AC 2009-91: VISUAL LEARNING TOOLS FOR AC CIRCUITS AND MACHINES

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Visual Learning Tools for AC Circuits and Machines

Abstract

This paper presents a series of interactive visualization tools to supplement textbooks and to aid students in learning a variety of basic AC machine concepts. The tools are purposely designed for maximum accessibility. They are available free of charge on the web, and require only the downloading and installation of a player application available for multiple platforms. They are easily modifiable to reflect instructor's comfort and convenience. The tools are effective in generating more enthusiasm among students because they provide alternatives to traditional approaches to clarifying difficult and unintuitive concepts.

Index Terms – AC Machines, AC Concepts, Visualization.

1. Introduction

The present generation of students has a mindset that lends itself to interactive displays and visually rich environments. Engaging them in the classroom has become an ever-widening challenge.

As it is widely assumed that this trend will continue[1] the possible impacts of various ways for engaging students through technology has been explored. Visualization in particular or the use of computer simulation is found to substantively improve the effectiveness of teaching as well as students' performance [2-3]. The illustrations, such as would be found in a textbook become active when the user manipulates the controls provided. This new level of engagement moves the learner from a passive to an active role, with the potential for more enthusiastic involvement in the learning process, as well as independent integration of concepts to be learned in the course[4-10].

There are a number of visualization tools already available for AC systems and electrical machines. These cover a broad range of subject material where the depth of coverage varies and is usually specialized. Many of the computer applications available are rather advanced for introductory courses or are narrowly specialized, making them more applicable for higher-level courses [13, 14, 18-21].

2. Objectives for visual learning tools for AC circuits and machines

The primary goal is to develop visual learning tools to supplement traditional approaches in an introductory level of AC circuits and machines course. Four critical issues are considered in developing effective visualization tools presented in this paper: (1) cognitive component, (2) visual perception, (3) level of interactivity and (4) program implementation and accessibility for users. In addressing the cognitive component it is assumed that foundational cognitive skills are developed through exposure to the theoretical basis of concepts, perhaps through text-based descriptions and formulae in the traditional classroom environment or other modes. In addition laboratory experience or some other hands-on exposure will serve to aid empirical understanding. Visual connection with concepts is used to facilitate the intuitive learning component. This is accomplished by presenting pertinent information clearly to the learner through effective graphical interfaces and appropriate visual metaphors.

The learner is engaged as an active participant in the education process when provided access to meaningful control functions in the visual learning environment, thereby facilitating empirical understanding of the subject or topic under discussion. Each of the virtual interfaces developed and presented in this paper reflect this design component. Users may freely interact with various parameters that feature in the mathematical models of the systems and concepts covered in the learning visualization tools. Such interactivity is essential in enhancing learning [21]. Although interactive graphic representations do not provide the same learning environment as field experience, they have effectively served to fill the void between abstract presentation and physical interpretation.

The choice of software development platform was hinged on three factors. First, it is desirable that the development environment should support a general-purpose program that is accessible to educators. Secondly, the visualization tool development software should be simple enough for courseware developers to quickly develop proficiency and finally, the courseware created should be platform-independent.

Wolfram-Mathematica software [22] offered the features that matched the criteria judged critical for the development environment. The program is readily accessible to educators and offers various functions for quick and easy development of graphic objects. Its platform-independent browser-based player makes the visualization tools accessible to a wide audience free of charge. Furthermore Wolfram Mathematica Project Demonstration website provides free hosting of the visualization tools.

The sections that follow highlight the visualization tools and student learning assessment.

3. AC Circuits and Machine Visual Tools

Twelve visual learning tools for AC circuits and machines concepts taught in an undergraduate course are developed and described in this section. The tools are organized and made available for free download on the web [23]. For convenience the tools are organized into four groups: AC Power Basics, AC Electrical Machines, AC Poly-Phase Principles and AC Drive Concepts. This is highlighted on the Webpage interface [24] to the tools shown in Fig. 1.

