AC 2008-931: ELECTRIC MACHINES PROJECT ACTIVITIES USING MATHCAD E-BOOK

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Electric Machines Project Activities Using a MathCAD® E-Book

Abstract

Recent software advances have made a wide variety of computer-based learning tools available for teaching induction motor theory. These tutorials and visualizations typically target specific fundamental topics, require detailed knowledge of the development software to produce, and provide a rudimentary connection with other relevant practical topics like cost of operation. These fundamental applications also do not allow them to explore alternatives within the presented material. MathCAD® E-books provide a platform for student learning which avoids the shortcomings of other instructional software and combines it with actual laboratory measurements to enhance students' learning experience. This paper presents assessment results for an E-book application that combines induction motor theory with engineering economics in a novel format. The study exposed students to several different pedagogical approaches and evaluated student learning with several different assessment tools. These approaches included traditional lecture/written homework, in-class introduction and application of the E-book, self-study using the E-book, and E-book simulations. Laboratory measurement of induction motor performance under various load levels and load types links theoretical analysis and practical motor applications. The project includes a detailed economic analysis of an induction motor application that simulates the work of practicing engineers. A data from a pilot study shows this to be a promising presentation method.

Induction Motor Analysis, Simulation, and Experiments

Analysis of induction motor parameters and performance characteristics are the cornerstones of any electric machines course. All students should understand these typical outcomes upon course completion. A review of available curricula and textbooks shows a traditional coverage of concepts and parameters that pays little or no attention to the economic aspects of induction motor selection and how mechanical load influences motor performance and efficiency. The economic impact of technical decisions is an important skill for any practicing engineer or technologist in the field. Electric machinery courses should cover these topics adequately to build the necessary practical skills.

Traditional induction motor theory emphasizes several key points to students. One of them is the speed-torque relationship and its dependency on motor parameters[1-3]. Current textbooks describe this topic well[4-5]. A typical student assignment requires students to simulate and graph such a relationship using various available software tools. Moreover, available laboratory equipment usually contains exercises, which allow students to obtain speed-torque characteristics experimentally[6]. Both simulation and laboratory experiments provide students with basic visualization of speed-torque characteristics. Recent advancements in computer simulation and data acquisition make it possible to enhance visualization and provide a broader and deeper coverage of material[7-8]. The MathCAD® E-book concept provides an easy to use method for integrating these topics and promotes student learning[9].

Integrated Approach to Simulation

The approach taken for this work was to combine the interactive capabilities of the E-book with a computerized active machine test stand. This technique gives students both a theoretical and experimental view of induction motor performance with various load types. Users can develop calculation sheets in MathCAD® without programming knowledge and produce self-documenting calculations. The computerized active test stand has the ability to dynamically change the mechanical load level for a given load type, which also produces an interactive response in the laboratory.

Utilization of MathCAD® in the form of an E-book creates a single integrated package linking several topics together. This provides students with easy to use tools for exploring different scenarios with a variety of motor parameters and load characteristics[10]. The E-book used for this work also introduces engineering economics principles not covered in any of the electric machines textbooks and presents a tool for performing life-cycle cost analysis of induction motor applications[11].

The E-book covers the basic principles of induction motor theory and engineering economics through examples. The first part of the book discusses induction motor theory, its equivalent circuit diagram and speed-torque function[11] . The E-book uses the steady-state induction motor model found in most texts that includes rotor and stator resistances, leakage reactances and magnetizing reactance[1-5]. Slip relates the mechanical load to the motor circuit model through a variable resistance that is a fraction of the rotor resistance. The E-book continues with the time value of money and presents functions for computing the present value of engineering alternatives. Another section covers the basic concepts of electricity rates and explains how to compute energy and demand charges. The rate section also introduces the time-of-use rate concept. The final section on economic analysis covers the basics of life-cycle cost analysis and culminates with a cost analysis project. The motor theory sections emphasize the relationship between motor efficiency and operating point and relate these topics to the annual operating cost of motors. This E-book is available on line at
http://www.engr.siu.edu/staff2/spezia/Web332b/home332b.htm#E_book
Solving a load-motor torque balance equation finds the operating point of an induction machine at steady state. Figure 1 shows an induction motor torque-speed plotted together with blower torque-speed curve that was generated from the E-book. Students use E-book content to find the electromechanical system operating point, which is the intersection of the two curves, and determine if the motor is overloaded. The interactive nature of the E-book allows students to change motor and/or load parameters and repeat the problem in a short time.

