DISTRIBUTED DESIGN IN THE ELECTRICAL ENGINEERING DEPARTMENT AT THE UNIVERSITY OF WISCONSIN – PLATTEVILLE

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Abstract

A variety of processes and methods exist to teach engineering design in universities today. Although some programs introduce simple design projects in freshman year, many programs provide design experience through a few concentrated courses in junior or senior year. Many students report that design methods are typically taught in high-level courses and in a compartmentalized fashion. In such cases, design is viewed as another hurdle to overcome rather than an important engineering process. This paper describes how the Electrical Engineering program at the University of Wisconsin – Platteville developed a curriculum to address this issue by implementing a distributed design in its curriculum. The idea behind the distributed design is to introduce simple design concepts early in the curriculum and gradually increase the complexity of design projects as students progress toward graduation. The paper provides examples of several design projects in various courses and how these projects are interrelated. The paper also provides a discussion of how the "major design experience" requirement of ABET is satisfied without having a capstone design course in the curriculum.

Introduction

A wide variety of methods for teaching engineering design are in use today. A number of universities have begun introducing design problems into lower level undergraduate courses.[1,2,3] Miller at the Massachusetts Institute of Technology has developed a number of small, hour long, design-like exercises that aim to give sophomore engineering students a feel for some of the engineering concepts. Other approaches to using design early in the curriculum include the Tip-A-Can project at Rochester Institute of Technology,[4] and MIT's Lighter-Than-Air project in a first year aerospace engineering course.[5]

One approach that is popular with educators is incorporating "hands-on" projects into engineering courses.[5,6,7] These "hands-on" projects are used to teach design concepts as well as provide more realistic problems to students. Another popular approach is mechanical dissection.[8,9] The basic philosophy in dissection is to provide a fun experience to students, to get them to probe the working principles of a system, and to motivate the students. Reverse engineering is also frequently used by educators in teaching design.[10,11] Reverse engineering allows the student to dissect an existing product and redesign it to achieve a given goal.

Capstone design courses, which are usually offered in the senior year in engineering curriculums, provide significant opportunities to teach design concepts and to provide design experience to students.[12] Dutson[13] provides an extensive review of engineering design experiences through capstone design courses.

Currently, there is no consensus as to the "best" way to teach design and to provide design experience to students. Engineering educators, however, are questioning whether the lack of sufficient hands-on design experience may be harming their students' educational experience. Many schools are striving to include more hands-on and design experience into their theoretical as well as design courses.[14]

Engineering educators generally agree that design projects provide significant opportunities to motivate students. The Electrical Engineering (EE) faculty at the University of Wisconsin-Platteville (UWP) believes that appropriately designed projects integrated into the curriculum provides immediate applications of the theory and also expands students' horizon regarding what kind of problems they will be dealing with in the real world after graduation. Furthermore, design projects help students develop their "soft skills" that are essential to be successful professionals. Hence, the EE faculty has designed a curriculum where design is distributed throughout the curriculum. The following sections detail our approach to teaching design and providing extensive design experience to our students. The paper also provides sample design projects.

Design in EE Curriculum

The mission of the EE program at UWP is "*to provide a quality electrical engineering education with extensive hands-on and laboratory experience that will enable our graduates to practice their profession with proficiency and integrity*." One of the main objectives derived from the mission is "*to graduate engineers who have the ability to use modern analysis and design techniques and have the laboratory skills to use state-of-the-art equipment to solve practical engineering problems*."

Consistent with its mission and objectives, the EE curriculum is designed to provide a quality undergraduate education complemented with extensive hands-on laboratory and design experience. This is achieved by having design and laboratory experience distributed throughout the curriculum rather than concentrated in a few courses. Hence, almost all courses in the departments have design and laboratory components in them.

We feel that the thought and decision making process involved in solving minimally-constrained, open-ended, and multi-objective problems are essential to an engineering education. To stress the importance of this way of thinking, it is essential to incorporate the design process at every level of curriculum. Therefore, the concepts of engineering design are taught throughout the EE curriculum. Hence, as listed in Table 1 and Table 2, all but three required courses, and all elective courses have some level of design in them. The level of design in a course is determined and assessed by a committee in the department.

