A Virtual Electric Machine Laboratory for Synchronous Machine Application

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ABSTRACT: Engineering education can reach the desired level if practical laboratory works are given together with the theory. In electrical engineering education, if foundation costs are considered the electrical machine labs become very important. Due to the increasing number of students accessing the university educational structures, the cost of laboratories for didactical electric machine applications is going to be very high. In this study, virtual laboratory, which is found to have wide application field in recent years, is introduced. For this purpose, a virtual electrical machine lab for electrical engineering lab courses is developed. An example of application was presented for the control of synchronous motor and no-load and blocked rotor test of synchronous generator. Moreover, this study explores the learning effect related to different learning styles of web-based virtual lab that has developed in electric engineering students. Comput Appl Eng Educ 17: 187–195, 2009; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20133

Keywords: virtual electric machines; synchronous machine; web-based virtual lab; interactive learning environments, V/f control; asynchronous starting; simulations

INTRODUCTION

Engineering education can reach the desired level if practical laboratory works are given together with the theory. Laboratories are common elements of training for the students to gain experience. Conventional labs are complementary parts of an education program. The practical works in the labs help students gain practical skills and prepare for professional life. However, various physical restrictions may force to look for more economical and convenient alternatives for real laboratories [1,2].

The conventional way of providing practical experience to electrical engineering students is through the use of extensive laboratory-based systems. Such systems require an actual hardware setup and a set of laboratory measurement systems that are sometimes costly to build and difficult to maintain. For safety and security reasons, access to the

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laboratory-based system is usually limited to a certain time and can only be given in the presence of a local facilitator [3].

Asynchronous starting and V/f control of a synchronous motor was realized to show the functionality of web-based virtual lab system. In this article, a real environment, which eases training of a student, was tried to realize in this virtual lab.

The advantage of virtual lab lies in the possibility of communicating information through high-speed communication systems, when needed, with a local facilitator to supervise the learning process at a local site. The local facilitator is a professor at a local university that will use the developed virtual system for instruction [4,5]. As known well, virtual environments provide assistance to the training of students by supporting with repetition and exercises, by training with simulation programs, by showing the data and figures attractively, by computer-leaded learning [6,7].

The training approach presented here uses simulations to help students, visualize contents and provide instantaneous graphical feedback during practices or experiments. With the help of virtual practicing environment, students can have information about synchronous motor and support the theoretical information he or she gained before. The student can also make the changes he or she desires during the application and see the results immediately graphically. Since the applications are on the simulation the mistakes and faults will not give any harm.

IMPLEMENTATION OF THE VIRTUAL LABORATORY ENVIRONMENT

The heart of the virtual learning system is an integrated C++ based GUI application compatible with Windows95-Xp/NT. The virtual platform was created by using Hypertext Markup Language (HTML), Active Server Pages (ASP) and Borland C++ Builder. The platform has a structure, facilitating learning of a student like in a course presentation. One of the important properties of the visual programs such as Borland C++ Builder is to design the screen with available form controls but not codes. Required design can be achieved by forming codes.

Moreover, C++ code is relatively easy to maintain, reuse, and modify and allows for groups of programmers to work on separate parts of the code. Programs written in C++ can be maintained and updated more easily and addition of functionality to the code is relatively straightforward with fewer risks of introducing errors. With the aid of Borland C++ Builder, various ActiveX forms, which include HTML indicator and support learning, can be formed [3,8,9].

Virtual platforms written in HTML and ASP can be transferred to Internet and reached by any software. The system architecture of web-based application is shown in Figure 1. When a client sends the HTTP server a request for a HTML page, the server can respond to this request directly. The application server communicates with the web server using TCP/IP sockets.

