signal and systems, communications, and electromagnetic waves and antennas) are included in Systems Engineering programs. The coverage of these ten topics appears to be arbitrary—there is no apparent pattern that shows what materials should be covered in such a program, not to mention the level of coverage.

Table 1. Coverage of Electrical Engineering Topics in System Engineering Programs

School	Number of Courses	Topic Coverage										
		Circuit Analysis	Electronics	Power	Electric machine	Microcontrollers or Microprocessors	Digital logic	Sensor and Instrumentation	Controls	Signal and Systems	Communications	Electromagnetic Waves and Antennas
University of Arizona	2					√	√		√			
University of Arkansas at Little Rock	7	√		√			√		√	√	√	√
Case Western Reserve University	2	√						√	√	√		
George Mason University	1								√			
Oakland University	3			√	√				√			
University of Pennsylvania	2					√			√			
United States Military Academy	2	√	√	√					√			
United States Naval Academy	5					√		√	√			
University of Virginia	*Based on information from the website, no courses in these areas offered*											
Washington University	2								√	√		

B. Development Considerations

Although many agree that the body of electrical engineering knowledge is important in a general engineering program, no agreement exists on what electrical engineering topics should be covered. This is due to a general engineering program's consideration of its own mission, concentrations, and program outcomes/objectives. An individual course (or courses) is obviously developed to support the entire program structure and objectives. The development of the electrical engineering course in our program took several considerations into account. Specifically, this course needs to 1) cover topical areas required by the Fundamentals of Engineering (FE) exam; 2) prepare students for their concentration (SE, EM, BioPro, BME) study; and 3) provide students with necessary electrical engineering skills to meet the program outcomes. These considerations are detailed in the following paragraphs.

Consideration #1: The course needs to cover topic areas required by the FE exam. Students in all engineering disciplines take the same FE morning session, nine percent of which tests electricity and magnetism (excerpt from NCEES references [5]).

Morning session:

XI. *Electricity and Magnetism*

A. Charge, energy, current, voltage, power
B. Work done in moving a charge in an electric field (relationship between voltage and work)
C. Force between charges
D. current and voltage laws (Kirchhoff, Ohm)
E. Equivalent circuits (series, parallel)
F. Capacitance and inductance
G. Reactance and impedance, susceptance, and admittance
H. AC circuits
I. Basic complex algebra

The afternoon session is discipline-specific. For General Engineering students, these are:[5]

Other/General Engineering afternoon session

VIII. *Electricity and Magnetism*

A. Norton, Thevenin equivalent circuits
B. Frequency domain AC circuit analysis
C. RLC circuits
D. Sensors and instrumentations
E. Electrical machines

Most of the items in the two lists are covered by common circuit analysis courses. However, it is worth mentioning, when preparing such a course, that the afternoon session tests areas such as sensors and instrumentation and electrical machines, which usually are not part of a regular circuit analysis course. Additionally, since in most universities electricity and magnetism concepts are introduced by Physics courses, the Circuit Analysis course should emphasize applications of engineering analysis methods.

Consideration #2: The course needs to prepare students for their advanced study in their concentrations. The four concentrations vary slightly in terms of required electrical engineering topical areas. For example, like the earlier research indicates, all Systems Engineering programs include controls in their curricula, which can greatly benefit from instrumentation background, which in turn requires this course to cover certain electrical engineering topics. Support of the different concentrations presents a bigger challenge as the department expands with additional concentrations. (This will be addressed in the Results section where a Biomedical Engineering concentration is added under the umbrella of General Engineering).

Consideration #3: The course needs to provide students with electrical engineering skills to meet the program outcomes. Referring to the ABET (a)-(k) program outcomes [6], the Circuit Analysis course should be able to support outcomes (a), (b), (e), and (k).