3.1 AC Power Basics

AC Power Factor Principle

This visual tool illustrates a phase plot of voltage and current as well as the pulsating instantaneous power. User interaction happens through a slider that changes phase angle between voltage and current waveforms. A screen shot of this tool can be seen in Fig 2.

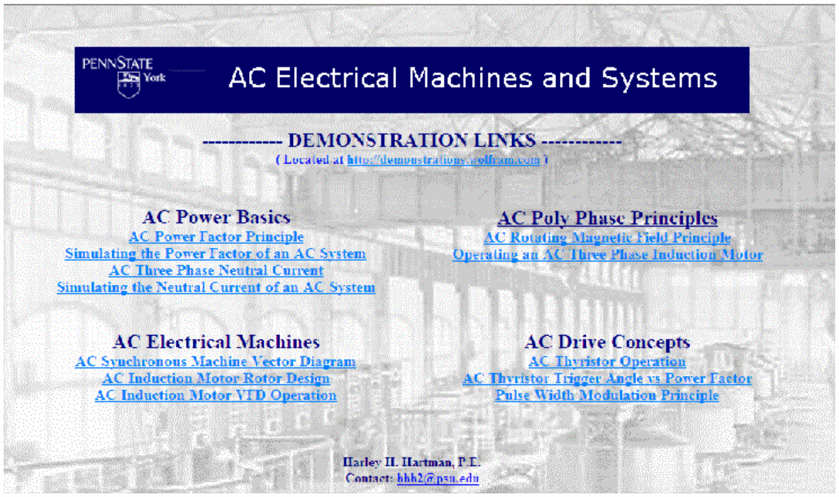

Fig. 1. Webpage Interface to Visualization Tools.

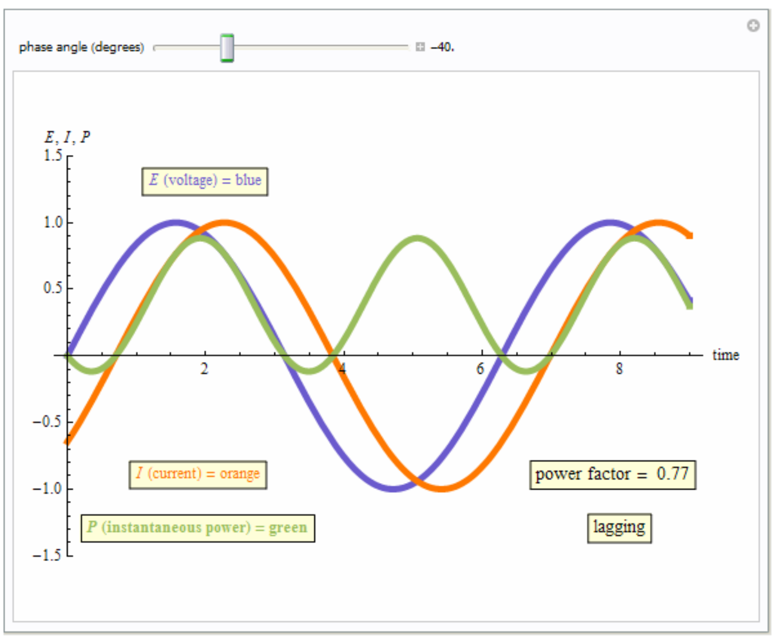

Fig. 2. AC Power Factor Principle

Simulating the Power Factor of an AC System

A slightly more advanced representation of power factor is presented in this tool where a system schematic, phase and vector plot options may be selected for display. Through simple sliders users may model common loads such as motors, lighting and capacitor bank for power factor correction. This power factor correction tool is presented in Fig. 3.

