Restructuring Energy Conversion Course Using An Integrative Approach and Computer Assisted Teaching Tools

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ABSTRACT

The course of Energy Conversion is a required course in EE curriculum at Texas A&M University – Kingsville (TAMUK). Traditionally, this course dealt with topics of transformers and electric machines, and was normally presented under the assumption of steady-state conditions. Students usually thought that the course was old-fashioned and boring, which greatly limited student’s ability to understand wide control applications of electric machines. However, modern electric machines are widely interacted with power electronics, DSP and digital control technology. These technology changes are not reflected in traditional teaching structures of the course. This paper gives the restructuring of the course at TAMUK through an integrative teaching approach and computer assisted teaching methodologies so as to provide students a complete view of an electric drive system that consists of electric machines, power electronics, controllers, power supply systems, and mechanical loads.

Index Terms – Electric machines, electric drives, power electronics, feedback controls, education, Microsoft PowerPoint, MathCad, PSpice simulation, MatLab.

1. INTRODUCTION

As the technology of Electrical and Computer Engineering (ECE) grows, undergraduate programs are under constant pressure to keep content up-to-date within a four-year context of a fixed number of credit hours allowed for graduation. This technology change also challenges traditional teaching structure to one of the core courses, Energy Conversion or Electric Machinery, in general ECE programs.

At Texas A&M University – Kingsville, the course of Energy Conversion also known as Electric Machinery, used to cover three-phase circuits, transformers, DC generators and motors, AC synchronous generators, and AC induction motors [1, 2]. The course basically dealt with line-fed and steady-state DC and AC electric machines with no attempt of controlling machine speed, torque, and/or position. This had greatly limited student’s capability to understand wide...
control applications of electric machines in modern electrical and computer engineering and the integrative characteristics of electric machines with many other ECE courses.

However, modern electric machines are usually used widely with power electronics in many control or digital control applications of dynamic systems which are normally related to several other fields and areas in electrical and mechanical engineering. At the present, many electric machines and drives are digitally controlled by embedded micro-controllers and some use sophisticated neuro-fuzzy controllers for self-commissioning. However, no information regarding those was provided in the traditional teaching structure of Electric Machines course or by other courses. Although some students show strong interest in electric machines and drives applied in dynamic control systems, the traditional teaching structure did not help them to gain necessary knowledge, which greatly limits quality undergraduate education in the fields. This paper presents an integrative teaching approach plus computer assisted teaching methodologies to provide students a complete view of electric machine and drive systems that are integrated with power electronic converters, feedback controls, power supply systems, and mechanical systems and loads.

2. AN INTEGRATIVE APPROACH IN TEACHING ELECTRIC MACHINES

The basic structure of the integrative approach is based on the controllable energy conversion or electric drive system of Figure 1 [3]. In the figure, the power-processing unit (PPU), consisting of power electronics based converters, gets its power from the utility source with single-phase or three-phase sinusoidal voltages of a fixed frequency and constant amplitude. The controller, by comparing the input command with actual measured values of speed and/or position through sensors, provides appropriate control signals to the PPU. The PPU, in response to the controller outputs, converts efficiently the fixed-form input voltages into an output of the appropriate form (in frequency, amplitude, and/or the number of phases) that is optimally suited for operating the electric machine. In other words, the foundation of this controllable energy

![Figure 1. Block diagram of a controllable energy conversion/electric drive system](image-url)
conversion/electric drive system is intended to led students to a complete knowledge background for all the subsystems in the figure, i.e., electric machines, power electronic converters, mechanical system requirements, feedback controller design, and the interaction with the utility system with major teaching focus still on the electric machines. That means that the introduction of the other subsystems should be just enough to provide necessary knowledge background for students to understand, analyze, and design typical energy conversion or electric drive systems with feedback controls.

