Session 2548

Teaching Electric Machines and Power Electronics: Emphasis and Challenges

Youakim Al Kalaani, Abul K M Azad

Northern Illinois University, Technology Department

Abstract

The widespread applications of industrial power electronics and electric machine drives have increased the need for graduates well trained in leading edge motor control technologies. Efficient and flexible power electronics circuits are used nowadays in most areas of industrial applications, including dc and ac motor control and commercial electric power transmission and generation. This paper describes the development of an electrodynamics program in the Engineering Technology Department at Northern Illinois University. An effective approach to introduce students to electric machines and the latest solid-state technologies as applied to motor speed controls is presented. A sequence of training modules is developed on low-power, industrial-type equipment that enables students to perform visual inspection of the machine's internal construction. Other supporting instructional technologies are also presented, and discussed, in this paper.

I. Introduction

Over the past decade, advancement in switching power conversion and variable-speed drives has dominated all aspects of industrial applications. Consequently, the need for well-trained people who can operate and maintain this high-tech equipment has substantially increased. This high demand for qualified engineers and technician has not gone unnoticed. Many colleges across the nation have witnessed growing enrollment in this rapidly changing field. Classically, electric machines and power electronics have been taught as two separate entities independent from each other. This is the case in most engineering institutions with graduate courses, since power electronics has many other industrial applications. However, teaching modern machines with variable-speed drives is no longer possible without considerable knowledge of power electronics[1].

The traditional approach in engineering technology education has been to offer students a sequence of core courses that is followed by specialty ones. However, this approach has recently been scrutinized due to documented[2] lack of connectivity between topics. The Herrick & Jacob series, for instance, has started combining ac and dc circuit theory with electronics to support circuit development and analysis. Technology educators are increasingly in favor of course integration to cover modern industrial applications. In fact, many institutions are considering this change, as the pressure in academia today is to keep, or even decrease, the number of courses required for a degree[3].

This paper describes the development and implementation of a modern electrodynamics program in the Electrical Engineering Technology at Northern Illinois University. A classical machine course was restructured to introduce basic power electronics and speed control aided by newly acquired state-of-the arts equipment. Five modular units were developed and include laboratory experiments on low–power, industrial-type equipment. The first unit introduces students to fundamental power conversion and basic power electronics principles; the second instruction unit covers dc machines and various types of dc motors and drives. The third unit deals with single-phase motors and their commercial applications. The fourth unit, the largest one, explains the operation and use of three-phase machines and variable-frequency drives; and the fifth unit is devoted to the study of single-phase and three-phase transformers.

II. Program Development

Northern Illinois University is strategically located in the industrial-belt area extended between Chicago and Rockford. While the Technology Department at NIU has an excellent Electrical Engineering Technology program, until recently, it has only one 3-credit hour course in electric machine theory. To avoid increasing degree requirements as mentioned earlier, it was necessary to revise the current program curriculum to allocate adequate instruction coverage for this area of study. As a result, a laboratory component was added to support student training.

Most modern power electronics and machine drive circuitry are semiconductor-based technology. Nearly all solid-state devices, such as diodes, transistors, thyristors, MOSFEETs, and IGBTs are covered in basic electronics courses. Thus, students eligible to enroll in the electric machine course should be ready to tackle advanced topics. During the development of this course, good efforts were made to avoid abstracts and general field theory that requires advanced math and calculus. Instead, basic electric circuit analysis was used to explain machine basics with some trigonometry and algebra. This applied approach was found to be far more productive and less intimidating to our students. Instead, much emphasis was spent on presenting the material in a consistent and systematic way. For instance, complete details were given to describe machine physical constructions, winding layouts, magnetic interactions, machine operation characteristics, motor drives, and real-word applications.

Most educators agree that it is not feasible to train students for all types of situations that may be encountered in the workplace. However, one can set an effective course of action by integrating both machine theory and laboratory experimentations in well structured units of instruction. The objective is to present students with variety of application scenarios so that they can tangibly relate theory to practice and be able to connect and see how the various concepts fit together. This way, course material can be covered at a faster pace since students have enough time to perform all the planned experiments and thus accumulate well-rounded skills required to succeed in this field of study.

Based on this concept, five modular units of instruction were developed to cover a modern electric machine course. The lesson plans listed in the Appendix are used to guide students and the instructor through weekly class and lab activities based on reference materials[4,5].

