A Pedagogically Effective Structured Introduction to Electrical Energy Systems With Coupled Laboratory Experiences

Giri Venkataramanan, *Member, IEEE*

***Abstract*—Electrical energy conversion systems and power supply systems form an integral component of electrical and electronic systems used in residential, commercial, aerospace, transportation, and manufacturing applications. Practicing electrical engineers are often called to solve electrical energy and power-related problems. Therefore, an effective course that provides graduating electrical engineers with an energy-oriented perspective is highly desirable in today's workplace. This paper documents a course that provides students with problem solving experience in electrical systems and electronic circuits. The paper presents the pedagogical premise, course objectives, and details of lesson and lab activities, student projects, and experiences.**

***Index Terms*—Engineering education, laboratories, power engineering education, professional communication, writing.**

I. Introduction

WHILE electrical energy conversion systems and power supply systems form an integral component of modern electrical and electronic systems, student engineers graduating from modern electrical engineering curricula are rarely aware of real-world design concerns that stem from power and energy issues [1]. The curricular demands posed by major developments in the field of microelectronics, computer, and communication systems have come to represent a large share of core competencies inculcated in undergraduate curricula and have displaced exclusive "power"-oriented courses gradually over several decades [2]. This was accompanied by a perceived maturity of the power engineering discipline. Therefore, the gradual overshadowing of power engineering education at universities has not resulted in the perception of a crisis. However, in recent years, several developments including industrial automation, solid-state power control, demographics, and industrial deregulation, have prompted educators at several universities to develop a course that not only introduces a power engineering perspective to the students, but also attracts the brightest students to pursue a career in power engineering [3].

Furthermore, within the larger context of university education today, a major concern is the disproportionately small share of minorities and women who opt to enter engineering careers [4]. In recent years, a large volume of scholarship on effective pedagogical techniques that aim at encouraging a positive learning climate for under-represented groups has emerged [5]. Beyond improving attrition rates among under-represented groups, these techniques have also been found to be effective in increasing the learning effectiveness of other groups of students [6]. Designing a course in power engineering provides an ideal opportunity for implementing several effective pedagogic techniques, due to the inherent multidisciplinary nature of the field and its ubiquity in modern daily life. Such a course was developed by the author at Montana State University-Bozeman (MSU) and soon became the favorite course of senior-level students after two offerings. This paper describes the salient features of the course along with lesson plans, laboratory experiences, and student projects.

Section II describes an overview of effective pedagogical objectives that have been identified from the body of educational research for incorporation into the course. In Section III, instructional topics of the course that include analytical tools and technical skills are described. A description of the laboratory space developed in conjunction with the course is presented in Section IV. Section V presents a summary of student assessment techniques used in the course along with selected evaluation results. The concluding section has a brief summary of the results from implementing the course. Details of the syllabus, timetable, sample student assignments, etc. are presented in the Appendix.

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The author is with the Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, WI 53706 USA (e-mail: giri@engr.wisc.edu).

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I. Pedagogical Plan

A. Diverse Learning Styles

As the pedagogical plan was developed, several research studies on learning effectiveness of students were reviewed [7]–[16]. These studies indicate that effective pedagogy begins with a classification of student learning styles, such as the Myer-Briggs type indicator (MBTI) or the Kolb's learning style inventory (KLSI). The Myer-Briggs Test provides a comprehensive type classification of personalities that has important implications for the learning style of individual students [8]. On the other hand, KLSI has a specific focus on the learning process and thus enables pedagogical design to address specific instructional objectives [9].

KLSI is based on the concept that the learning process follows a cycle of activities consisting of four distinct segments, namely feeling [through concrete experience (CE)], thinking [through abstract conceptualization (AC)], watching [through reflective observation (RO)] and doing [through active experimentation (AE)]. Although all of these four segments constitute