The fundamental knowledge and concepts for traditional steady-state analysis of electric machines is still covered in this teaching approach. However, this is done by removing the controller and sensors from Figure 1 and by developing steady-state models from corresponding dynamic models for DC machines and from space vector concepts for AC machines, making it possible to introduce both dynamic and steady-state models and analytical approaches of electric machines in limited credit hours. The machine characteristics working both as generators and as motors are still covered in controlled and uncontrolled ways (steady-state). Actually from machine control points of views, the block diagram of Figure 1 can more realistically present how the PPU's should be controlled in a way to allow electric power flowing in and out of the machines.

The integrative approach requires many topics to be covered. For a course of 3 hours in one semester, the teaching module of Table 1 is used. Appropriately developed models and approaches have been used for quick introduction of mechanical systems, typical power electronic converters, feedback control designs, and AC machines space vectors as shown in the following sections. Significant computer assisted teaching methodologies have been developed. All these are important for successful teaching and restructuring of the integrative electric machine/energy conversion course.

Table 1. Restructured Electric Drives Course Modules and Lab Sessions

<table>
<thead>
<tr>
<th>No.</th>
<th>Topics</th>
<th>Lectures (39 hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to Energy Conversion/Electric Drive Systems</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Understanding Mechanical System Requirements</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Review of Basic Electric and Three Phase Circuits</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Basic Understanding of Switch-mode Power Electronic Converters</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Magnetic Circuits and Transformers</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Basic Principle of Electromechanical Energy Conversion</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>DC Generators and DC Motor Drives</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Designing Feedback Control for DC Motor Drives</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>Introduction to AC Machines and Space Vectors</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Sinusoidal PMAC Drives and Synchronous Generators</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Induction Machines: Balanced, Sinusoidal, Steady State Operation</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>Adjustable Speed Induction Motor Drives</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>Vector-control of induction motor drives</td>
<td>2</td>
</tr>
</tbody>
</table>
3. UNDERSTANDING MECHANICAL SYSTEM REQUIREMENTS

Students usually clearly familiarize the basic concepts, equations, and relationships of linear motion mechanical systems. However, for electric machine/drive systems as shown in Figure 1, good understanding of rotating mechanical systems is important. A comparison between the linear motion and rotating systems has been shown a successful start for quick introduction of rotating mechanical systems to students at TAMUK. Figure 2 illustrates the two systems and Table 2 gives corresponding variables and equations. By comparing the two systems by Figure 2 and Table 2, students can quickly and effectively get the concepts of angular position, speed, and acceleration, the meanings of inertia and torque, and Newton’s law in rotation systems. Then, based on Newton’s law in rotation, a simple example such as a solid cylinder can be used for calculation of inertia to let students more clearly understand the concept of inertia and factors that can affect it.

![Figure 2. Illustration of a linear motion and a rotating system](image_url)

Table 2. Comparison between linear motion and rotating systems

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>position: x</td>
<td>angular position: 0</td>
</tr>
<tr>
<td>speed: u = dx / dt</td>
<td>angular speed: ω = dθ / dt</td>
</tr>
<tr>
<td>acceleration: a = du / dt</td>
<td>angular acceleration: α = dω / dt</td>
</tr>
<tr>
<td>mass: M</td>
<td>inertia: J</td>
</tr>
<tr>
<td>force: f_M</td>
<td>torque: T = f · r</td>
</tr>
<tr>
<td>Newton’s law in motion: f_M = M · a</td>
<td>Newton’s law in rotation: T = J · α</td>
</tr>
<tr>
<td>energy: W_M = f_M · x</td>
<td>energy: W_M = T · q</td>
</tr>
<tr>
<td>power: P_M = f_M · u</td>
<td>power: P = T · ω</td>
</tr>
</tbody>
</table>

This introduction will give students good knowledge background to understand a combined electrical and mechanical system such as Figure 3. In the figure, T_em is the electromagnetic torque produced by a motor, T_L is the load (or mechanical drive) torque, and J_eq is the moment of inertia of the combined system. The torque difference, T_f = T_em - T_L, will accelerate the system. T_em can be controlled by controlling the PPU and T_L can either be a constant torque or be a variable torque depending on the mechanical system performance.

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Although the dynamic transfer function of a mechanical system is not under the consideration of this integrative teaching approach, the combined energy conversion or electric drive system plus its mathematical description of Figure 3 b) present a good and typical mechanical and dynamic representation of the combined system.