- *Outcome a: "an ability to apply knowledge of mathematics, science, and engineering"*

- *Outcome b: "an ability to design and conduct experiments, as well as to analyze and interpret data"*
- *Outcome e: "an ability to identify, formulate, and solve engineering problems"*
- *Outcome k: "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice"*

With these outcomes in mind, this consideration helps to shape the delivery of the course and to define lab activities and projects. These laboratory experiences will enhance students' hands-on skills and improve their ability to analyze and interpret data and to become proficient at using engineering tools to analyze electric circuits.

C. Course Philosophy

The course should expose students with fundamental electrical engineering concepts and circuits analysis methods at a system-level and ideally try to relate topics to practical applications and emphasize development of hands-on skills, while at the same time support the program mission. (This "system-level" delivery philosophy led to a discussion among our engineering faculty about the possibility of changing the course title to Electrical Systems from the usually titled Circuit Analysis.) In addition, this course is math-intensive by nature and it should serve as a good opportunity to integrate mathematics (e.g., integration, derivative, and differential equations) with engineering applications. This integration should be an important part of the course design, development, delivery, and assessment.

D. Course Objectives and Topics:

The Circuit Analysis course should give students a system level understanding of selected-topics and allow them to analyze basic electric circuits and other electrical systems. Specifically, the course was designed with the following objectives in mind. Upon completion of the course, students should be able to:

- Analyze simple DC circuits.
- Find Thevenin and Norton equivalences of circuits.
- Understand AC steady-state responses of resistance, inductance and capacitance in terms of impedance.
- Determine transient responses of capacitors and inductors.
- Analyze AC circuit in frequency domain.
- Perform DC and AC steady-state power calculations.
- Understand principles of major classes of sensors and their applications.
- Use magnetic circuit models to analyze transformers.
- Understand the principles, classification, configuration, and characteristics of DC/AC electric machines.
- Construct circuits on breadboards.
- Perform electrical measurements.

With these considerations, the following topics were proposed:

- Fundamental concepts of electric circuits

- Circuit elements and their i-v characteristics
- Node and mesh analysis
- Principles of superposition
- Thevenin equivalent circuits
- Norton equivalent circuits
- Maximum power transfer
- Dynamic electric circuit elements
- Circuit excited by sinusoid signals
- Complex numbers and Euler identity
- Phasor transformation
- Circuit steady-state response
- Circuit transient responses
- Complex power
- Three-phase power
- Magnetism and magnetic circuits
- DC electric machines
- AC electric machines
- Special-purpose electric machines
- Sensor/transducer clarifications

E. Textbook selection

One of the challenges in developing a fundamental electrical engineering course in a general engineering program was to find an appropriate textbook that meets most if not all the course objectives and outcomes. There were a few textbooks available for non-electrical engineering majors. Some common areas (i.e., circuit analysis and electronics) are covered by all the books, while other areas are not. Table 2 lists the books that we reviewed for possible adoption and the topics included in those books.

1. Allan R. Hambley. Electrical Engineering: Principles & Applications (3rd Edition). Prentice Hall. 2004. ISBN: 978-0131470460.
2. John R. Cogdell. Foundations of Electrical Engineering (2nd Edition). Prentice Hall 1995. ISBN: 978-0130927019.
3. Giorgio Rizzoni. Principles and Applications of Electrical Engineering (5th Edition). McGraw-Hill. 2005. ISBN: 978-0073220338**.**
4. David V. Kerns and J. David Irwin. Essentials of Electrical and Computer Engineering. Prentice Hall. 2004. ISBN: 978-0139239700.
5. Russell Mersereau and Joel Jackson. Circuit Analysis: A Systems Approach. Prentice Hall. 2005. ISBN: 978-0130932242
6. Charles Alexander and Matthew Sadiku. Fundamentals of Electric Circuits (2nd Edition). McGraw-Hill. 2004. ISBN: 978-0073048352**.**

Table 2. Textbooks and included topic areas.