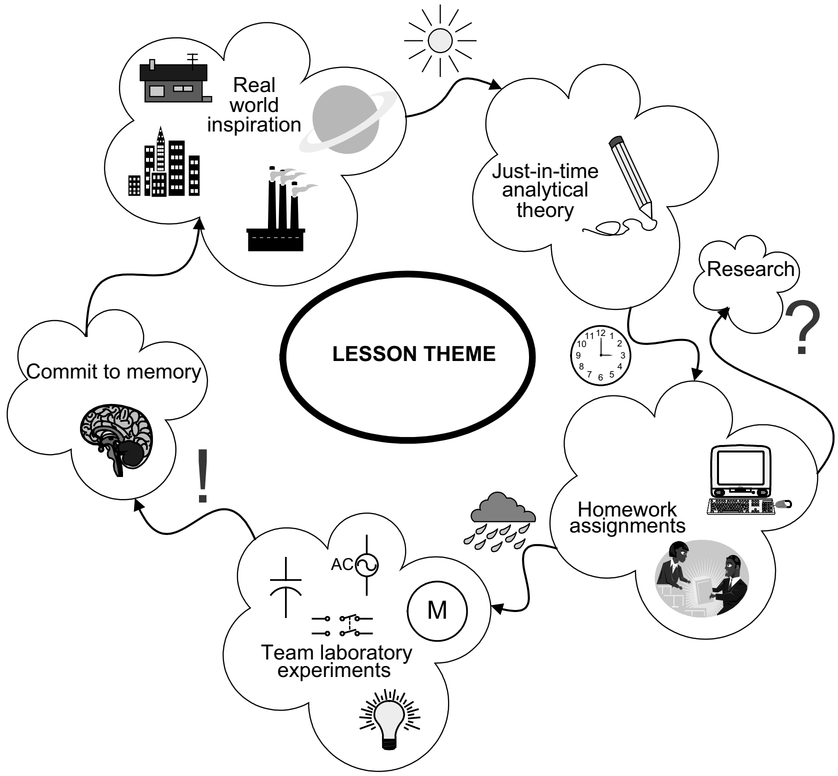

Fig. 1. Illustration of the inquiry-based pedagogic process used in the course.

the learning cycle, one or two of these activities typically dominate a person's learning style [10]. Since any student body may contain a diverse distribution of learning styles, in order for the pedagogic process to be effective, it is imperative to incorporate all of the segments of the learning cycle into the instruction [11]. The design of the instructional structure to provide a balance of several activities that appeal to all the learning styles is one of the key features of the course development described here.

B. Inquiry-Based Learning

The general pedagogical objectives of the course were laid out to follow an inquiry-based learning process. Fig. 1 illustrates specifically how this process occurs in a cyclical manner in the course. The process was developed from the recommendations of various meta-studies presented by educational researchers and leaders aimed at reinforcing the educational mission at modern universities [12]. It may be observed from the figure that this process incorporates all the segments of a KLSI learning cycle.

The real world is used as the bank from which topics of inquiry are chosen—this step addresses the CE segment of the learning process. Analytical tools that are necessary to address the questions are developed during lectures using an active participatory process, in a just-in-time fashion—this step addresses the AC segment of the learning process. The students then receive a team assignment to complete within a strict deadline. Completion of the task-oriented assignment typically involves a nominal amount of research to be completed and the use of computational modeling tools—this segment addresses the RO segment of the learning cycle. Soon after the assignments are completed, the teams conduct laboratory experiments to verify their solutions and to examine the validity and limitations of the analytical model—this segment addresses the AE segment of the learning cycle. A discussion of the consequences and applications of the findings brings a tentative closure to the inquiry process. This step often leads into the lesson theme for the next real world inspired inquiry process.

Thus, each inquiry-based lesson module is designed to proceed through the "problem identification → theoretical analysis → computer modeling → design solution → experimental study → problem solution and application" cycle, which is common in real-world engineering processes. Twelve weekly cycles of pre-designed inquiry based lesson sequences are carefully selected to fulfill the instructional objectives of the course, as described in the next section. After the completion of 12 such cycles, students become familiar with the inquiry-based engineering process and the laboratory facilities available to assist in the AE segment of the inquiry process. Student teams are then expected to develop their own inquiry module that comprises all of the steps in the cycle of activities on a power engineering topic of their own design. The teams have three weeks to complete the project. During the last week of the course, each team prepares a professional report and presents their results to the class including a laboratory demonstration.

C. Experiential Learning

The "cone" of learning shown in Fig. 2 illustrates the effectiveness of various domains of experience from a pedagogic point of view [13]. The activities at the bottom of the cone are said to provide learning opportunities with higher motivational and retention levels compared to those that are at the top. The limited effectiveness of the "top heavy" classical teaching styles with three weekly lectures supplemented with textbook reading may be readily observed from the figure. The structured inquiry-based approach applied in the course described herein extends the teaching style beyond the classroom and the textbook to provide more effective learning experiences for the students. The course incorporates within itself various dimensions of participation and contrived experiences, thereby dramatically improving pedagogical effectiveness. In particular, the authentic inquiry process and the insistence of originality in the student-directed inquiry project provides the best learning opportunity possible within the context of a university setting.

The course structure shifts the central objective of instruction away from imparting content. Instead, the instructional content is transformed into a vehicle for focusing on and improving the students' learning process. This shift teaches the students to become lifelong learners. Such lifelong learning skills are broadly considered to be of paramount importance in the engineering workplace with rapidly and constantly evolving technology elements [14].

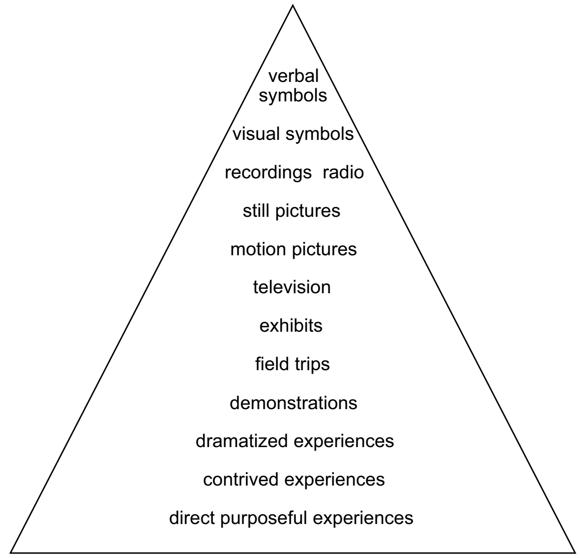

Fig. 2. Cone of experience, adapted from [13].