Figure 3. An energy conversion/electric drive system

4. INTRODUCTION OF POWER ELECTRONIC CONVERTERS FOR ENERGY CONVERSION/ELECTRIC DRIVE CONTROLS

In the integrative teaching approach, introduction to power electronic converters is necessary. But, this introduction should be brief, clear, and sufficient to be able to lead students to the basic understanding of typical power electronic converters for the feedback control design and analysis of typical energy conversion/electric drive systems represented by Figure 1. At TAMUK, the power-pole building blocks and the average power-pole models [4] have been successfully used for this purpose.

Basically, a power processing unit can be represented by a diode rectifier plus a switch-mode converter as shown in Figure 4. Typically, the switch-mode converter can be either a four-quadrant converter for DC machine or a three-phase inverter for AC machine. The bi-positional

Figure 4. Switch-mode converter and its power-pole representation in electric drive systems
switches of the power-poles are used to represent the same functionality of practical electronic switches under ideal switching condition but make it much easier and faster for students to understand and analyze basic characteristics of the switch-mode power electronic converters.

The average model of a power-pole makes it possible to quickly introduce basic knowledge of power electronic converters for the purposes of both general steady-state analysis and dynamic control designs for the electric drive system. For feedback control of energy conversion/motor drive system of Figure 1, the controller bandwidth usually needs to be one to two order of magnitude smaller than the converter switching frequency. In other words, the controller mainly responds the average change of the converter that can be approximated by the average power-pole model represented by an ideal transformer with controllable turn-ratio as shown in Figure 5. This average model is very easy to use and PSpice simulation [5] can let students more clearly understand the average model and its performance compared to a practical switch-mode converter. With the average power-pole model, however, the mathematical relationships of the switch-mode converters are very easy to obtain, providing an efficient and possible fast teaching approach for necessary knowledge background of power electronic converters for electric machine feedback control analysis and designs.

![Diagram of a power-pole and its average model](image)

Figure 5. A power-pole and its average model

5. FROM MAGNETIC CIRCUITS TO TRANSFORMERS

The course of Electric Machines usually has transformers as one of the major topics because transformers are essential for transmission and distribution of electric power and also facilitate the understanding of AC machines effectively. In traditional teaching, transformer models are usually presented under the assumptions of steady-state conditions. However, to facilitate the development of the dynamic models for DC and AC machines, a different methodology is used, i.e., from magnetic circuits and inductance to the development of various transformer models. This includes 1) basic concepts of magnetic field and circuits, 2) inductance and calculation of leakage and magnetizing inductances, 3) ideal transformers and voltage, current and impedance transformation, and 4) transformer equivalent circuits and referred equivalent circuits to primary and secondary sides. In this way, approaches, models and/or concepts beneficial for both dynamic and steady-state analysis of transformers and electric machines are appropriately presented.
The concept and calculation of leakage and magnetizing inductance are presented to students based on the single coil configuration of Figure 6. This configuration can lead to fast development and quick understanding of the equivalent circuit of the two-coil transformer configuration of Figure 7. However, unlike traditional teaching approach, the development of the transformer equivalent circuit starts with the calculations of various transformer inductances for the purpose to facilitate the development of dynamic models for electric machines.

The voltage, current, and impedance transformations of an ideal transformer are based on Figure 8. According to the ideal transformer characteristics, the voltage, current, impedance transformations looking from primary and secondary sides are shown by (1) and (2) in which $I_{21}$, $V_{21}$, and $Z_{21}$ represent the secondary current, voltage, and impedance referred to primary side and $I_{12}$, $V_{12}$, and $Z_{12}$ represent the primary current, voltage, and impedance referred to secondary side. These relationships are then be applied to Figure 7 to get various referred and approximate equivalent circuits for a practical transformer so that the traditional concepts and analytical approaches for steady-state transformers are still covered in this teaching methodology. It is important to point out that a highly dynamic and animated power-point presentation is critical to cover all these topics.