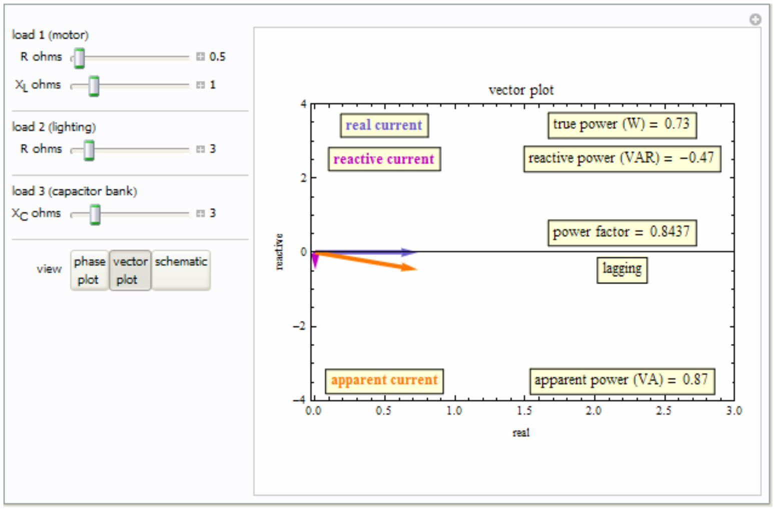

Fig. 3. Simulating the Power Factor of an AC System

AC Three Phase Neutral Current

The three-phase neutral current visualization tool enables learners to explore potential sources for neutral currents. It presents the phase plot for a three-phase power source and as well as the existing neutral current. The student can manipulate the magnitude and phase shift on one of the phases to create system imbalance. The tool is illustrated in Fig 4.

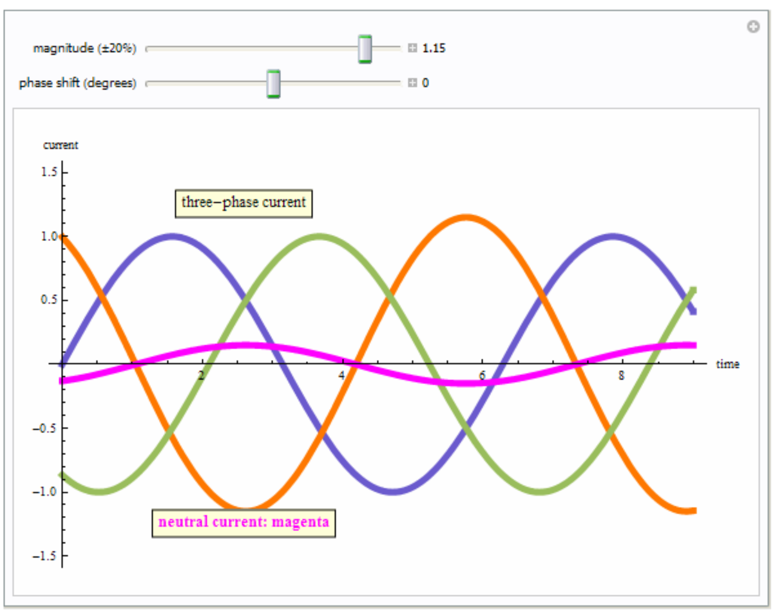

Fig. 4. AC Three Phase Neutral Current

Simulating the Neutral Current of an AC System

This tool is a slightly more advanced version of the AC Three-Phase tool in Fig. 4. It provides a vector plot as well as a schematic diagram for the system. The student may modify the resistance and reactance on each of the phases and observe the effects on the plots. A three-phase phasor display is shown in Fig. 5.