III. Laboratory Equipment

Given the importance of hands-on experience and practical applications, it was necessary to develop a strong lab component to achieve the desired outcomes. However, the wide scope of the training program requires a formidable collection of equipments that must be made available to students. This includes many different types of ac and dc machines, variable-speed drives, power electronics circuitries, power supplies, wiring cables, control panels, power meters and various measuring instruments.

Our research concluded that commercially prepared apparatus that contain all the necessary equipments in one stand are convenient and cost-effective. They are not only self-contained but also essentially safe to work on. As a result, the department has acquired Lab-Volt electrodynamics trainers completely equipped with industrial-type dc/ac machines and transformers. Power electronics and variable-speed drive modules are also provided to teach students how to operate and troubleshoot control systems using dc and ac drives. The trainers are of the latest solid-state technology and include speed control, acceleration, low-frequency boost, as well as, different switching mode operations. Each mounted machine has a cutaway bell housing that permits visual inspection of its internal construction. This feature was found to be particularly appealing because one can fully appreciate the machine's internal layout.
Below are some pictures of the equipment in the Power Systems Lab in NIU's Technology Department. These trainers are known to build student confidence and experience with electrically operated equipment and devices. Applications range from the use of electric motors, generators, and speed drive control to various electrical power distribution and transformers.

Figure 1. Electrodynamics Trainer

Figure 1 shows a 0.2 KW electromechanical trainer including ac and dc equipment. All machines have cutaway bell housings to permit visual inspection of the internal construction and a separate power supply including three-phase voltages. It provides additional applications dealing with various techniques associated with the generation and use of electrical energy.

Figure 2. Speed Drive and Control Trainer

Figure 2 is a Drive Control Trainer that teaches students how to operate and troubleshoot a control system with an industrial dc drive and ac variable frequency drive.

Figure 3. Power Electronics Trainer

The power electronics trainer shown in Figure 3 is a versatile and flexible system that can be used to support a wide variety of power electronics circuits involving diodes, thyristors, IGBTs, power MOSFETs, and industrial motor drives.

IV. Lab Enhancement

Due to their high cost, only two electrodynamics trainers can be made available at this time, and students will have to wait to use the equipment. Therefore, other instructional technologies were employed to help students of this program bridge the gap between theory and experience.

Five computer stations were installed with Lab-Volt Virtual Lab instrumentation. The simulation software shown in Figure 4 provides a valuable step in the electrodynamics training process. Simulation also gives students the opportunity to practice and test their skills before they apply what they have learned to actual laboratory equipment.

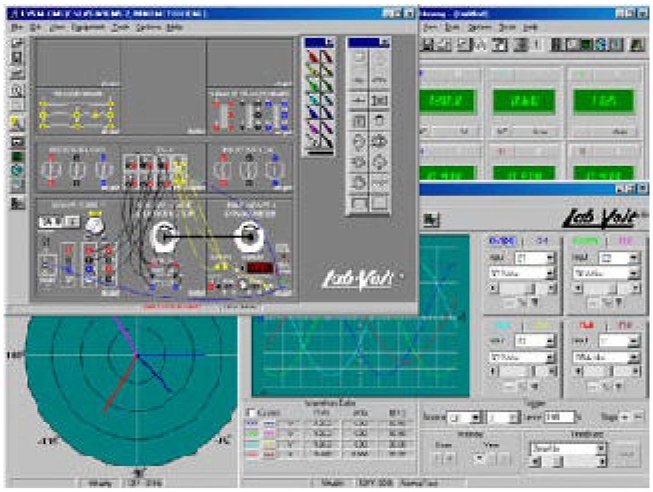

Figure 4. Virtual Lab Instrumentation

Another supporting tool is underway to develop audio-visual documentation that will be used in conjunction with the real laboratory environment to support the relevant work competencies associated with this course. Preliminary plans call for each student team to professionally present and videotape two experiments during the semester. Once pilot-tested and evaluated for effectiveness, the document will be converted to electronic media for instructional technology starting Spring 2003.