Buffalo State College recently acquired new electromechanical laboratory equipment manufactured by Lucas-Nulle[12]. It consists of a variety of 0.37kW motors, a servo-brake, and computerized control equipment. The computer system controls the servo-brake, provides data acquisition, and graphing capabilities. Figure 2 shows typical equipment setup required to perform induction motor experiments.

Students control the equipment from the control panel or from a personal computer (PC). The servo-brake has the capability to emulate mechanical loads such as pumps, fans, calendars, and hoists. The servo-brake can change load torque for each load type by simulating changes in the load's moment of inertia. The active machine test stand can demonstrate a motor's operating point for various load conditions by emulating different types of available loads and different moments of inertia. Students can then observe the impact these load changes have on other motor parameters such as speed, torque, current, and power.

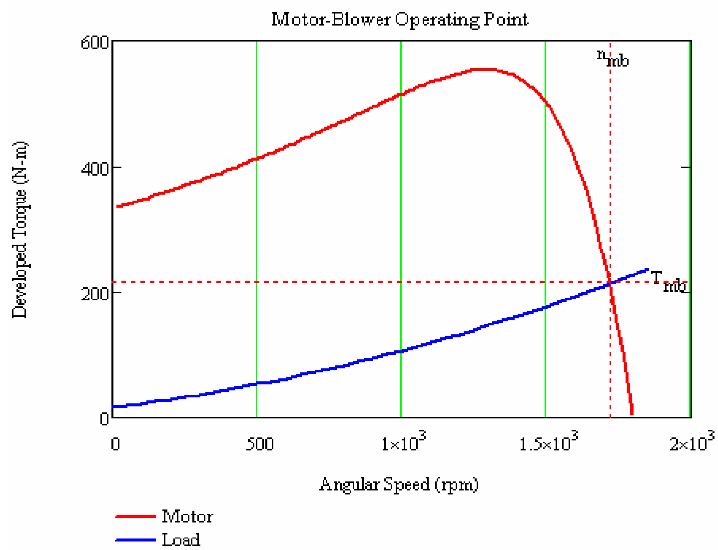

Figure 1. Induction Motor Speed-torque and Load Torque Characteristics.

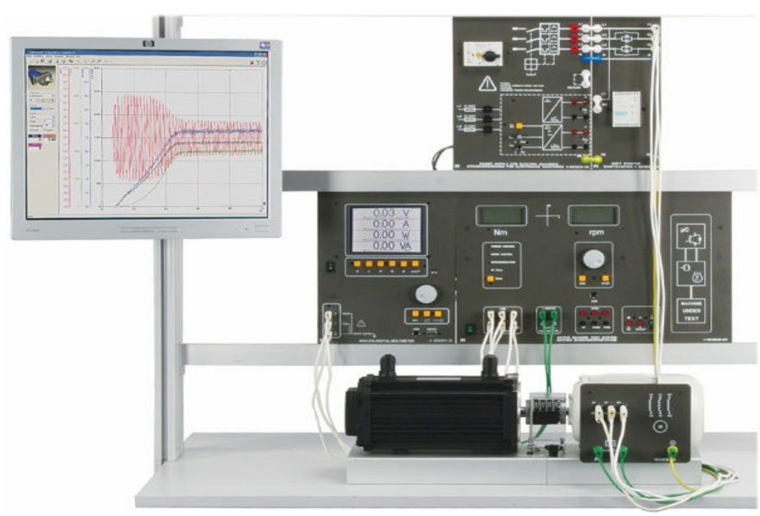

Figure 2. Lucas-Nulle active machine test stand (photo courtesy of Lucas-Nulle)

The active machine test stand demonstrates how the motor-load system reaches a steady-state operating point that is the intersection between motor and load speed-torque curves. This is the physical counterpart to the E-book simulation. Students can observe how an induction motor slows down from an unloaded condition to the speed that corresponds to the required load torque. They are able to increase the load torque and observe the motor's response until it stalls. This dynamic load change can occur during motor operation without stopping and restarting the machine. Figures 3 to 5 show typical motor-load combinations produced by the active machine test stand. Students can observe actual measured electromechanical system operating points for a variety of loads and reinforce the knowledge acquired during simulation exercises.