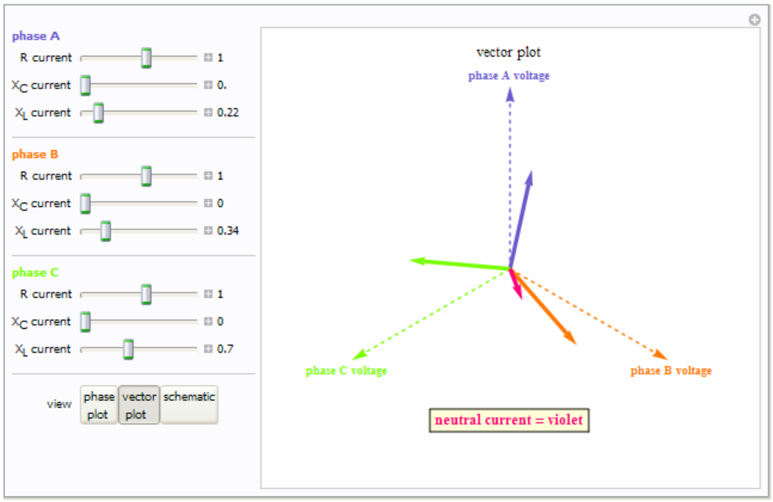

Fig. 5. Simulating the Neutral Current of an AC System

3.2 <u>AC Poly-Phase Principles</u>

AC Rotating Magnetic Field Principle

Concepts of AC rotating magnetic field may be reinforced through the tool illustrated in Fig. 6. Learners may observe the animated illustrations in a phase plot format as well as a vector format for single, two and three phase systems. Phase sequence and the speed of the animation are available to users for manipulation. The magnitude and phase shift are also available for adjustment on one of the phases to illustrate the effects of imbalances in a system.

Although two-phase systems are obsolete, the tool is very applicable for teaching concepts of single-phase split phase motors.

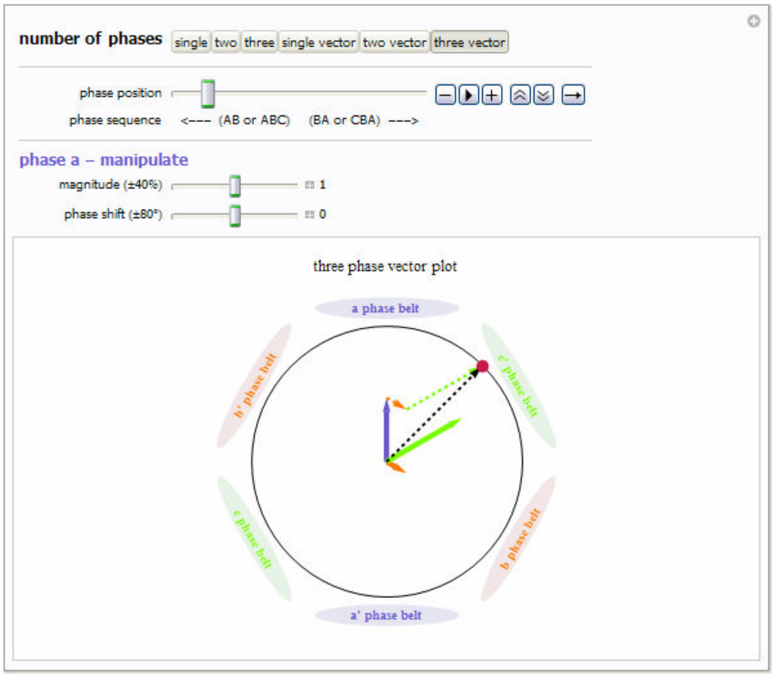

Fig. 6. AC Poly-phase Magnetic Field Principle (Three-phase, Vector plot).

Operation of AC Three-Phase Induction Motor

The visualization tool in Fig. 7 provides a way for close-up examination of the parts and functions of the AC induction motor (IM). The graphical representation of the induction motor shows the stator conductors, rotor bars and the field rotation associated with conductor placement in the machine. The physical effect of changes in flux magnitude, phase shift and rotor skew are mapped to the 3-D model as user interacts with the slider controls. In addition the physical orientation of the motor and speed of animation are easily changed by the user.