D. Learning Levels

In addition to addressing the diverse learning styles of students across the board, specific learning activities in the course were selected specifically to realize higher levels of learning in the cognitive as well as affective dimensions.

Cognitive learning levels progress higher as the learning objectives proceed along a continuum of activities identified to be: (a) knowledge →(b) comprehension →(c) application →(d) analysis →(e) synthesis, and →(f) evaluation [15]. Weekly lesson themes that are built around the real world *application* become the canvas onto which the media of content-specific *knowledge* is applied using the tools of *analysis*, thus honing the skills of *comprehension*. The laboratory experience following the homework assignment becomes a natural setting for *evaluation* of the results and *synthesis* of the learning material. Thus, the pedagogic process threads all of the dimensions of cognitive learning levels into the learning cycle.

In the affective dimension, learning levels progressively build on a continuum of three steps: a) receiving instruction →b) responding/internalizing instruction, and →c) valuing the instruction [16]. The authenticity of the learning experience is considered to have a positive effect on the increasing the affective levels of learning from merely receiving instruction toward responding to the instruction and valuing it.

II. Instructional Topics

Once the instructional structure of the course was laid out, a concrete set of learning objectives for the course was drawn up. A list of course objectives (no order of importance implied) is shown in the Appendix, in Section VII–A. Objectives (1)–(4) dovetail with the program objectives of degree programs in engineering, broadly aligned with Engineering Criteria 2000 formulated by the Accreditation Board of Engineering and Technology [17]. These objectives address "softer" skills that are generally reported to be lacking among engineering graduates by employers and alumni, and the instructional plan addresses these objectives throughout the course. On the other hand, objectives (5) through (12) represent core content that is used as a vehicle to impart experience for the students in learning to learn. These objectives are broad in scope and provide a high degree of flexibility in choosing specific lesson themes.

Practice of power engineering today involves a huge masse of art and skills. The particular topics were chosen to include studies of power circuits, principles of rotating machines, introduction to power electronics, and structure of ac power systems to provide a flavor of the breadth of modern power engineering practice. A weekly timetable of lesson themes, homework assignments, and laboratory topics are listed in Table II, in the Appendix. One of the main considerations in the particular choices of lesson themes is their amenability to a university laboratory setting. Although this provides roughly only four weeks to study each of the topical areas, the intensity and completeness of the learning process results in better preparedness in the students to face the real world.

Once the lesson topics are chosen, the association between the lesson themes in each problem solving exercise and the learning objectives are clearly identified during the course and constantly kept as backdrop throughout the course. For instance, the sample problem illustrated in the Appendix (Sections VII–B and VII–C), studied during week 3–4 of the course, addresses all of the course objectives with the exception of (5). Fig. 3 illustrates the process being applied to the topic of phasors and ac circuit analysis using complex algebra.

As shown in Fig. 3, the instructional cycle follows a series of activities addressing various elements of the learning cycle. After an introduction to the problem to be solved in the lecture format, a brainstorming of possible design alternatives for operating a 115 fan from a 230-V source is conducted in the classroom. Various alternative solutions such as step-down transformers, autotransformers, and resistive voltage dividers are introduced and their advantages and disadvantages are discussed in the class. Having been steered toward an impedance voltage divider as the preferred solution, the students go home and apply phasor-based power circuit analysis to solve the problem. The