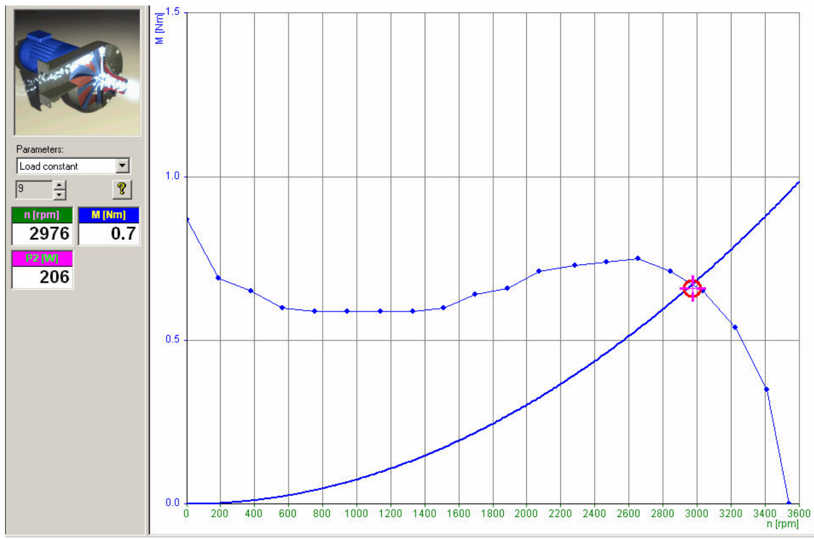

Figure 3. Motor Speed-Torque Curve, Load Torque Curve, and Operating Point for Pump or Fan Loads Generated with the Active Machine Test Stand.

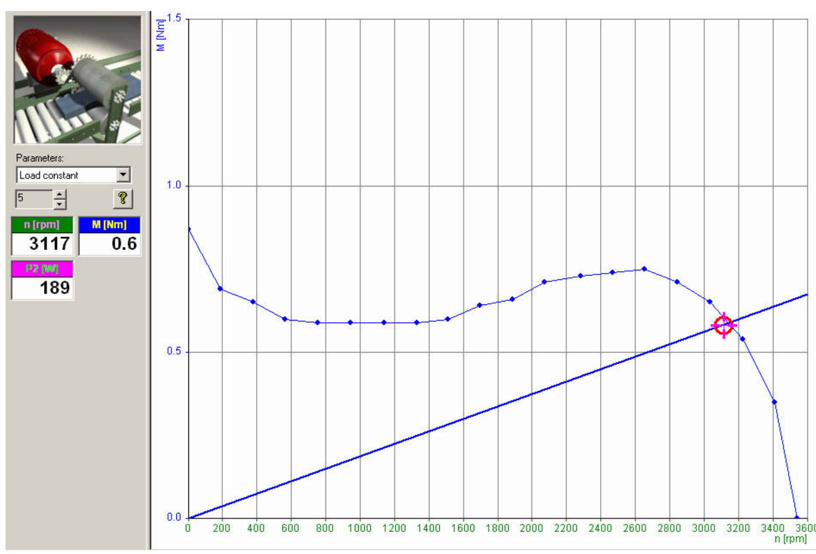

Figure 4. Motor Speed-Torque Curve, Load Torque Curve, and Operating Point for a Calendar Load Generated with the Active Test Stand.

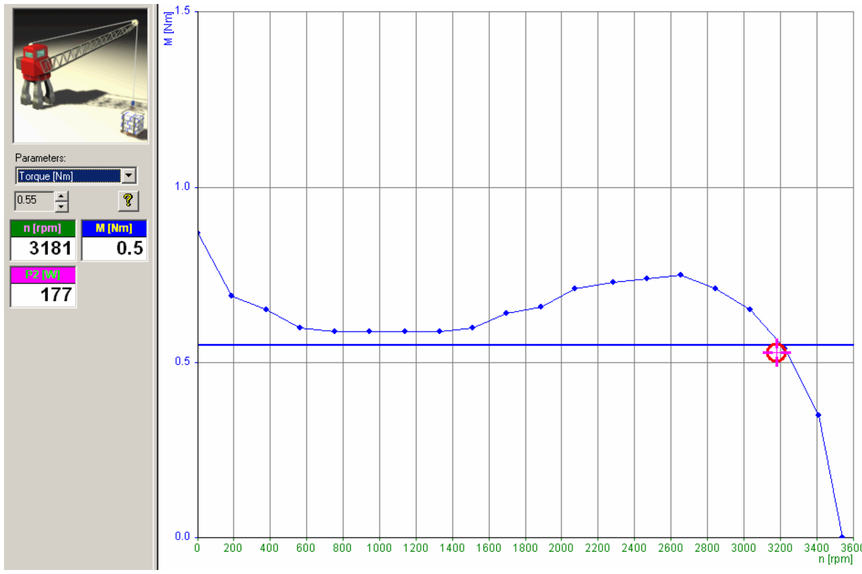

Figure 5. Motor Speed-Torque Curve, Load Torque Curve, and Operating Point for a Hoist Load Generated with the Active Test Stand.