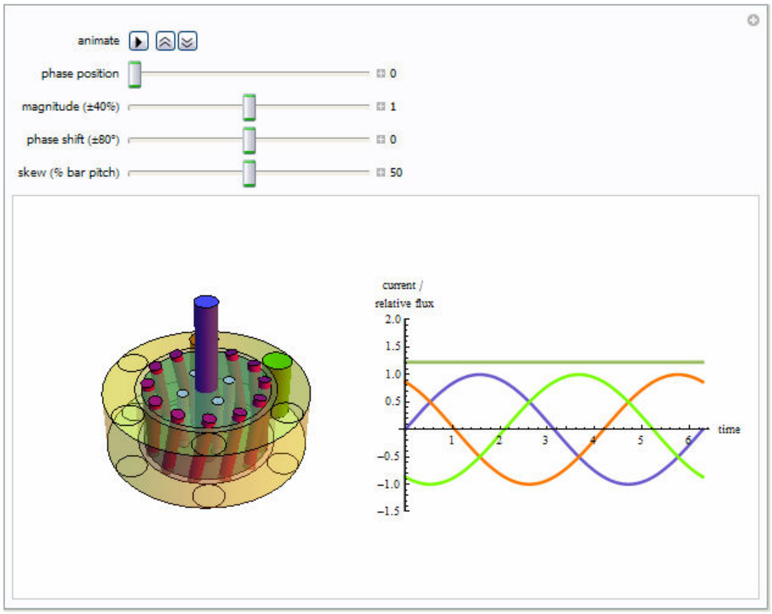

Fig. 7. Operation of AC Three-phase Induction Motor.

3.3 AC Electrical Machines

AC Synchronous Machine Vector Diagram

The steady-state model of the elementary synchronous machine is explored with the tool shown in Fig. 8. All of the variables of the power angle expression are available for the user to modify. The phase response to the changes is observed in the dynamic vector diagram.

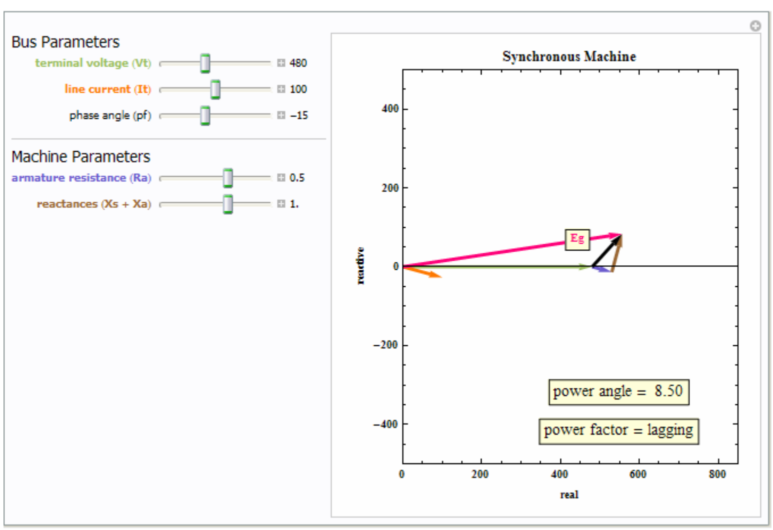

Fig. 8. Synchronous Machine Vector Diagram.

An interactive torque curve is shown in Fig. 9. The tool allows for closer examination of the effects of rotor design parameters on the torque speed characteristic curve. Standard values can be set with buttons for NEMA type A, B and D designs.