\[
I_{21} = \frac{I_2}{a}, \quad V_{21} = aV_2, \quad Z_{21} = a^2Z_2 \tag{1}
\]

\[
I_{12} = aI_1, \quad V_{12} = \frac{V_1}{a}, \quad Z_{12} = \frac{Z_1}{a^2} \tag{2}
\]
DYNAMIC AND STEADY-STATE MODELS FOR DC MACHINES

Traditional teaching of DC electric machines generally concerns only the steady-state conditions. However, this is inappropriate from DC machine control point of view. In our teaching practice, both DC machine dynamic and steady-state models as well as corresponding analytical approaches are presented. The basic of this teaching practice is to develop from DC machine dynamic models to steady-state models.

The fundamental principles used for developing DC machine dynamic models are $e = Blv$, induced voltage for a moving conductor, and $f_{em} = Bli$, the electromagnetic force for a current carrying conductor in the presence of a magnetic field. Based on the fundamental principles and the knowledge background related to mechanical systems and magnetic circuits as shown in sections 3 and 5, a complete dynamic model of a DC machine (Figure 9) can be quickly introduced to students as shown by (3) to (6).

$$e_a = k_e B_f \omega_m \text{ or } e_a = k_e \omega_m \text{ for constant } B_f$$

$$T_{em} = k_f B_f i_a \text{ or } T_{em} = k_f i_a \text{ for constant } B_f$$

$$v_a = e_a + R_a i_a + L_a \frac{di_a}{dt}$$

$$\frac{d\omega}{dt} = \frac{(T_{em} - T_i)}{(J_M + J_{mech})}$$

From the dynamic model, the steady-state model of DC machines can be obtained by omitting the armature winding inductance and by assuming constant rotating speed as shown by
Both the dynamic and steady-state models are suitable for DC machines working as generators or motors as well as for machines running in forward and backward directions. This will not only give students good understanding of four-quadrant operation of a DC machine but also provide a proper example of controlling the power processing unit of Figure 1 to implement this four-quadrant operation requirement. With the basic steady-state DC machine models, other concepts related to traditional steady-state DC machines such as different field winding configurations and DC machine characteristics can still be covered with highly animated power-point presentation.

\[
E_c = k_e B_f \omega_m \quad \text{or} \quad E_a = k_e \omega_m \quad \text{for constant} \ B_f \quad (7)
\]

\[
T_{em} = k_t B_f I_a \quad \text{or} \quad T_{em} = k_t I_a \quad \text{for constant} \ B_f \quad (8)
\]

\[
V_a = E_a + R_a I_a \quad (9)
\]

7. FEEDBACK CONTROL FOR DC MOTOR DRIVES

In traditional teaching of electric machines, machine feedback controls were usually not covered. This greatly affected students’ interests in the course and understanding of electric machines and drives related to technology advances in electrical and computer engineering. Introducing feedback controls in this course has been proven to be beneficial and successful at TAMUK.

However, control background is not required as a prerequisite for this integrative teaching approach. It is very easy to lead students from some typical control examples to basic control concepts and block diagrams as shown in Figure 10 and to let students understand the design purposes of making controlled variable to follow the reference input change by designing feedback H(s) or compensator D(s) [6]. This design requirement can be accomplished by using bode plots which students have extensive practices and understanding from previous courses such as Electric Circuits [7], Electronics [8], and Circuits and Electronics Lab. When designing a controller, a student just need to draw and/or modify a bode plot to achieve desired gain and phase margin requirements in MatLab. The performance of the designed controller can be examined using MatLab Simulink files such as the one shown in Figure 11. Both the MatLab and Simulink files are typical and easy to modify for most DC motor drive controls and can be accessed by students over the course webpage.

![Figure 10. Block diagrams of feedback control systems](image-url)
It is needed to specify that the understanding and knowledge gained by students on feedback controls in this course cannot be replaced by other courses. In other words, students will have more comprehensive views on how it works when all the parts of Figure 1 are put together. They will have clearer view on obtaining more practical plant transfer function with combined consideration of electric machines, power electronic converters, and mechanical loads (Figure 1 and 11), and on designing controller to achieve the desired design goal on torque, speed, and/or position of the integrated electric drive system.