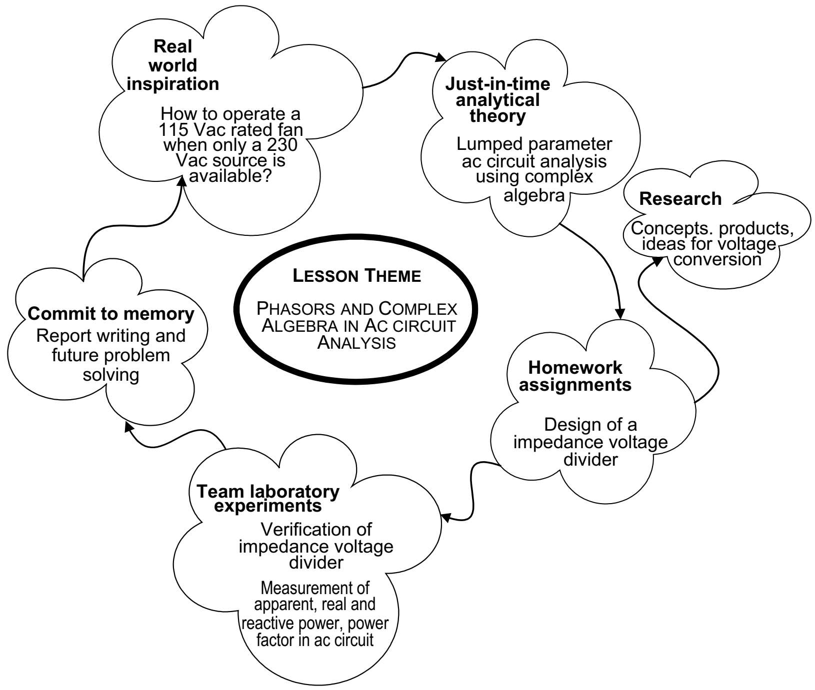

Fig. 3. Illustration of the application of inquiry-based pedagogic principles during weeks 3 and 4 of the course.

complexity of the problem invariably requires a mathematical computational tool such as MathCAD or Mathematica for developing the solution and study design sensitivities [18], [19]. A quick introduction to these tools is provided during the second week of classes in the context of sensitivity analysis in engineering design, which is enthusiastically received by the students after having struggled through the first exercise using a calculator, pencil, and paper. After the student's solutions are received, the instructor's solution is presented in the class, which typically expresses the elegance in the solution process, challenging the students to perform better during the next cycle. Additional alternative student solutions are encouraged through extra credits provided in the grading process. This was found to provide an incentive for those students who fall behind during the first rounds of grading but can use this as an opportunity to demonstrate competency and improve their grades.

The laboratory experiment in the following week verifies the instructor's solution in hardware and the students are encouraged to verify their own solutions when appropriate equipment is available. This step not only verifies the design, but also brings out an opportunity to observe often surprising unmodeled phenomena. A sample of the detailed procedure for the laboratory experiments is provided to the students as shown in Appendix VII–C. In the procedure, the electric circuit diagram to be built is left for the students to complete, allowing them to reflect over the circuit assembly process before the lab. In the lab, one person of the team assembles the circuit and another person checks the correctness of the assembly. A systematic assembly process using a highlighter to check the circuit to ensure error-free interconnections is introduced. It is notable that almost all of the junior electrical engineering students build circuits from their memory, without a schematic, having picked up the habit from their signal level electronics laboratory experiences. The risks of this unsafe practice while working with power circuits are typically brought out after the first week of lab experience.

This cyclic learning process accompanied by an implicit reflection on the process is repeated over and over again through the first 12 weeks of the course.

The process culminates in a student-directed laboratory project that aims to develop their personal real world problem to form a capstone experience within the course. Students have the flexibility to select any power engineering-oriented problem that includes the complete learning cycle using the facilities available in the laboratory. Details of the organization of the project experience are shown in the Appendix, Section VII–D. All of the student teams are required to write a report describing the analytical development, laboratory procedure, experimental results, and conclusions. They are also required to present a demonstration of their work to their section of the class, and their presentation is videotaped. Fig. 4 illustrates the experimental results from a typical student team project. The graph provides a comparison of the discharge characteristics of three different alkaline batteries tested by the student team as their project. A list of selected student team projects is shown in the Appendix, Section VII–D.5. The authenticity of the learning experience is readily demonstrated by these projects. The project experience has proven to be the climax of the course for students and the instructor alike.

III. Laboratory Space

Due to ongoing facilities development at the university, an opportunity to develop the accompanying laboratory space arose during the course development process. Ideally, the laboratory space provides maximal opportunities for the active experimentation (AE) segment of the learning cycle and intellectual stimulation at large. A review of pedagogical literature examining the

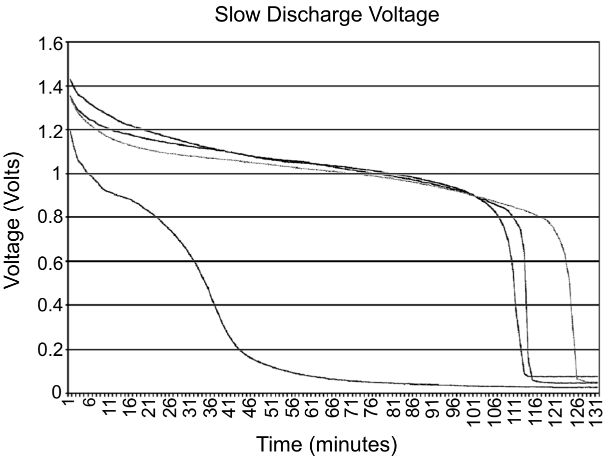

Fig. 4. Sample of experimental results from student projects—discharge curves from a comparative characterization of alkaline batteries from different manufacturers.