Textbook Number	Topic Coverage								
	Circuit Analysis	Electronics	Digital systems	Power	Electric machines	Instrumentation	Communications	Laplace transform	Filters
1	√	√	√		√				
2	√	√	√	√	√	√			
3	√	√	√	√	√	√	√		
4	√	√	√	√	√				
5	√	√						√	√
6	√	√		√				√	√

A general impression after this extensive search was that it is very difficult to find a book that fits into an integrated curriculum that uses the course as a prerequisite to subsequent concentration courses. The Cogdell book (#2 in the list) appeared to be an ideal choice for our program in terms of topic coverage, but the course instructor wanted to have more supporting resources. The Rozzni book (#3) was adopted for our course because it had a comprehensive list of topics that best suited the requirements for the course and the engineering program at the time. This book, however, can benefit from more careful editing efforts to reduce the number of typographical errors.

F. Laboratory activities

The purpose of the laboratory activities are to: 1) provide practice and design opportunities for major topics covered in the lectures; and 2) fulfill those program outcomes that this course is supposed to reinforce. The following experiments were planned:

1. <u>Safe laboratory procedures and NI ELVIS overview.</u> This introductory laboratory was developed to introduce the necessary safety rules for electrical experiments. In addition, the students learn how to build simple electrical circuits on a breadboard and use the NI ELVIS digital multimeter to measure resistance, current, and voltage.
2. <u>Ohm's law and Kirchhoff's laws.</u> In this lab, the students verify the validity of Ohm's Law Kirchhoff's Laws.
3. <u>Voltage and current dividers.</u> The students apply the voltage/current-divider rules to calculate a voltage in a series/parallel resistive network and experimentally verify the voltage/current-divider rules.

4. Thevenin and Norton equivalent circuits. The students are required to determine the Thevenin/Norton equivalent circuit for a known network and verify the validity of Thevenin/Norton's theorem.
5. Charging and discharging capacitors. The students are to observe the voltage/current-time curves of a charging/discharging capacitor and experimentally determine the time constant of an RC circuit.
6. Three-phase power. This lab was developed to expose the students to MATLAB in a laboratory setting. The students are to simulate and observe the magnitude and phase of a 3-Φ voltage and show that the neutral node of a balanced 3-Φ source has a voltage of zero and that a balanced 3-Φ source can provide constant power.
7. Resistance in a DC Motor. In this lab, the students are to use Hampton dissectible motors to investigate the nature of the windings of a DC motor by observation and resistance tests.
8. DC Motor field connections and direction of rotation. This lab requires the students to investigate the possible configurations that a DC motor can be connected to the power source (i.e., separately-excited shunt connection, self-excited shunt connection, and compound connection).

IV. RESULTS

This course was first offered in spring 2006. An online student survey was conducted to assess the course outcomes. The questionnaire was defined to particularly evaluate the students' system-level understanding. Out of 34 students, 21 responses were received. The survey results (Table 3) demonstrated positive feedback to all five questions, although the instructor had a higher expectation for the first question, given the math-intensive nature of the course. This was probably caused by deficient math skills demonstrated by most of the students at the beginning of the semester. Overall, this course was well-received and the students gained most of the required knowledge for their concentration study.

Several issues emerged during the semester and deserve further consideration.

1. The students' math deficiency: The math prerequisite for this course was Calculus II, which was initially thought to be the appropriate level for a circuit analysis course in a general engineering program. It is now recommended that the math prerequisite for this course be adjusted to include differential equations as at least a co-requisite. The coverage of second-order circuits without a differential equations background or experience was extremely difficult. The instructor had to "take advantage of" this limitation and use it as a reason to transition to the introduction of circuit analysis methods in phasor-form, thus changing differential equation problems into algebraic equation problems.
2. The students' physics deficiency: Physics II (Electricity and Magnetism) is a co-requisite for this course. The fact that some students did not take any physics courses in high school required a substantial amount of time to convey the very fundamental electrical concepts. Precious time was lost and coverage of all the intended topics was impossible.

Table 3. Course assessment survey result.

Question 1
As a result of this course, I am better able to apply knowledge in mathematics, science, and engineering science to electrical engineering problems.

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Total	9	6	6	0	0
Percentage	42.86	28.57	28.57	0	0

Question 2
As a result of this course, I am better able to design and conduct electrical engineering experiments, interpret data, analyze results, and draw conclusions.