8. INTRODUCTION OF SPACE VECTORS FOR AC MACHINES

Introducing ac machine space vectors [9] is necessary in leading seamlessly to how AC machine speed and position ought to be controlled optimally. This is different from the traditional teaching when one’s concern is only on steady-state AC machine analysis. In order to avoid time-consuming issues related to AC machine windings, a hypothetical sinusoidally distributed winding [3] is used as an equivalent representation of field distribution generated by each phase winding of a practical AC machine (Figure 12). This hypothetical sinusoidally distributed winding presents very clear and easy understanding concepts about the sinusoidal flux density distribution in the air gap as well as its space vector representation.

![Figure 11. Block diagrams of feedback control systems](image)

![Figure 12. Hypothetical sinusoidally distributed winding and space vector representation of sinusoidal flux density distribution](image)
When sinusoidal flux density distributions or space vectors from the three phase stator windings are added together, a rotating field distribution or space vector will be generated. In teaching the concept of the rotating magnetic field, computer assisted teaching and animation tools in both MatLab and MathCad are used. Through the computer simulation and animation, and analysis of MatLab or Mathcad code, the rotating magnetic field concepts can be proved, introduced, and demonstrated very easily and quickly. This rotating field distribution can be represented by an equivalent hypothetical sinusoidally distributed winding with a position $\theta_s(t)$ and a current $\hat{I}_s(t)$ passing through the winding or be represented by a rotating space vector $\hat{v}_s(t) = \hat{I}_s(t) \angle \theta_s(t)$ (Figure 12). The $\theta_s(t)$ and $\hat{I}_s(t)$ depend on the currents in the three stator windings at a time $t$. The computer assisted teaching approaches are also critical in introducing and proving many other concepts such as the transformation relationship from the rotating current space vector to three phase stator current space vectors in Mathcad as shown below.

$$i_a := 10 \; \text{A} \quad i_b := -10 \; \text{A} \quad i_c := 0 \; \text{A}$$

$$i_s := i_a \cdot e^{j \cdot 0 \; \text{deg}} + i_b \cdot e^{j \cdot 120 \; \text{deg}} + i_c \cdot e^{j \cdot 240 \; \text{deg}} \quad i_s = 15 - 8.66i \; \text{A}$$

$$i_{a1} := \frac{2}{3} \cdot \text{Re} \left( i_s \cdot e^{j \cdot 0 \; \text{deg}} \right) \quad i_{a1} = 10 \; \text{A}$$

$$i_{b1} := \frac{2}{3} \cdot \text{Re} \left( i_s \cdot e^{j \cdot 120 \; \text{deg}} \right) \quad i_{b1} = -10 \; \text{A}$$

$$i_{c1} := \frac{2}{3} \cdot \text{Re} \left( i_s \cdot e^{j \cdot 240 \; \text{deg}} \right) \quad i_{c1} = 0 \; \text{A}$$

Figure 13. Mathcad used for teaching transformation relationship from the rotating current space vector to three phase stator current space vectors

9. SPACE VECTORS USED FOR TEACHING AC MACHINES DYNAMIC CONTROLS AND STEADY-STATE ANALYSIS

The space vector concepts are beneficial in developing both dynamic and steady-state analytical approaches for AC synchronous and induction machines. On the one hand, this will allow it possible to analyze and design controller for AC machine controls. On the other hand, the traditional steady-state analysis methods can still be covered. This section gives the development of dynamic and steady-state models and approaches for PMAC drives and synchronous generators using space vectors.

In PMAC drives, the space vector concepts can easily lead to the understanding of the basic control principle of the PMAC drives, i.e., the resultant stator current space vector is controlled in such a way to be ahead of the rotor field space vector by 90°. Based on this basic relationship, control reference stator current space vector can be obtained according to a rotor position and a desired torque requirement (6). Then, through the transformation from the resultant stator current space vector to stator three phase currents, control reference values for stator currents on phases A, B, and C can be obtained as shown in Figure 13. In this ways, the basic control principle and structure associated with Figure 14 can be quickly introduced to students.