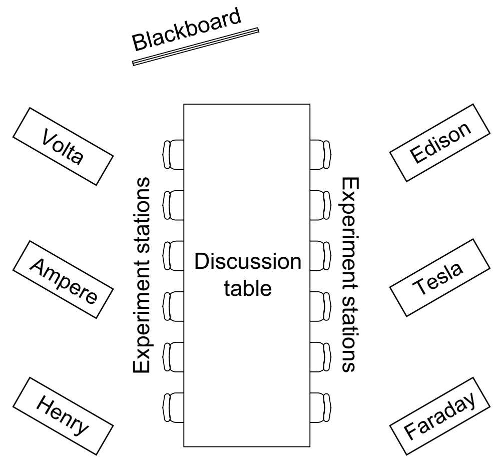

Fig. 5. Approximate layout of the laboratory space used for the course.

relationship between spaces and learning was found to focus on integrating computers and instructional technology within the space to provide collaborative and active learning opportunities [20]–[23]. Although these experiences could not be directly applied to a power engineering laboratory, the essential elements of improved learning spaces were adapted to develop a final layout to fit requirements of available footprint, safety, flexibility, and economy. Fig. 5 illustrates the approximate layout of the laboratory space.

The space was designed to enable two types of interactions to take place—(1) a safe and flexible workspace for several team-based experimenting activities to occur simultaneously (2) a gathering table for all of the teams to come together. The large table is the central aspect of the space where the entire lab section gathers together to discuss the objectives of the exercise. They then disperse as teams of two or three to conduct the laboratory experiments at the modular experimental stations along the sides of the space. After the laboratory experiments are completed, a brief discussion of encountered problems, solutions and a preliminary comparison of data became a common ritual. This open architecture of space provides a maximal sightline for the laboratory facilitator, while providing booth-like private spaces for the teams.

A photograph of the modular test station is included in Fig. 6. A listing of the facilities available for the students at each test station is provided in the Appendix, Section VII–E. These apparatus were chosen carefully and specifically to enable the authentic AE segment of the learning cycle for all of the chosen instructional topics. The facilities allow *a contrived experience* during the learning cycle, reaching toward the bottom of the cone of experience illustrated in Fig. 3. For instance, the ready availability of 115-V ac source and 230-V ac source, a fan, and a series impedance, along with appropriate instruments and connectors allows the verification of the solution to the real world problem illustrated in Fig. 3.

At the workstation, the electrical machines were placed under the test surface with all of the connections brought to the patch panel, saving valuable floor space. The instrument shelves at the workstation were open at the rear to allow easy access to the back-panel of measuring instruments, where most of their connections are made. The work-surface of test stations was high enough to be accessed in a standing position with no provision for seating. This provides maximum mobility in case of any mishaps and limits unproductive web-surfing. Furthermore, this draws people together to the discussion table where comfortable seats are conveniently placed and, thus, encourages collaborative discussion between different teams. A portable blackboard on wheels for sketching and communicating with the entire group was handily placed next to the discussion table.

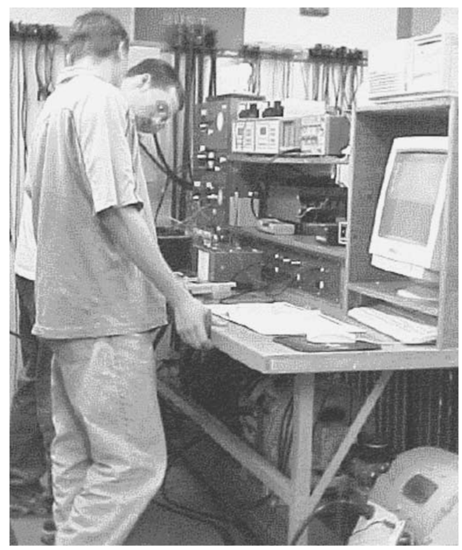

Fig. 6. Photograph of the modular workbench.

The space was designed with several features to encourage a thematic perspective. The workstations were named in honor of eminent contributors to the field of electrical sciences. Each station carried a portrait and a short biography of the honoree. The instructional laboratory space was also seamlessly integrated with the research lab space, thereby opening a window for the students to peep into advanced experimental research in the field. Physical props, such as sections of overhead transmission cables, a vintage distribution transformer, and a mobile robot were also installed in the space.

TABLE I
ASSOCIATION OF GRADING CRITERIA (COLUMNS) WITH COURSE OBJECTIVES (ROWS)

	VII.B.2					VII.C.4							VII.D.4	VII.F
	1	2	3	4	5	1	2	3	4	5	6	7		
1	x	x		x	x				x		x	x	x	
2						x	x						x	
3						x				x	x	x	x	
4			x	x	x					x	x	x	x	
5	x							x					x	x
6	x							x					x	x
7	x							x					x	x
8	x							x					x	x
9													x	x
10	x							x					x	x
11	x					x	x						x	x
12						x	x		x				x	

IV. LEARNING ASSESSMENT

A. Student Assessment

An outcome-based approach was used for student assessment of learning in the course. Grading criteria for the homework problems, laboratory reports, and projects are shown in Sections VII–B.2, VII–C.4, and VII–D.4 of the appendix, respectively. These criteria are designed to address the different course objectives listed in Section VII.A. The details of the association between the various grading criteria and the course objectives are illustrated in Table I. The headings of various rows indicate the various course objectives listed in Section VII–A. The headings of columns indicate the different grading criteria for the specific homework assignment (VII–B.2), laboratory exercise (VII–C.4), project (VII–D.4), and examinations (VII–F), respectively. It may be noticed from the table that the realization of learning objectives is assessed in a seamless manner as the students participate in the learning activities. Thus, all of the learning activities and exercises steadily provide feedback to the students in a formative manner.