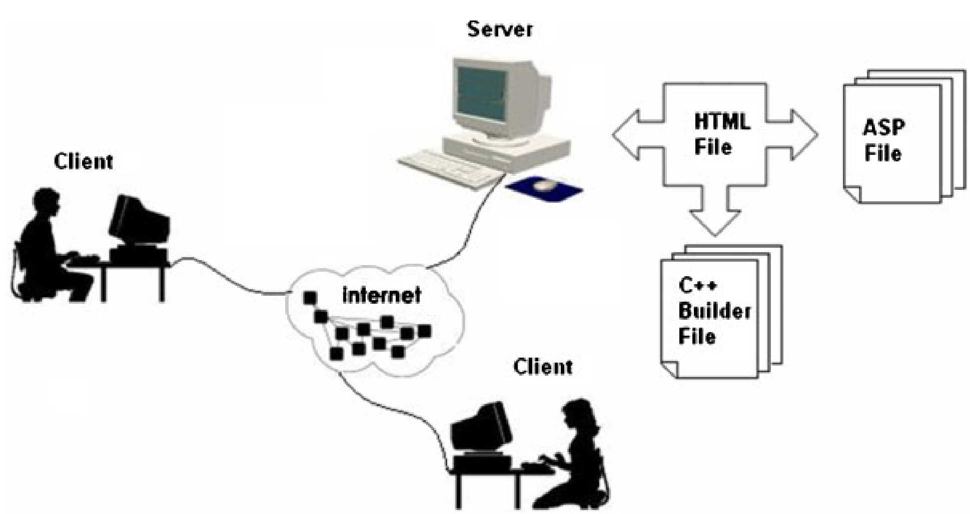

Figure 1 The system architecture of web based application.

MATHEMATICAL MODEL

In modeling it was accepted that synchronous motor had three phases, salient pole, a damping coil in $d-q$ axis, it was fed by a constant frequency, sinusoidal voltage power source. Harmonics, damper coils, vortex currents and saturation effects were not considered. Voltage equations of the machine can be developed in rotor reference frame for two rotor windings and three-phase stator windings [10]. Equivalent circuit with respect to the rotor reference frame is seen in Figure 2. All motor parameters and electrical quantities are shown at the stator side. Abbreviations used are defined as follows:

d,*q*, *d* and *q* are axis quantities;
r,*s*, rotor and stator quantities;
l,*m*, leak and magnetization inductance;
f,*k*, field and damper quantities.

By the aid of equivalent circuit the following equations can be written.

$$v_q = r_s i_q + \omega_e L_d i_d + E_f \tag{3.1}$$

$$v_d = r_s i_d - \omega_e L_q i_q \tag{3.2}$$

$$E_f = \omega_e L_{md}\left(\frac{v'_f}{r'_f}\right) \tag{3.3}$$

All variables are in the rotor reference frame. Linkage fluxes depend on the currents in different windings with respect to $d-q$ axis variables and can be written in the following:

$$\psi_q = x_{ls} i_q + \psi_{mq} \tag{3.4}$$

$$\psi_d = x_{ls} i_d + \psi_{md} \tag{3.5}$$

$$\psi'_f = x'_{lf} i'_f + \psi_{md} \tag{3.6}$$

Electromagnetic torque produced by synchronous motors is dependent to the angular velocity and can be written in the form of Equation (3.7).

$$T_e = \frac{P_e}{\omega_r} \tag{3.7}$$

Considering pole number of the motor the dynamic equation of the rotating system is written