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\[ \hat{I}_s^*(t) = \frac{T_{em}(t)}{k_T}, \quad \theta_m^*(t) = \theta_m(t) + 90^\circ, \quad \hat{I}_s^*(t) = \hat{I}_s^*(t) \angle \theta_m^*(t) \] (6)

Figure 14. Block diagram representation of controller and power-processing unit for PMAC drives

The space vector concepts can also easily lead to clear understanding of steady-state models and approaches for traditional synchronous machine analysis. With the application of the resultant stator current space vector and the rotor magnetic field space vector, the induced voltages contributed from the two in the equivalent hypothetical sinusoidally distributed winding of Figure 12 c) can be obtained as shown in (7) and (8). The combined induced voltage of (9) can be easily transformed to per-phase induced voltage of (10). Based on that, an equivalent circuit for steady-state synchronous motor drives can be obtained (Figure 15). The same equivalent circuit can be quickly introduced to students for steady-state analysis of synchronous generators when the direction of power flow is changed from flow-in to flow-out.

\[ \bar{e}_{ms,i_s}(t) = (j\omega_m L_m)\hat{I}_s(t) \angle \omega t \] (7)

\[ \bar{e}_{ms,B_r}(t) = j\omega_m \left( \frac{3}{2} \pi r \frac{N_s}{2} \right) \vec{B}_r(t) = j \frac{3}{2} k_E \omega_m \angle \theta_m(t) = \frac{3}{2} k_E \omega_m \angle \left( \theta_m(t) + 90^\circ \right) \] (8)

\[ \bar{e}_{ms}(t) = \bar{e}_{ms,B_r}(t) + \bar{e}_{ms,i_s}(t) = \frac{3}{2} k_E \omega_m \angle \left( \theta_m(t) + 90^\circ \right) + j\omega_m L_m \hat{I}_s(t) \] (9)

\[ \bar{E}_{ma} = k_E \omega_m \angle \left( \theta_m(t) + 90^\circ \right) + j\omega_m L_m T_a \] (10)

Figure 15. Steady-state equivalent circuit for synchronous generators and motors

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10. DEVELOPING COMPUTER ASSISTED TEACHING ENVIRONMENT

Developing computer assisted teaching environment has been an important factor for successful teaching of the course using the integrative approach. It would not be possible to cover so many contents without the significant use of computer teaching methodologies. Teaching materials for each chapter are developed using various computer software and hardware including Microsoft PowerPoint, MatLab, MathCad, PSpice and LabView. The computer-teaching environment is developed with a highly animated effect with different software systems are linked together in Microsoft PowerPoint. This can not only allow many contents to be covered but also make a lot of tough concepts, principles, and theories be taught easily and clearly.

The PowerPoint [10] presentations are designed with strong animation effects. This provides much more effective and efficient environment for teaching the course. Figure 16 shows the development of the induction machine equivalent circuit under steady-state condition.

![Steady-state induction machine equivalent circuit](image)

Figure 16. Using PowerPoint animation to develop steady-state induction machine equivalent circuit
in one animated PowerPoint slide. The animation starts with Figure 16 a) [11] and then continues in a step-by-step and easy understanding way to the final animation of Figure 16 b). Links to some pre-knowledge represented in other slides, Internet links, or other programs and software as well as to some examples are also provided in the animation. In this way, students can quickly understand the concepts and apply the knowledge to analyze practical induction machine steady-state problems.

The computer-teaching environment also includes the significant use of powerful mathematical software tools. They have made a lot mathematical related theoretical backgrounds of the course much easy to understand. MathCad [12] is one of the two software packages used for this purpose. Mathcad has been proven a very successful mathematical tool to be able to effectively show the relationship between mathematical equations and electric machine variables, principles, and theories represented in data, curves, and plots for this course. Its powerful animation tools can provide a strong dynamic environment for students to see both theories/equations and what may happen in an electric machine under the theories/equations. In our teaching practice, MathCad as well as its animations is used for teaching of concepts, principles, theories and examples such as the one shown in Figure 13.