Project-Based Activities

Students at Buffalo State College were assigned a project during fall 2007 semester in electric machines course. The project included the following activities:

- Introduction and orientation to MathCAD® E-book
- Perform homework exercises on slip and synchronous speed from the E-book
- Perform homework exercises on motor circuit model calculations from the E-book
- Plot motor and load torque-speed curves from the E-book
- Calculate motor efficiency from the E-book
- Determine impact of light load on motor efficiency from the E-book
- Perform experiments with wye and delta induction motor stator winding configurations and examine motor performance differences
- Determine load characteristics, motor operating point, and efficiency experimentally
- Find the effect of reactive power compensation experimentally
- Study engineering economics and electric rate fundamentals using the E-book.

Assessment Instrument and Results

At the end of the project, students filled out a survey instrument to evaluate their learning experience. The instrument has four sections that evaluate the E-book/lab combination and its effectiveness as a teaching tool. Students rate their agreement with each item using a five-point scale with five representing the best rating. Tables 1-4 list the survey instrument items. Since this is a pilot study, only five students participated in this survey. This survey instrument will be revised after this pilot study and used for larger student groups.

The items in Table 1 test student satisfaction with the software and determine it usability in an educational setting. Items in this section cover the general layout, color schemes, navigation, and readability of the E-book.

Table 1. Layout and Usability

1. Navigating through the E-book was easy

2. Their were enough hyperlinks

3. The hyperlinks were generally well place and easy to follow

4. The color scheme of the E-book was pleasing and did not distract from the technical content

5. Text was readable

6. There was too much text on each screen page

7. Graphs and figures were readable

8. Content was in a logical order and built on previously introduced topics adequately

Table 2 survey items gage student utilization of the content and software. Some of the items in this section test the example complexity. Other items gage how students interacted with the E-book materials. The E-book book design should invite students to make changes in the examples and develop insights into how parameter variations change the answers to problems and affect motor performance.

Table 3 lists the survey items used to measure the effectiveness of the E-book as a learning tool. These items ask students to compare the experience of using the E-book to that of a conventional textbook. The items also test how well students think the E-book met its educational objectives.

Table 2. Utilization of Content and Software

1. I could follow the examples and understand them

2. The graphs and figures help me understand the material better than a standard textbook

3. I mainly just read the material on the screen

4. The E-book would be better if it had more animation in it

5. I interacted with the program examples by changing variables and observing the results

6. I experimented with the examples to see how the numerical results and graphs changed

7. I used the sample calculations to work the assignments included in the tutorial

Table 3. E-Book Educational Utility and Effectiveness

Compared to a standard course textbook…

1. I feel better prepared to take a test on this material after using the E-book

2. I remember more of the material after using the E-book

3. I have a better understanding of the material after using the E-book

4. I have a better understanding of how the induction motor model describes its performance

5. I can better visualize the interaction between motor mechanical loading and electrical performance after using the E-Book

6. I have a better understand of where motor losses occur after using the E-Book

7. I can see the relationship between motor loading and efficiencies after using the E-book

8. **I recognize that interest rates and time impact economic decisions in engineering**
9. **I can explain what costs comprise a customer electric bill after using the E-book**
10. **I recognize that the economic selection of electrical equipment requires on more than comparing initial costs after using the E-book**

These objectives include the relationship between the motor model and performance, the relationship between motor load and efficiency, and sources of motor losses.

Table 4 covers the experimental component of the project. The questions measure the learning effectiveness of the laboratory component of the project. They also gage how useful the laboratory component is in enhancing student learning and meeting the intended educational objectives.

Table 4. Laboratory

1. **I feel better prepared to take a test on this material after performing lab experiment**
2. **I feel better prepared to take a test on this material after performing lab experiment**
3. **I remember more of the material**
4. **I have better understanding of how the induction motor model describes its performance**
5. **I can better visualize the interaction between motor mechanical loading and electrical performance**
6. **I can see relationship between motor loading and efficiency**
7. **I gained more confidence after performing experiments**

Table 5 and Figure 6 summarize the assessment results for this combined simulation and experiment project using the E-book and the active machine test stand.