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Total	6	15	0	0	0
Percentage	28.57	71.43	0	0	0

Question 3
As a result of this course, I am better able to model and design an electric circuits, systems, or processes to meet performance, safety, quality, and economic requirements.

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Total	8	9	2	2	0
Percentage	38.1	42.86	9.52	9.52	0

Question 4
As a result of this course, I am better able to identify and formulate an electrical engineering problem, collect and analyze data, and develop a solution.

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Total	7	12	2	0	0
Percentage	33.33	57.14	9.52	0	0

Question 5
As a result of this course, I am better able to demonstrate the technical and interpersonal skills to develop and manage complex projects.

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Total	5	13	2	0	0
Percentage	25	65	10	0	0

3. Since this was the only one electrical engineering course at the time and so many basic concepts had to be included, it was difficult for the course to emphasize hands-on experiences. The instructor had planned to incorporate a course design project but failed to do so due to limited time and the students' background.
4. Not all material was fully covered as planned: the course did not get into the areas of sensors and instrumentation. This is partially due to the background issue mentioned in 1 and 2. As is typically the case, the original plan was somewhat too ambitious.

To address problems encountered from this experience, some major changes in the study plan have been proposed to the university curriculum committee. These include: (1) move the course from the second semester in the sophomore year to the first semester in the junior year; (2) make

Physics II a pre-requisite. Additionally, as the program continues to evolve, some changes have to be made to this course in the future. Two primary factors that affect this course are: (1) a second electrical engineering course—instrumentation and control—will be offered for all the concentrations; and (2) the department added a fourth concentration: Biomedical Engineering, which brings in a new Biomedical Measurement and Instrumentation course:

> *BIME 4000 Biomedical Measurement and Instrumentation: Examines array of instrumentation and techniques used in acquisition, processing, and presentation of biomedical signals. Topics include transducers, sensors, Fourier analysis, the ECG signal, flow measurement, medical imaging, and biosensors. Lab covers amplifier, bridge circuits, and measurement of physical parameters (temperature, pressure, strain) and electrophysiological signals.*

The offering of a bioinstrumentation course requires students to have a good background in certain topics (e.g., operational amplifiers), which should be covered by the circuit analysis course. The offering of an Instrumentation and Controls course will alleviate some of the Circuit Analysis course load and help meet the particular requirement (on these topics). These changes will greatly release pressure on the Circuit Analysis course from covering the "sensors and instrumentation" topic required by the FE exam, address item 4 in the list above, and allow broader coverage of topics with greater depth.

V. Discussion

The undertakings of planning, developing, and delivering an electrical engineering course in a general engineering program is indeed challenging. Some of the first issues that need to be resolved are the definition or understanding of the scope of a general engineering program and how the program intends to deliver electrical engineering knowledge. There is no common rule outlining important issues such as topic coverage, laboratories, and credit hours.

Although the instructor understood the conflict of available time and the coverage of broad topics and wanted to emphasize system level understanding of electrical engineering concepts and methods, it was hard to implement this systems approach in a single course. Most of the time was spent helping the students obtain a good understanding of basic concepts, leaving little time to cover system-level concepts. Trade-offs have to be made, sometimes multiple trials of the course with modification are needed, to better fit the program mission and objectives and to better prepare students for their future study and career.

One more specific issue was the need for a better electrical engineering introductory textbook for non-electrical engineering students. An ideal textbook for such a course should include concise coverage of basic circuit analysis, electronics, digital circuits, power, and facilitate understanding of electrical systems such as sensors and industrial instruments. The book should balance the requirement of math, theory, and engineering applications.

VI. Summary

The article describes the experience of developing and teaching an electrical engineering course in a general engineering program. It examines coverage of the electrical topics, discusses teaching approaches and encountered difficulties, and presents possible improvement opportunities. The authors believe that offering electrical engineering course(s) in a general engineering curriculum is important. Successful offering of such course(s) requires through understanding of the program, careful planning, and good systems approaches.

Reference:

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