In addition to the seamless assessments integrated with the homework and laboratory assignments throughout the semester, periodic summative assessment was also conducted through quizzes. These primarily tested mastery of content of the course. Sample quiz questions are provided in Section VII–F. The quiz included a mix of narrative problems and multiple-choice questions, again designed to provide a balanced assessment geared toward different styles of learners. Although the problems in the quiz had a real world flavor, the complexity of these problems was similar to those found at the end-of-the-chapter problems in textbooks.

The final project was completely graded through a self-and-peer assessment process. Students assessed their own performance and those of other members of the team using the criteria listed in Section VII–D. This tended to result in a uniform grade distribution for this segment of the course and it reflected the high level of achievement shared by all of the students.

In one of the offerings of the course with 60 students divided into five sections, the average percentage grade points in one of the sections was 82% with a standard deviation of 9.3%. The lowest percentage received by any student was 60%, while the highest was 94%. The grades in the other sections had a similar distribution. Unfortunately, data for a detailed comparison of student performance with a similar course offered in a classical format is not readily available. Even though the course average grade was in the "low B" category, students generally perceived the outcome-based grading process to be fair and equitable. Students felt a sense of personal learning achievement through the completion and public demonstration of their project, independent of the grades they received.

B. Student Evaluation

At the time of course development, as well as during previous offerings in the classical format, controlled instruments to perform a comparative and comprehensive learning effectiveness assessment were not conducted, thus precluding any definitive conclusions. However, end-of-semester student evaluation scores from both cases were available for comparison. The cumulative average student evaluation score for the inquiry-based course was 4.2 for the lecture section and 4.1 for the lab sections, on a scale of 1–5. As a comparison, the scores for a similar course previously taught in a more classical style were 3.75 and 4.0, respectively. This indicates a definite higher level of learning satisfaction as perceived by the students.

Whereas student comments in the classical format reflected a theme of "too much material being covered in too short a time," the newer format elicited comments reflecting the course to be "dynamic with no time to get bored or spaced out."

V. CONCLUSION

This paper has documented the salient experiences from the development and offering of a junior level power engineering course. A description of pedagogic objectives, learning objectives, lesson, and laboratory themes have been presented in the paper. The pedagogic objectives were developed to provide an effective learning experience for a wide variety of learners based on documented best practices. Inquiry-based lesson themes of each of the topics in the course were based on real-world problems leading to weekly lab experiments, while student assignments preceded the laboratory experiments. The lecture topics provided just-in-time introduction and review of theoretical principles. During the final weeks of the semester, student teams chose and conducted a personalized real world inquiry project and presented their results to the entire class, including a laboratory demonstration. The presentations were videotaped and peer-graded by the other students. A brief discussion of the laboratory space was also presented in the paper. The space became enormously popular among the students for engaging in independent inquiry.

The project did not include any formal assessment course development during the offerings. However, student evaluation results indicated the course to be enormously successful in stimulating interest in power engineering and beyond. Some of the undergraduate student projects led to research publications [23], [24]. Two students (both women) continued on a Master's program in power engineering, leading to successful careers.

APPENDIX
COURSE OBJECTIVES

1) To develop sensitivity analysis skills for design and performance prediction of engineering systems.
2) To function in a team and task-oriented work structure to meet deadlines.
3) To prepare laboratory reports of professional quality.
4) To communicate effectively in technical fields.
5) To illustrate applications of electrical circuits and systems from an energy conversion viewpoint
6) To apply electrical circuit analysis techniques from a design-oriented viewpoint.
7) To predict the operating characteristics of electrical power devices using equivalent circuits and mathematical models and use their characteristics to match the devices to their loads appropriately.
8) To develop the relationships between electrical quantities such as voltage, current, power factor, real power, etc., magnetic quantities such as flux density, magnetic field, etc., and mechanical quantities such as speed, torque, etc. in rotating electrical machines.
9) To apply electronic switching devices for dc power control, and predict their performance in power converter circuits.
10) To define and specify power supply systems for application circuits and systems.
11) To define and formulate calculations and experiments to determine the performance of electrical systems.
12) To develop and conduct experiments to determine or verify the characteristics of electrical machines and other power devices in a systematic and safe manner.

VI. SAMPLE STUDENT ASSIGNMENTS

A. Homework Problem

An electric fan is rated to operate from a 120-V ac source, drawing 0.35 A of current lagging 55° on the high-speed setting and 0.25 A of current lagging 53° on the low-speed setting. It is desired to operate the fan at a location where only 208-V ac source is available.