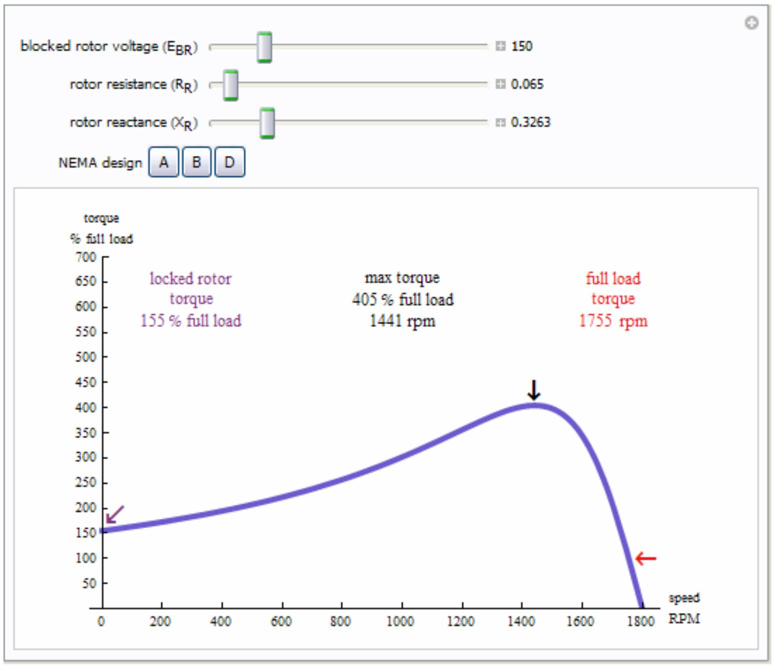

Fig. 9. AC Induction Motor Rotor Design

AC Induction Motor VFD Operation

The AC Induction Motor VFD Operation tool (Fig. 10) is a three-dimensional (3-D) version of the torque speed characteristic curve of Fig. 9. In addition it provides a visualization of the effects of varying frequency drives (VFD) on the operation of an induction motor. It also includes a representation of the induction machine in the generation mode.

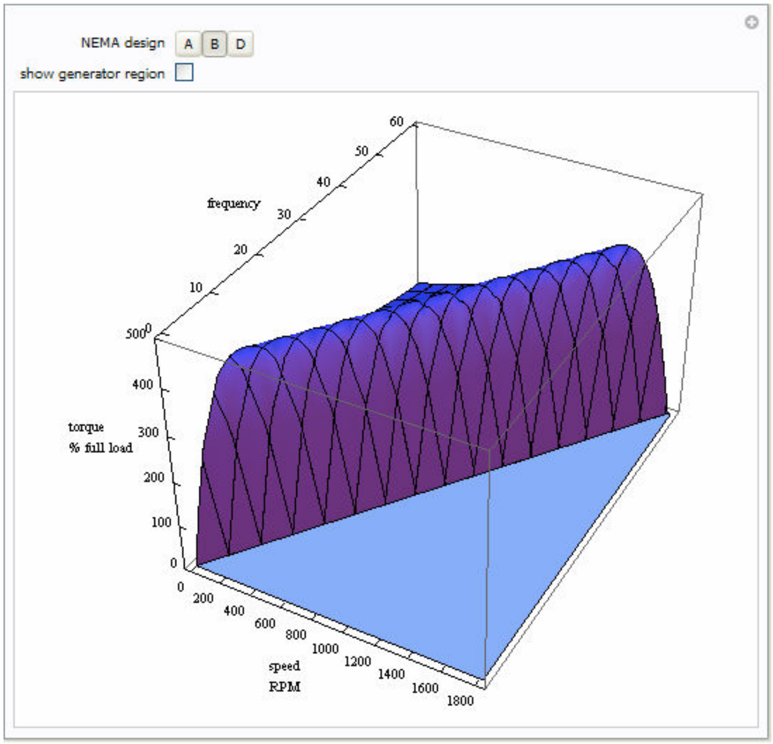

Fig. 10. AC Induction Motor VFD Operation

3.4 AC Drive Concepts

AC Thyristor Operation

This visual tool in Fig. 11 provides a phase plot representation of the operation of SCRs and TRIACs. Various waveform parameters such as conduction and turn-on angle, average, RMS and peak values are displayed as the triggering angle is adjusted. In addition provision is made for users to modify the resistive and inductive characteristics of the load.