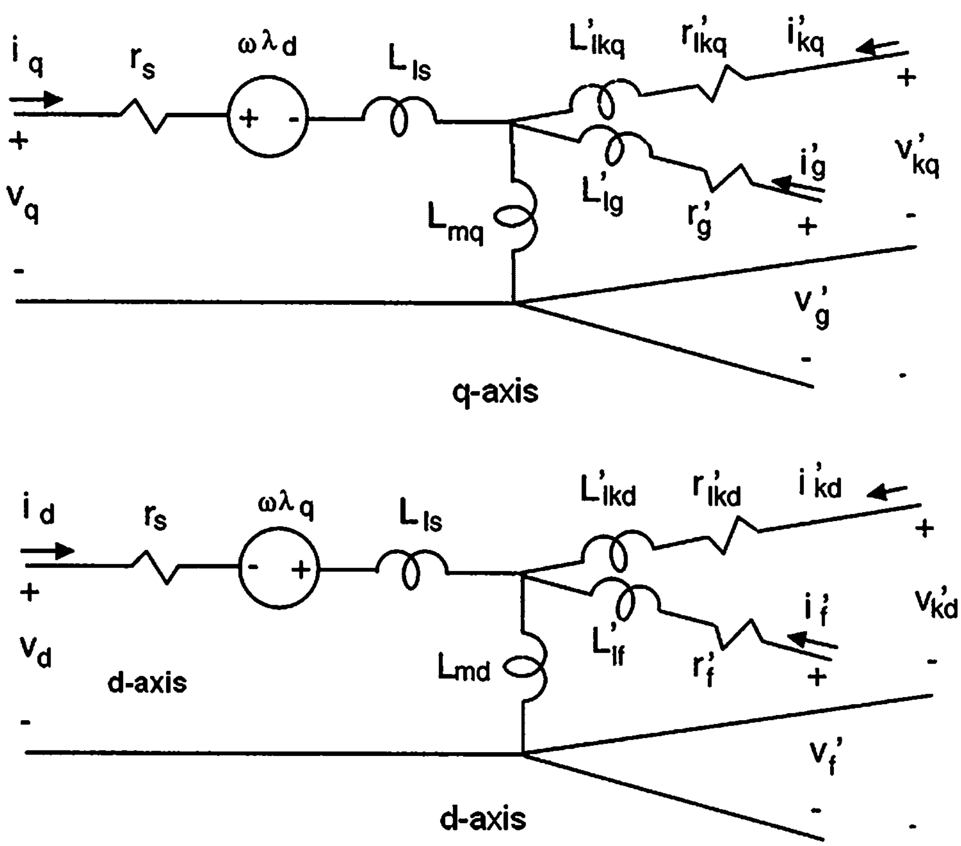

Figure 2 Synchronous motor and d−q equivalent circuit.

as in Equation (3.8) as regarding the stator circuit parameters

$$T_e = \frac{2}{P} J \frac{\mathrm{d}}{\mathrm{d}t}\omega_r + \frac{2}{P} B\omega_r + T_L \tag{3.8}$$

B can be ignored since it is too small and Equation (3.8) can be rewritten as in Equation (3.9).

$$T_e = \frac{2}{P} J \frac{\mathrm{d}}{\mathrm{d}t}\omega_r + T_L \tag{3.9}$$

Rotor position and mechanical angel becomes,

$$\theta_r = \int_0^t \omega_r \mathrm{d}t, \theta_m = \frac{2}{P}\theta_r \tag{3.10}$$

Electromagnetic torque produced in the motor is given by,

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_d i_q - \psi_q i_d) \tag{3.11}$$

EFFECT OF WEB-BASED VIRTUAL LAB ON LEARNING

Virtual lab environment was applied to the students of electrical machines course. The students were divided into two groups. Control group performed the experiments only in real electrical machines lab while the experiment group used both virtual lab and real lab environment.

Method

The method used in this study includes web-based virtual lab procedures and experimental studies. In the study a pre- and post-group experiment model was implemented. The effect of independent variable or virtual lab applications on the dependent variable or student success was measured. In addition, a questionnaire was applied to learn the attitude of the students that participated in the virtual lab applications to the virtual lab [11]. Arithmetic average, Standard deviation and t test were used in analyzing the data from the questionnaire.

Operation of Web Based Virtual Lab

In traditional electrical engineering laboratories, the data are collected using traditional analog voltmeters, ammeters, wattmeters, digital multimeters, and oscilloscopes. Students spend a large portion of time