1) Design an impedance voltage regulator to realize the function. The voltage across the fan should stay within 10% of rated conditions under both speed settings.
2) Determine the line currents and the lag angles of the new load system, under each of the speed settings?

B. Grading Criteria

1) technical integrity 50%;
2) accuracy of solution 10%;
3) presentation, grammar, spelling, legibility 10%;
4) diagrams, graphs—cleanliness, axes, labeling 20%;
5) conclusions, reflective comments on learning 10%.

TABLE II
WEEKLY LESSON TOPICS

Week	Lecture topics	Homework	Laboratory
1	Heating system for a process plant Cable sizing for heater with a dc, ac source		Lab tour electrical safety review
2	Sensitivity analysis in engineering design Cable sizing with an ac source and transformer	Heater design and analysis	Extension cable losses
3	AC sources in series and parallel Lumped parameter characterization of ac loads AC circuits with lumped elements	Impedance voltage divider	Ac power Systems
4	Power in non resistive ac circuits Power factor and correction **QUIZ 1**	Power factor correction	Impedance voltage divider
5	Dc generator magnetic circuit Dc generator operation Dc generator performance	DC generator analysis	Power factor correction
6	Dc motor operation Dc motor application	Performance of dc motor	Dc generator model
7	Alternator operation Alternator performance Rotating magnetic field	Alternator analysis	Performance of dc motor
8	Induction motor operation and application Induction motor application **QUIZ 2**	Performance of induction motor	Equivalent circuit of alternator
9	Starting and reversing of motors Grounding, fuses and circuit breakers Needs and principles of power control	Motor control center	Performance of induction motor
10	Dc motor controller operation Dc motor controller design Dc motor controller performance	Design of dc motor speed controller	Testing of circuit breakers
11	Single phase rectifier operation Single phase rectifier design	Design and analysis of single phase rectifier	Dc motor speed controller
12	Power supplies for electronic equipment Power entry module **QUIZ 3**	Final project selection	Single phase rectifier
13	Batteries Inverter operation Inverter as power amplifier	Final project experimentation period	
14	Inverter UPS application Inverter ac drive application Generation of electrical energy		
15	Transmission of electrical energy Distribution of electrical energy Economics of electrical power utilization	**FINAL PROJECT PRESENTATIONS**	
FINAL EXAM			

VII. Laboratory Exercise

A. Objective

To verify the operation of the fan at 120-V source and compare it with operation at 208-V source with an impedance regulator network.

B. Apparatus

1) 120-V single phase ac source;
2) 208-V single phase ac source;
3) fan under test;
4) one power analyzer;
5) series impedance of required value $(Z = \Omega)$.

C. Procedure

1) Prelab Assignments:

1) Completion of the circuit diagram shown in Figs. 7 and 8 so that the electrical characteristics of the fan may be determined and its the operation from a 208-V source may be verified.
2) Indication of the value of the series impedance in the circuit diagram.

2) Inlab:

1) Approval of circuit diagrams by the instructor.
2) Identification of the physical components and terminals indicated in the circuit diagrams.
3) Assembly of Fig. 7 using the highlighter method.
4) Verification of circuit assembly against the circuit diagram.
5) Approval of circuit assembly by the instructor.
6) Energizing the circuit and completion of the measurements under the 120-V source (fan only) columns of Table III.
7) De-energizing of circuit.
8) Modification of the circuit assembly to represent the second circuit diagram.
9) Verification of circuit assembly against the circuit diagram.
10) Approval of circuit assembly approved by the instructor.
11) Energizing the circuit and completion of measurements under the 230-V source (fan and series Z) columns of Table III.

3) Postlab:

1) Complete a report of the experiment.
2) List the learning accomplishments of this exercise

D. Grading Criteria

1) prelab work 10%;
2) inlab conduct 20%;
3) technical integrity 20%;
4) accuracy of results 10%;
5) presentation, grammar, spelling, legibility 10%;
6) diagrams/graphs—cleanliness, labeling 20%;
7) conclusions, comments 10%.

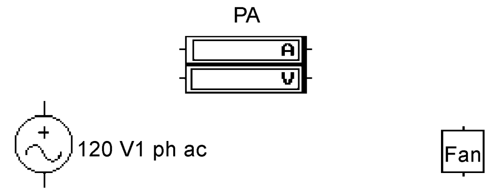

Fig. 7. Schematic of the incomplete circuit diagram to verify the electrical behavior of the fan under nominal conditions.

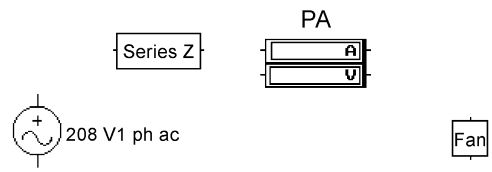

Fig. 8. Schematic of the incomplete circuit diagram to verify the operation of the fan with an impedance to operate from a higher voltage source.

Fig. 9. Photograph of a 120-V 60-Hz 6-kW alternator.