To enhance class participation, students are encouraged to work in teams and get fully involved in all lab activities. When conducting experiments, each group was required to assign a team leader, a recorder, and a connector. The team leader's function is crucial in overseeing the overall team actions and hence promotes safety and proper procedures. Additionally, students were also required to draw complete wiring diagrams showing all internal winding layouts and machine connections. This approach to circuit schematics was found to be especially effective in making the students envision the whole picture instead of merely focusing on outside terminal connections. The students were strongly encouraged to use Laboratory notebooks and laboratory reports separately to complement each other [6,7], as well as reading assignments and references to understand underlying electric machine theory. For documentation purposes, students were asked to use two different forms of documents to report their lab activities. The first is a laboratory notebook to record raw data, carry out calculations, and record personal observations. The second is a lab report similar to an executive summary where students can briefly explain the results, connect to other subjects, and specify the impact of the work accomplished.

V. Program Assessment

The electrodynamics program described in this paper was preliminary developed[8] and offered to NIU students during Spring 2001. The original version did not have the power electronics component and related lab equipment. Preliminary results, however, showed excellent student retention and success rate. Out of twenty-three students enrolled during that semester, only one student dropped the class. Nineteen students passed with a C or better, and none has flunked the course. Students also rated high a field trip to the Byron Nuclear Power Plant. During the trip, students attended an on-site presentation about the plant operation, environmental concerns, and safety considerations. They also toured the main control center, inspected the plant generators and transformers, and enjoyed the majestic view of its cooling towers.

With the proposed improvement made to this program, it is anticipated that student performance and satisfaction will even be greater. At the end of the Spring 2002, the program will be evaluated using the following criteria: 1) student success in the course, 2) student satisfaction with the program, and 3) student evaluation of the effectiveness of the program. Those who score a grade of "C" or better will measure student success. Student satisfaction and student evaluation of the effectiveness of the program will be assessed using a course evaluation form and a student questionnaire.

VI. Conclusion

This paper describes the development and implementation of a modern electrodynamics program in the Engineering Technology Department at Northern Illinois University. An effective approach to integrate power electronics into an existing electric machine class was presented. A sequence of five instruction units was developed to introduce students to electric machines and the latest solid-state technology. It was shown that this approach to electrodynamics is in line with current trends to course integrations and may serve as a model for other goals-oriented engineering technology programs. Other supporting laboratory environments were also discussed in this study to explore the use of different instructional technologies, specifically virtual lab instrumentations and audio-visual documents. Program assessment and a complete course outline with learning objectives and laboratory experiments are also presented.

Bibliography

1. Charles I. Hubert "Electrical Machines, Theory, Operation, Applications, Adjustment, and Control", Second edition,2002, Prentice Hall.
2. J. Michael Jacob "Power Electronics: Principles & Applications", 2002 by Delmar.
3. Tim Skvarenina &William DeWitt, "Electrical Power and Controls", book, 2001, Prentice Hall.
4. Wildi Theodore, "Electrical Machines, Drives, and Power Systems", 4th edition,2000, Prentice Hall.
5. Lab Textbook: Investigation in Electric Power Technology, Wildi/DeVito, by Lab-Volt
6. Donald V. Richardson," Laboratory Operation for Rotating Electric Machinery and Transformer Technology", Lab, 2nd edition, 1997, Prentice Hall.
7. John B. McCormack and et al.,"The Complementary Roles of Laboratory Notebooks and Laboratory Reports" IEEE Transactions on Education, Vol. 34, NO. 1, February 1991, pp.133-137.
8. Al Kalaani Youakim and Said Oucheriah, "Integrating Electrodynamics Into a modern Engineering Technology Program", Proceedings of the ASEE, 2001 IL/IN Conference, pp 136-138.

Biography

YOUAKIM AL KALAANI
Youakim Al Kalaani graduated from Cleveland State University with MS and Doctoral degrees in electrical engineering with a concentration in power systems. He is a member of IEEE and ASEE professional organizations and has research interest in electric power generation, renewable energy, unit scheduling, and optimization. He is currently an Assistant Professor in the Technology Department at Northern Illinois University.

ABUL KM AZAD
Obtained a PhD (control engineering) from the University of Sheffield (UK) in 1994. He is now an Assistant Professor with the Engineering Technology Department of NIU. He has extensive experience in the design of engineering systems. Dr. Azad has over 50 papers and is active with professional bodies. His current teaching and research interests include digital electronics, mechatronics, and intelligent control of engineering systems.