MatLab and MaLab Simulink are another mathematical software package used for teaching the course [13]. MATLAB is a high-performance language for technical computing. Compared to C or Fortran languages, MatLab is much easy to understand and use. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. It also features a family of add-on application-specific solutions called toolboxes. The control systems toolbox of the MatLab is very useful and efficient for teaching of the basic concepts related to the electric machine controls. The Simulink representation of the electric machine control systems such as the one shown in Figure 12 can give students a clear understanding of the block diagram representation of an electric machine feedback control system such as Figure 12, the transfer functions of the controller, electric machines and mechanical systems, and the simulated machine control system time-domain performance. MatLab can also be used to develop animations for teaching of many

Figure 17. Using PowerPoint and MatLab animations for teaching induction machines

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very complicated electric machine theories, principles, and concepts. Actually, the following three approaches are used interactively to teach the course: 1) presentation of simple code lines written in MatLab, 2) execution of a MatLab program, and/or 3) running animation generated through MatLab in a movie player software. Figure 17 shows an animated PowerPoint slide for teaching of the squirrel cage induction motor. It has two links to two movies generated by MatLab animation and a link to an example in MathCad. This highly animated and dynamic teaching environment can let students quickly understand complex topics such as the one shown in Figure 17 [14].

11. CONCLUSIONS

The paper presents an integrative approach used in teaching and restructuring the traditional course of electric machines at Texas A&M University - Kingsville. The teaching approach covers all the subsystems consisting of a controllable energy conversion or electric drive systems, i.e., electric machines, power electronic converters, mechanical systems, and power supply systems. It presents developments of models and approaches not only for dynamic controls of electric machines but also for traditional steady-state analysis of electric machines. The power-pole and average models are used for quick introduction of power electronic converters, which enables students to quickly understand and design basic feedback controller for electric motor drive or energy conversion systems. The paper presents how AC machines space vector concepts and principles are taught based on the hypothetical sinusoidally distributed winding and are used to develop both dynamic and steady-state models and approaches for AC machine controls and traditional steady-state AC machines analysis. The paper illustrates the significant use and design of highly animated and dynamic PowerPoint presentation combined with other mathematical software packages such as Mathcad and MatLab for fully computer assisted teaching/learning environment. The integrative teaching approach and the completely computer assisted teaching/learning environment was used successfully to teach the restructured electric machine course at TAMUK in Fall 2003 with the coverage of issues related to both dynamic feedback controls of electric machines and traditional steady-state analysis of transformers and DC/AC electric machines.

12. REFERENCES

SHUHUI LI received his B.S. and M.S. degrees in Electrical Engineering from Southwest Jiaotong University in Chengdu, China in 1983 and 1988 respectively and Ph.D. degree in Electrical Engineering in 1999 from Texas Tech University. From 1988 to 1995, he was with the School of Electrical Engineering at Southwest Jiaotong University, where his research interests were in the areas of modeling and simulation of large dynamic systems, dynamic process simulation of electrified railways, power electronics, power systems, and power system harmonics. From 1995 to 1999, he involved into the research areas of renewable energies, neural networks, and applications of massively parallel processing. He joined the Department of Electrical Engineering and Computer Science at Texas A&M University – Kingsville (TAMUK) in 1999. He is currently an associate professor at TAMUK. He is a member of IEEE and a member of ASEE.

RAJAB CHALLOO is a professor in the EE/CS department. He has been teaching and conducting research at Texas A&M University – Kingsville since 1988. In the department of electrical engineering, he has severed as acting chairman, graduate coordinator, chairman of the curriculum committee, scholarship committee and research committee. At the college level, he has severed as the chairman of the graduate council, chairman of the executive committee of the graduate council, as a senator representing college of engineering, and a number of many committees. He has been honored by the students in EE/CS department to be the recipient of the professor of the year award four consecutive times and a merit of excellence award. He was named as an honoree for the 1993 University Alumni Association’s Distinguished Teaching Award. He has published over forty research papers and has severed as organizer, chairman, and reviewer for many national and international conferences.