With design being an integral part of virtually every course, the complexity of design projects increase with the complexity of the subject matter. In addition to the increase in technical complexity, increased consideration is given to other constraints such as economic, safety, reliability, manufacturability, and environmental. During their senior year, students are

Table 1. Required EE Courses

Course Code & Title	Design Credits	Total Credits
EE1210: Circuit Modeling I	0.0	2
EE2210: Circuit Modeling II	0.5	4
EE2220: Signals and Systems	0.5	4
EE3020: Analog Electronics	2.0	4
EE3130: Solid State Electronic Devices	0.0	3
EE3140: Electric and Magnetic Fields	0.0	3
EE3310: Automatic Controls	1.5	3
EE3410: Electric Power Engineering	0.5	3
EE3610: Communication Systems	0.5	3
EE3750: Microprocessor Logic Design & Prog.	1.5	3
EE3760: Microprocessor Systems	2.0	3

Table 2. EE Professional Elective Courses

Course Code & Title	Design Credits	Total Credits
EE4050: Advanced Analog Electronic Circuits*	2.5	4
EE4310: Modern Control Systems	1.5	4
EE4320: Digital Signal Processing	1.5	4
EE4350: Discrete Time Control Systems*	2.5	4
EE4430: Power Electronics & Electrical Mach.	1.5	4
EE4450: Power System Analysis & Design*	2.5	4
EE4620: Optical Systems	1.5	4
EE4630: Advanced Communication Systems	1.5	4
EE4720: Microcomputer Architecture & Interfacing	1.5	4
EE4750: Advanced Digital Design*	2.5	4

*: Students must take two of these courses during their senior year.

required to take two of the four heavy design courses marked with an asterisk (*) in Table 2. These courses have major design work which requires the knowledge of topics from previous courses and designs. Many times, the design projects in these courses are provided by industry. Students in these courses work in teams and deal not only with technical constraints, but also with economical, social, environmental, and safety constraints.

The faculty members feel that this approach of having distributed design and having design work building in complexity prepares our students well for their profession.

Sample Design Projects

In teaching design, one important consideration for faculty is to develop projects that are open-ended with multiple solutions and with increasing complexity. For example, the design of a simple regulated DC power supply with a certain current and voltage capacity can easily be integrated into EE2210. On the other hand, a sophisticated programmable, switched-mode power supply with voltage and current protection can be assigned to students in EE4430 course. The following sections provide a summary of three design projects in three different courses.

<u>Design Project 1</u>. This design project was assigned to student teams in EE1210, which is primarily a theory course in DC resistive circuits. In this project, students worked in teams to investigate whether or not a proposed DC transmission system was capable of serving a seven-city region. The proposed system was given as:

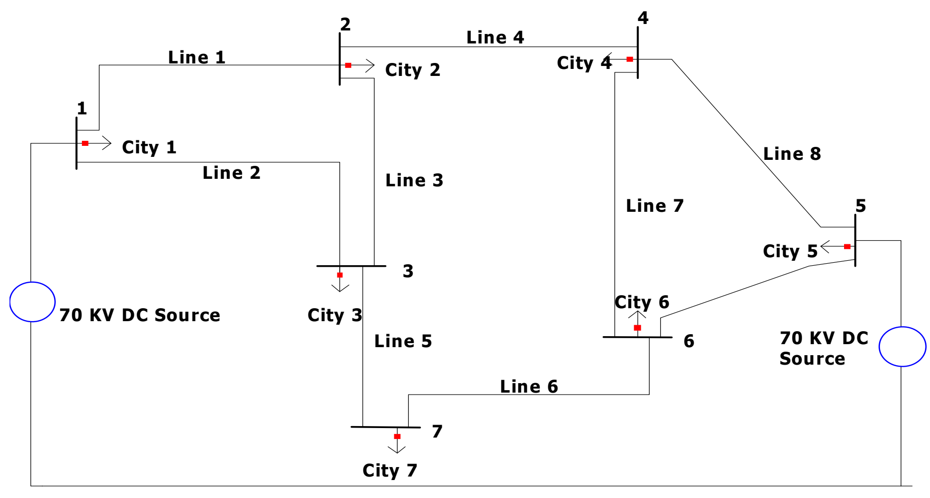

Figure 1. Proposed DC transmission system for the seven-city area

In addition, the following were given for the proposed system:
- The length of each line.
- The line characteristics in terms of its resistance and current carrying capacity.
- The expected peak demand (in Megawatt) at each city.

The following design constraints were also provided:
- When the transmission system is constructed and operating, the voltage at each city must be within +5% of the nominal voltage (70 KV).

- When transmission system is constructed and operating, lines should not be overloaded.
- The list of cities between which a line can't be constructed.

Design teams were asked to investigate the proposed system to see if there were any constraint violations. If there are any violations, teams were asked to develop a system expansion plan (additional transmission lines) that would eliminate the violations and propose a final transmission system with no violations. Teams were also asked to write a formal report explaining team's findings about the original system, the approach they used in solving any violation, and the final recommended system with its cost implications.

Design Project 2. This design project was assigned to student teams in EE3410, which is the first power course in the curriculum. The design involved the study of the voltage profile in a small power distribution system with a three phase ideal source, a transformer, two feeders, and three loads. The radial power distribution system was given as:

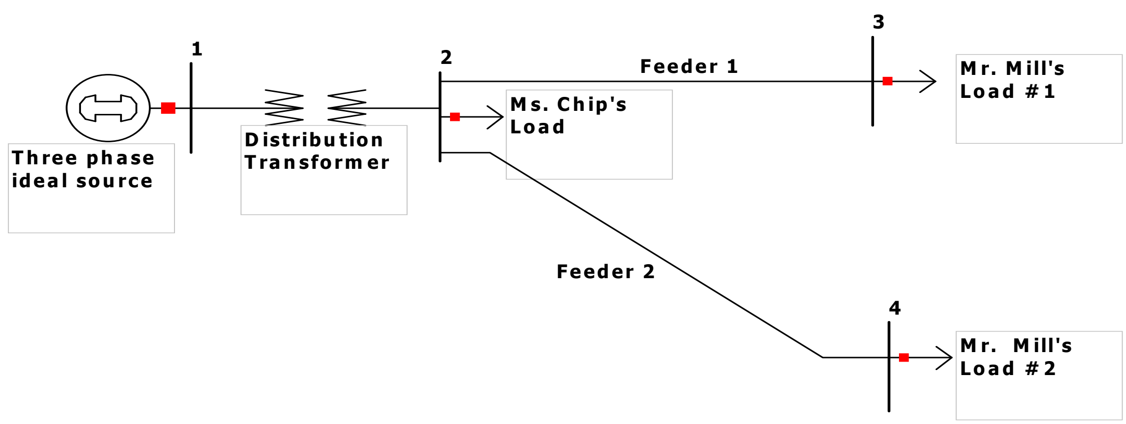

Figure 2. The proposed power distribution system for Mr. Mill and Ms. Chip

The following information was provided regarding the proposed system components and loads:

- Source is a three phase, 13.2 KV, ideal AC source.
- Transformer is a three phase, Δ/Y transformer consisting of three single phase units. Each single phase unit is rates at 150 KVA, 13.2KV/277KV and has an impedance of 20+j70 ohms on the high voltage (Δ) side.
- Both feeders are identical with an impedance of 0.03+j0.09 ohm.
- Mr. Mill's load #1 absorbs 200 KW at 480 V and at a power factor of 0.8 lagging.
- Mr. Mill's load #2 is a synchronous motor that absorbs 100 KW. The power factor of the motor can be between 0.8 lagging and 0.8 leading.
- Ms. Chip's load is negligible in power demand but very sensitive to voltage fluctuations.
- All loads can be represented as constant impedances.