Appendix: Units of Instructions

Unit I: Fundamentals, Control Devises, and Basic Power Electronics
Duration: 3 Weeks
Text Reference: Chapters 1,2,3,20,21
Objectives: The student will be able to:

1. Define and calculate force, energy, power, and torque using SI and British systems
2. Describe transformation of energy, heat, losses, and calculate the efficiency of a machine
3. Explain the operation of basic control devices and overload protection circuits
4. Draw a schematic diagram of basic motor control circuits
5. Explain the operation of the three-phase SCR bridge rectifiers
6. Explain the principles of operation of converters and inverters
7. List several applications of variable-speed motors

Learning Activities:

- Handouts and text reading assignments
- Selected exercises at end of Chapters
- Test for Unit I

Laboratory:
Week 1: Experiments 1-4: Lab familiarization and safety procedures
Week 2: Experiments 5-9: Circuit fundamentals
Week 3: Experiments 65,66: SCR control circuits

Unit II: Direct-Current Machines and Speed Control
Duration: 3 Weeks
Text Reference: Chapters 1,2,3,4,5,22
Objectives: The student will be able to:

1) Describe various sources of dc power
2) Explain the theory of operation of dc motors and generators
3) Explain the relationship of current and voltage to torque and speed
4) Describe equivalent circuits, physical layouts, and operations of the following:
    i. Shunt motor
    ii. Series motor

iii. Compound motor

5) Calculate dc machine power losses and efficiency
6) Explain the applications of variable-speed dc motors

Learning Activities:

- Handouts and text reading assignments
- Selected exercises at end of chapters
- Test for Unit II

Laboratory

Week 4: Experiments 11,12: The series and shunt dc motor/generator Part I and II
Week 5: Experiments 26, 29: DC compound motors and generators
Week 6: Experiments 65,66: SCR speed control Part I and II

Unit III: Single-Phase Motors
Duration: 3 Weeks
Text Reference: Chapters 7,18,19
Objectives: The student will be able to:

1) Describe various sources of ac power
2) Calculate real, reactive, apparent power, and power factor
3) Explain why a single-phase motor produces no starting torque, but can run once started.
4) Explain how rotating magnetic field can be produced.
5) Describe the construction and principle of operations of the following:
   i. Split-phase motor
   ii. Capacitor motor
   iii. Shaded-pole motor
   iv. Universal motor
   v. Stepper motor
6) Calculate machine power losses and efficiency

Learning Activities:

- Handouts and text reading assignments
- Selected exercises at end of chapters
- Test for Unit III

Laboratory

Week 7: Experiments 31-33: Split-phase motor Parts I, II, and III
Week 8: Experiments 34,35: Capacitor-start and run motors
Week 9: Experiments 36-38: The universal motor Parts I and II

Unit IV: Three-Phase Machines and Controls
Duration: 4 Weeks
Text Reference: Chapters 8,13,14,15,16,17,23
Objectives: The student will be able to:

1) Describe the construction and types of induction and synchronous three-phase machines
2) Describe the principles of operation of the squirrel-cage and wound-rotor induction motors
3) Perform calculations using the equivalent circuit of the induction motor
4) Calculate speed, slip, and explain operating torque-speed characteristics
5) Use complex diagrams to determine synchronous machine operations

6) Explain the V-curves and how a synchronous motor is used to improve power factor
7) Calculate machine power losses and efficiency
8) Explain the application of variable-speed ac motors

Learning Activities:

- Handouts and text reading assignments
- Selected exercises at end of Chapters
- Test for Unit IV

Laboratory

Week 10: Experiments 49-51: The wound-rotor induction motor Parts I, II, and III
Week 11: Experiments 52,53: Squirrel-cage motor
Week 12: Experiments 54,55: Synchronous motor Parts I, II, and III
Week 13: Experiments 56-62: Variable-frequency drives

Unit V: Transformers
Duration: 3 Weeks
Text Reference: Chapters 9,10,11,12,13,14
Objectives: The student will be able to:

1) Describe the basic transformer constructions and operations
2) Describe the relationships between voltages and currents
3) Develop and analyze the transformer equivalent circuit
4) Determine voltage regulation and transformer efficiency
5) Describe the four various configurations of the three-phase transformer
6) Use transformer nameplate data to solve practical applications

Learning Activities:

- Handouts and text reading assignments
- Selected exercises at end of chapters
- Test for Unit V

Laboratory

Week 14: Experiments 39-44: Single-phase transformers (selected)
Week 15: Experiments 47,48: Three-phase power and transformers
Week 16: Experiments 63,64: Power and frequency conversions