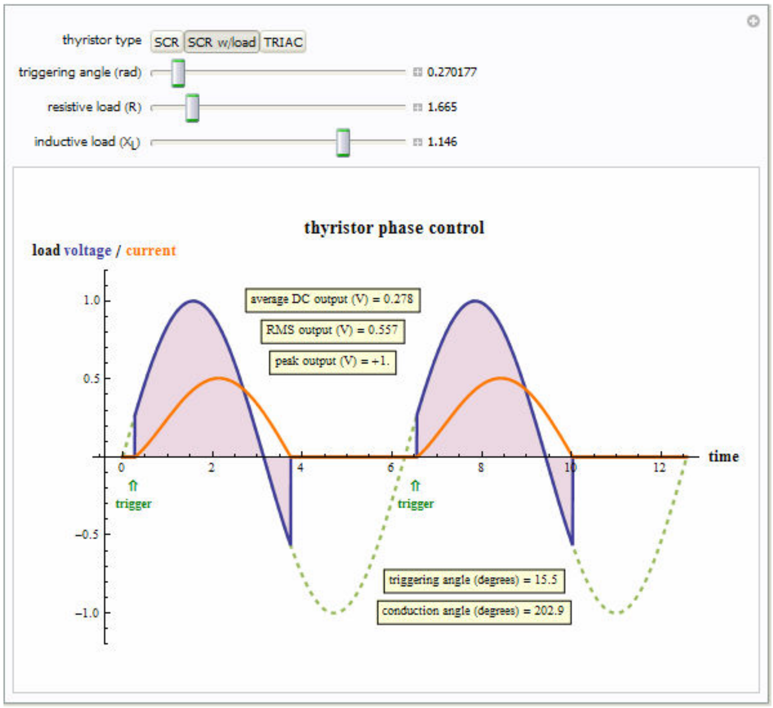

Fig. 11. AC Thyristor Operation

AC Thyristor Trigger Angle and Power Factor

The effects on source variables related to a thyristor switching device are explored in the tools illustrated in Fig. 12. The visualization allows for an adjustment of trigger angle and load impedance to study their effects on load current and power factor.

Pulse Width Modulation (PWM) principles are investigated in the tool shown in Fig. 13. The user may modify the reference signal to observe the pulses created through sine-triangle intercept method.