Power system needed to satisfy the following constraints:

- Ms. Chip's load is very sensitive to the voltage fluctuations. Hence, the voltage at Ms. Chip's facility must be within the +/- 3 % of the nominal voltage (480 V
- The voltage at load #1 and load #2 at Mr. Mill's facility is required to stay within +/- 6% of the nominal voltage.

Students were asked to work in teams to investigate the proposed distribution system to see if the customers (Ms. Chip and Mr. Mill) are expected to have any problems with the proposed system. If there are any constraint violations, teams were expected to modify the proposed system and recommend a final solution that satisfies all the constraints. Teams had the options of adding capacitor banks, inductor banks, feeders, or transformers to the existing system. Teams were also asked to write a formal report explaining the final recommendation and one alternative solution. Cost implications of their recommended solution were also to be included in the report.

Design Project 3. This design project was assigned to student teams in EE4450, which is one of the heavy design courses in the curriculum. The project was provided by the American Power Transmission Company (ATC) in Wisconsin. In addition to providing one-line diagram of its 345, 138, and 69 KV transmission system, ATC also supplied relevant data such as bus data, line data, transformer data, load data, and generator data for the system. The relevant data for the project, which was too large to produce in this paper, was forwarded to design teams in electronic form.

The following information and constraints were also provided about ATC's system:

- Power base for the system is 100 MVA.
- Load flow voltage limits: 0.95 pu. < | V | < 1.05 pu.
- Contingency voltage limits: 0.90 pu. < | V | < 1.10 pu.
- Steady sate branch limits are to be used in load flow.
- Emergency limits are to be used for contingency.
- Load growth is expected to be approximately 2.5 % per year in the next 10-15 years
- If a team decides to put additional lines/transformers between buses, then these additional lines/transformers must have the same parameters as the existing ones.
- Approximate cost figures for various components, including installation cost, are:
  * Construction cost of lines:
    345 KV: $1,000,000/mile
    138 KV: $450,000/mile
    69KV: $230,000/mile

  * Transformer cost:
    138/345KV, 300/400/500 MVA rating $2,000,000.
    69/138KV, 100/130/150MVA ratings $800,000.

  * Breakers (include relays, control panels, surge arresters, disconnect switches and CTs and PTs):
    345KV $500,000/unit
    138KV $150,000/unit

69KV $70,000/unit

* Shunt Capacitor Banks: $20,000/MVAR

* Shunt Reactors: $15,000/MVAR

ATC requested that design groups do the following:

1. Base case study: It is the study of the existing system to see if there were any voltage and/or branch limit violations in the existing system under normal operating conditions. If there are violations, each team was asked to list them and explain possible reasons for the violations.

2. Contingency analysis:

   a. Contingency analysis on the existing system: In this part, teams were asked to perform a contingency analysis on the system and find out if the system can withstand contingencies. If there are contingencies that cause flow or voltage violations the teams were asked to tabulate them. The teams were also to discuss if there are any contingencies that are more serious then others, and also if there were any part of the system that is weaker (more affected by different contingencies) then other parts.

   b. System expansion studies and recommendations for 2012: In this section, teams were expected to come up with a system expansion plan for ATC for the year 2012. This involved doing a contingency analysis on the system and modifying the system so that there are no longer any violations in the target year of 2012. Teams were asked to consider the cost of system expansion and come up with their final recommendations to ATC.