TABLE III
EXPERIMENTAL DATA

Speed setting	120 V source (fan only)			230 V source (fan & series Z)		
	Fan Voltage (V)	Fan Current (A)	Fan Power (W)	Fan Voltage (V)	Fan Current (A)	Fan Power (W)
Lo						
Hi						

c) Post-lab

1. Complete a report of the experiment.
2. List the learning accomplishments of this exercise

4) Grading criteria

1. Pre-lab work 10%
2. In-lab conduct 20%
3. Technical integrity 20%
4. Accuracy of results 10%
5. Presentation, grammar, spelling, legibility 10%
6. Diagrams/graphs - cleanliness, labeling 20%
7. Conclusions, comments 10%

VIII. Student Projects

A. Report

One report per team, in the same format as lab reports with clear statement of objectives, procedure with schematics, experimental data, tabulations, graphs, and conclusions, due at the time of presentation. The report may be copied and distributed to audience if it will help to understand the presentation better.

B. Presentation

Each team gets half an hour, including set up time and question time. Each student must participate "equally" in the presentation and will be graded on an individual basis. Presentation can include hardware presentation, pre-made charts, and blackboard.

C. Questions

Each team should be ready to answer any questions from the audience after their presentation. Team members must participate "equally" in answering questions. Each person in the audience must ask a question.

D. Grading Criteria

1) technical integrity;
2) diction and intensity of speech;
3) grammar and technical lucidity of speech;
4) answering questions;
5) audience comprehension;
6) demonstration of technical comprehension through questions;
7) grammar and technical lucidity of question.

E. Sample Student Projects

1) overload tripping behavior of fuses under dc currents;
2) a single phase ac controller;
3) power line harmonic filters;
4) characterization of a UPS system;
5) run-up testing of induction motor drives;
6) construction of an axial field induction motor.

IX. Listing of Laboratory Apparatus at Each Station

1) dc source 110 V 60 A;
2) ac source 1 230 V 25 A, three-phase three-wire delta;
3) ac source 2 208/115 V, 25 A, two-phase four-wire star;
4) dc source 2 x 0–30 V, 3 A dc;
5) dc source 5 V, 5 A dc;
6) function generator;
7) two-channel digital storage oscilloscope;
8) 250-V differential probe;
9) 5-kW power analyzer;
10) true rms multimeter;
11) 50-A current shunt;
12) 4.5-kW three-phase resistive load bank;
13) 2.5-kVAr three-phase capacitor bank;
14) 0.5-kVAr three-phase reactor bank;
15) 180-W three-phase lamp load;
16) dc machine 5 kW, 100 V;
17) 230-V, 5-h.p. three-phase slip-ring induction machine;
18) 230-V, 5-kVA three-phase alternator with wound field;
19) shaft torque transducer;
20) optical noncontact tachometer;
21) 3-kVA one-phase/three-phase diode bridge rectifier;
22) 500-W dc field regulator;
23) 5-kVA three-phase inverter;
24) 5-kVA three-phase-controlled SCR-based dc drive;
25) personal computer with network interface;
26) miscellaneous items such as fans, circuit breakers, fuses.

X. Sample Examination Questions

A. Multiple Choice Questions

1) An induction motor spun at 1200 r/min upon no load on a 120-V, 60-Hz excitation. When fed with a 30-Hz source, and upon loading, the speed was 540 r/min. The slip was
   (a) 10%;
   (b) 55%;
   (c) 45%.
2) A single-phase rectifier with a capacitor filter was fed with a 120-V, 60-Hz ac voltage. The dc voltage will be
   (a) 170 V;
   (b) 120 V;
   (c) 110 V.
3) In order to reverse the speed of a three–phase induction motor
   (a) two of the three wires have to be reversed;
   (b) all three wires have to be cyclically rotated;
   (c) the field winding has to be reversed.

B. Sample Classical Problem

The generator shown in Fig. 8 is rated 120 V 60 Hz and has a maximum output of 6 kW and continuous output rating of 5.5 kW. It is driven by a 10-h.p. diesel engine spinning at 3600 r/min. It has a 13.5 liter fuel tank and runs for eight hours at full load on a single tank. The efficiency of the diesel engine is estimated to be 20%.

1) determine the number of poles of the alternator;
2) estimate the efficiency of the alternator;
3) estimate the amount of energy in a liter of diesel.

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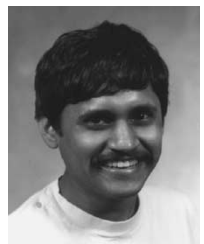

Giri Venkataramanan (M’92) received the B.E. degree in electrical engineering from the Government College of Technology, Coimbatore, India, the M.S. degree from the California Institute of Technology, Pasadena, and the Ph.D. degree from the University of Wisconsin, Madison.

Currently, he is teaching electrical engineering at Montana State University, Bozeman. He returned to the University of Wisconsin, as a faculty member in 1999, where he continues to direct research in various areas of electronic power conversion as an Associate Director of the Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC), Madison, WI. He holds four U.S. patents and has published many technical papers.