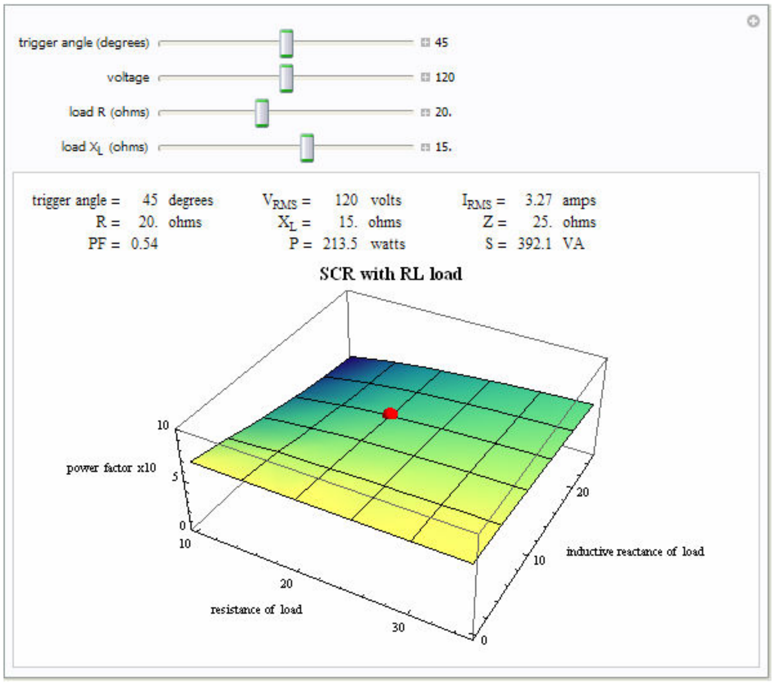

Fig. 12. AC Thyristor Trigger Angle and Power Factor

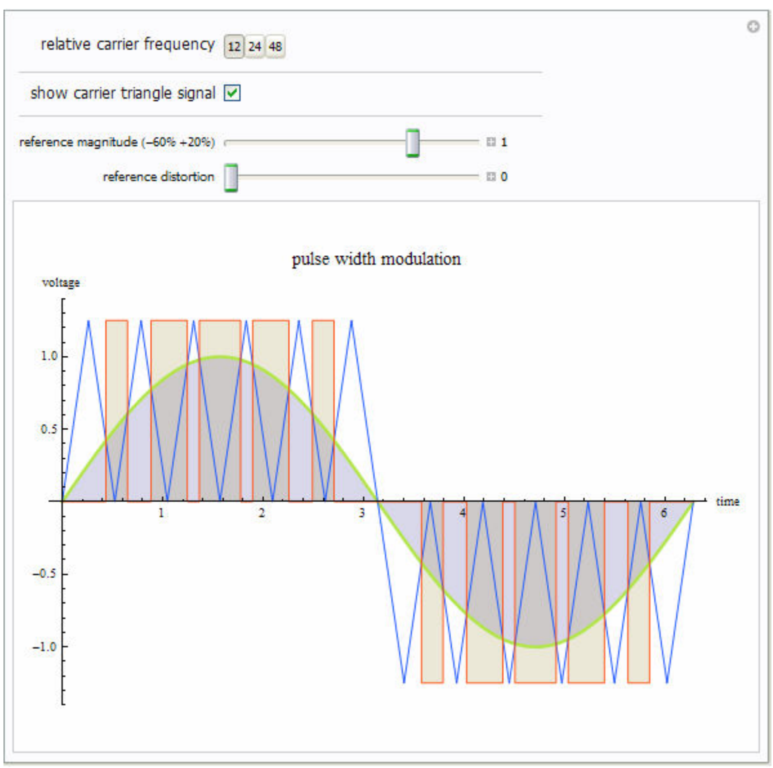

Fig. 13. Pulse Width Modulation (PWM) Principle.

4. Impact of the Visual Tools on Learning

During the process of developing these visual tools, twelve students enrolled in an introductory electrical machines course were exposed to some of the illustrations. They were pre-tested to assess their understanding of concepts after a typical lecture on the subject matter, but before exposure to the visual tools. Following a time of familiarization and interaction with some of the visual tools another test was administered to evaluate the effectiveness of the visual tools. Results and observations are provided in Table 1. Although the population sample used was small, results clearly show the positive impact of the series of interactive tools in the learning experience of this first group of students exposed to the tools. Since these students were closely involved in the early development and testing of the tools their unique needs and learning styles were embedded in the design. To further validate the learning results a larger population sample could be tested over three to four semesters when the AC machines classes are offered.

Table 1. Pre-questionnaire and Post-questionnaire - Assessment of Courseware Effectiveness

	Pre-test	Post-test	Changes
AC Power Factor Principle	76.67%	85.42%	8.75%
AC Three Phase Neutral Current	70.42%	87.50%	17.08%
AC Rotating Magnetic Field Principle	67.88%	82.42%	14.55%
AC Thyristor Operation	52.50%	90.00%	37.50%

5. Conclusion

This paper highlights a collection of visual tools designed to supplement traditional instructional materials in the typical alternating current circuits and electrical machinery course. The design reflects a variety of criteria deemed necessary to make the tools effective. Among other features the learner is engaged as an active participant in the education process through access to meaningful control functions in the visual learning environment, thereby facilitating empirical understanding of the subject. The software development environment, Wolfram-Mathematica is general-purpose, accessible to educators and easy to use and quickly develop proficiency in courseware development. The visualization tools hosted on the Wolfram-Mathematica Demonstration Project website is platform-independent and accessible to a wide variety of users. A free viewer as well as source code for each of the tools is available at the website for free download to enable instructors adapt or modify the tools for other purposes.

Comments and questions generated from the classroom experience confirm the effectiveness of the visual tools. Students generally value the interactivity afforded by the tools and noted that the ability to adjust system variables helped their understanding of the concept presented in the classroom. More extensive learning assessment over three to four semesters of use of the courseware tools will be conducted to further validate the immediate observations outlined in this paper.

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