3. Economic dispatch: In this section, teams were asked to use the original ATC system and investigate whether or not the generator schedules given in the base case was an optimal schedule. Teams were asked to include the emissions costs in their studies and were expected to come up an optimal schedule for ATC system. The cost curves as well SO_2 emissions for each power plant were provided by ATC as follows:

   Cost curves (in $/hour when PG is in MW)
   Point Beach: $800+4.0PG+0.0005PG^2$
   Kewaunee: $800+4.10PG+0.0005PG^2$
   Rocky Run: $250+4.5PG+0.0015PG^2$
   Edgewater: $300+4.6PG+0.002PG^2$
   Oak Creek: $350+4.4PG+0.004PG^2$
   Pleasant Prairie: $200+4.9PG+0.0015PG^2$
   Zion: $50+7.5PG+0.02PG^2$

   SO_2 emission rates were given as:
   Rocky Run: 0.001 ton/MWH

Edgewater: 0.002 ton/MWH
Oak Creek: 0.001 ton/MWH
Pleasant Prairie: 0.002 ton/MWH

Where the cost of emission was given as $300/ton.

4. Presentation and Report: Each team was asked to make a 20-minute presentation regarding their recommended system for the year 2012 and also write a formal report summarizing their findings and recommendations for each section.

As seen in the previous section, all three projects are in the power area of electrical engineering. While the first project is about a simple DC transmission system which primarily requires DC circuit theory and load modeling, the second project requires the knowledge of AC analysis, load modeling, power factor correction, transformer and feeder representation, as well as synchronous motor operation. The last project was provided by a company and involved not only with technical constraints, but also with right-of-way issues in transmission system design, and environmental issues related to emissions in power plants. Similarly, distributed design with increased complexity are provided in other areas of electrical engineering as well.

Major Design Experience

Most EE programs in the nation have one or two-semester capstone design courses to teach design and also to satisfy the ABET's major design experience requirement. Although, such courses are excellent for teaching design, they do not provide sufficient design experience to students. Also, when design work is concentrated in a few courses, it becomes difficult to incorporate non-technical constraints such as: economic; environmental, ethical, social, and manufacturability into a few design projects. Having design work distributed throughout the curriculum allows the students develop better design skills and allows the faculty to develop design projects with increased complexity for higher level courses.

The EE faculty at UWP has designated four courses as heavy design courses. During their senior year, students are required to take two of these four courses. These courses have design work which require the knowledge of topics from several previous courses as well as design experiences from previous semesters. Also in these courses, students deal with many non-technical constraints such as social, environmental, ethical, and safety. Many times, the design projects in these courses are provided by industry. The faculty believes that having distributed design and designating some courses as heavy design courses provide the students an excellent design experience and prepares them well for their profession.

Evaluation of Design Projects

Since the complexity and percentage weight of the design projects vary in each course, there is no uniform method of evaluating design projects in every course. Each faculty teaching the course develops his/her own method of evaluating design projects. However, in order to emphasize the importance of written communication skills, a written report (one for each design team) is mandatory for all design projects and 10-25% of the design grade is assigned to the report quality rather than its content. In EE professional elective courses, design teams are required to make oral presentations as well. In cases where a design project is sponsored by an industry, industry representatives are also invited to the final presentations and asked to evaluate the final design. Design teams are evaluated on the effectiveness of their presentations as well as their report quality. Some faculty members use peer evaluation by students in the assessment of student presentations.

Summary and Discussion

The EE department at UWP has incorporated engineering design in virtually every course in its curriculum. As a result, the concepts in engineering design are taught throughout the curriculum. With design being an integral part of every course, the complexity of design projects increase with the complexity of the subject matter. In addition to the increase in technical complexity, increased consideration is given to other constraints such as economic, safety, reliability, manufacturability, and environmental as students advance in their studies.

The faculty feels that this approach of teaching design and having design work built in complexity prepares our students well for their profession. This approach not only provides more design experience to students, but also enhances their knowledge of course material by having them actively work on the application of theory they learn in a course.

Although, distributed design provides a better educational environment for students, it must be pointed out that it also puts additional demand on students and faculty. In addition to the regular load in a course such as exams, quizzes, labs, etc., students need to spend extra time and energy to work in teams to complete their design work. When a student takes two or more EE courses, this additional demand may be significant. Faculty also needs to spend additional time to prepare, teach, and evaluate design projects. It is important that faculty teaching loads be appropriately adjusted if design is to be taught in every course in a curriculum.

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