Table 5. Results of Assessment Questionnaire

Layout and user friendliness total	4.628
Use of content and software total	4.171
Educational utility and effectiveness total	3.92
Experimental component total	4.833

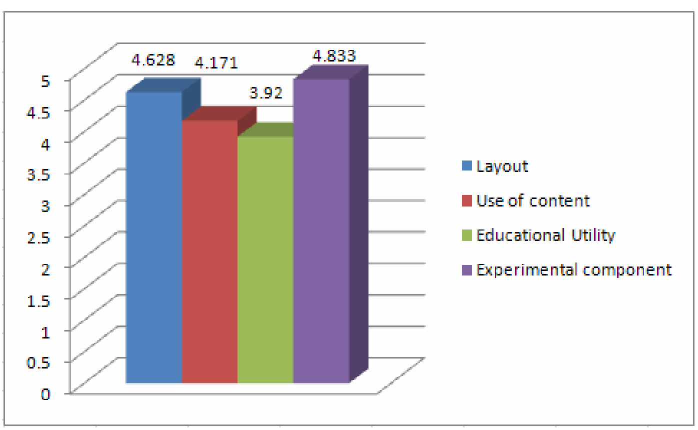

Figure 6. Overall Assessment Results of the Combined E-book -Active Motor Test Stand Project.

Conclusions

This paper demonstrates the effectiveness of combining the interactive simulation tools available through a tailored MathCAD® E-Book and a strong laboratory component. The E-book enables the instructor to build even better and more effective interactive simulations than available previously, attractively presented and specifically focused on the students and their learning style. In the work at hand, several fundamental concepts of electrical behavior of an induction machine were interleaved with important economic issues relating to the same machine's performance. This produced a uniquely effective learning exercise for students who, as a matter of learning style, appreciate the flexibility of simulation but demand appropriate experimental verification. A set of parallel simulations and experiments first establishes the simulations' credibility; then students are encouraged to return to the simulations to extend their learning of the machine behavior and concurrently incorporate economic influences that would be otherwise difficult to establish experimentally. Interleaving of simulation and laboratory experiment continues throughout the project. Using this innovative combination of E-book simulation and laboratory experiment, an ambitious ten-point laboratory program was successfully completed. Assessment of this laboratory program reveals that the students appreciated the simulations and learned from them, but they insisted that a laboratory experimental component was necessary and not merely an enhancement. Experimental observation is the yardstick that they use to evaluate the credibility of the simulation and even the quality of its graphics and animations. This study will extend to students at other institutions; further results will be presented at the conference.

Bibliography

1. A. E. Fitzgerald, Charles Kinsley, Jr., Stephen D. Umans, Electric Machinery, 5th Ed. McGraw-Hill, 1990.
2. Stephan J. Chapman, Electric Machinery Fundamentals, 3rd Ed. McGraw Hill, 1990.
3. Syed A. Nasar, Electric Machines and Power Systems Vol. 1 Electric Machines, McGraw-Hill, 1995.
4. Turan Goen, Electrical Machines, Power International Press, 1998.
5. Charles I Hubert, Electric Machines Theory, Operation, Applications, Adjustment, and Control, 2nd Ed. Prentice Hall, 2000.
6. Student Laboratory Experiments for the Hampden Universal Laboratory Machine, Bulletin #120EX-VTED.5, Hampden Engineering Corp.
7. Thomas W. Greda, Seungwon An, Qamar H. Arsalan, Swakshar Ray, "Unified Power Engineering Laboratory for Electromechanical Energy Conversion, Power Electronics, and Power Systems", IEEE Trans. on Power Systems, Vol. 19, No. 1, Feb. 2004, pp.112-119.
8. Saffet Ayasum, Chika O. Nwankpa, "Induction Motor Tests Using MATLAB/Simulink and Their Integration Into Undergraduate Electric Machinery Courses", IEEE Trans. on Education, No. 48, No. 1, Feb. 2005, pp. 37-46.
9. http://mathcad.com/resources/electronic_books/
10. Khalid A. Nigim, Ronald R. DeLyser, "Using MathCad in Understanding the Induction Motor Characteristics", IEEE Trans. on Education. Vol. 44, No. 2, May 2001, pp. 165-169.
11. Carl J. Spezia, "A Mathcad Application for Teaching Energy Economics and Efficiency in Undergraduate Electric Machines Courses", ASEE Annual Conference Proceedings, 2007.
12. http://www.lucas-nuelle.de/263/Products/Training_Systems/Electric_Machines,_Power_Electronics,_Drives/Electric_Machines/Machine_Test_Stand,_Servo_Drive_Brake.htm