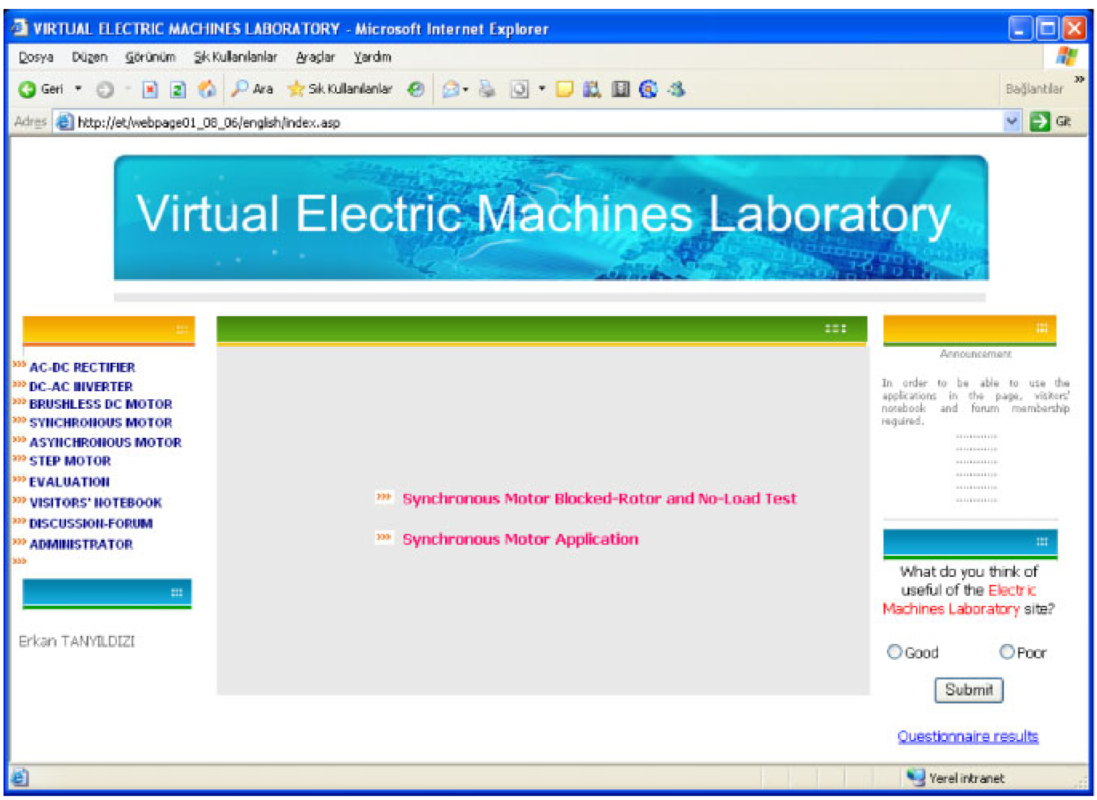

Figure 3 The view of virtual electric machines laboratory page. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

connecting the standard hardwired instrumentation, which allows them to measure only root mean square (RMS) voltage, RMS current and real power. The quantities not measured, such as reactive power triangle, are calculated as part of the lab write-up using the power triangle and trigonometric identities. Since such quantities are calculated after the lab, student cannot observe the effect on these quantities due to changes of other experimental parameters [12].

The virtual lab created has the capability of performing the actual experiment in the field of electrical engineering. For example, students can immediately see result of loading a synchronous motor, changes in a supply voltage, or make necessary changes they want. When entered web page, the view in Figure 3 is seen on the screen.

No load test and short blocked circuit test pages can be loaded by clicking the appropriate link in the main window (Figs. 4 and 5).

The model for the V/f control and asynchronous drive applications of synchronous motor was developed with respect to the rotor reference frame. After choosing the parameters of motor, the application is started by clicking start button and the results of the simulation can be obtained graphically. Whenever needed, the application can be stopped or finished. Virtual application can be run for different synchronous motors by changing all motor parameters, simulation time (t), sampling frequency (Khz) and voltage (Vf) to be applied to the motor winding. Selecting the boxes on the right side of the graphics, desired graphic can be visualized. For example, if the graphic of the velocity of synchronous motor is desired to see on the screen, the select box is activated. After virtual application is run, the output graphics of speed and torque are given in Figure 6.

By choosing the graphic buttons placed inside a window on the screen, the graphics can be recorded,

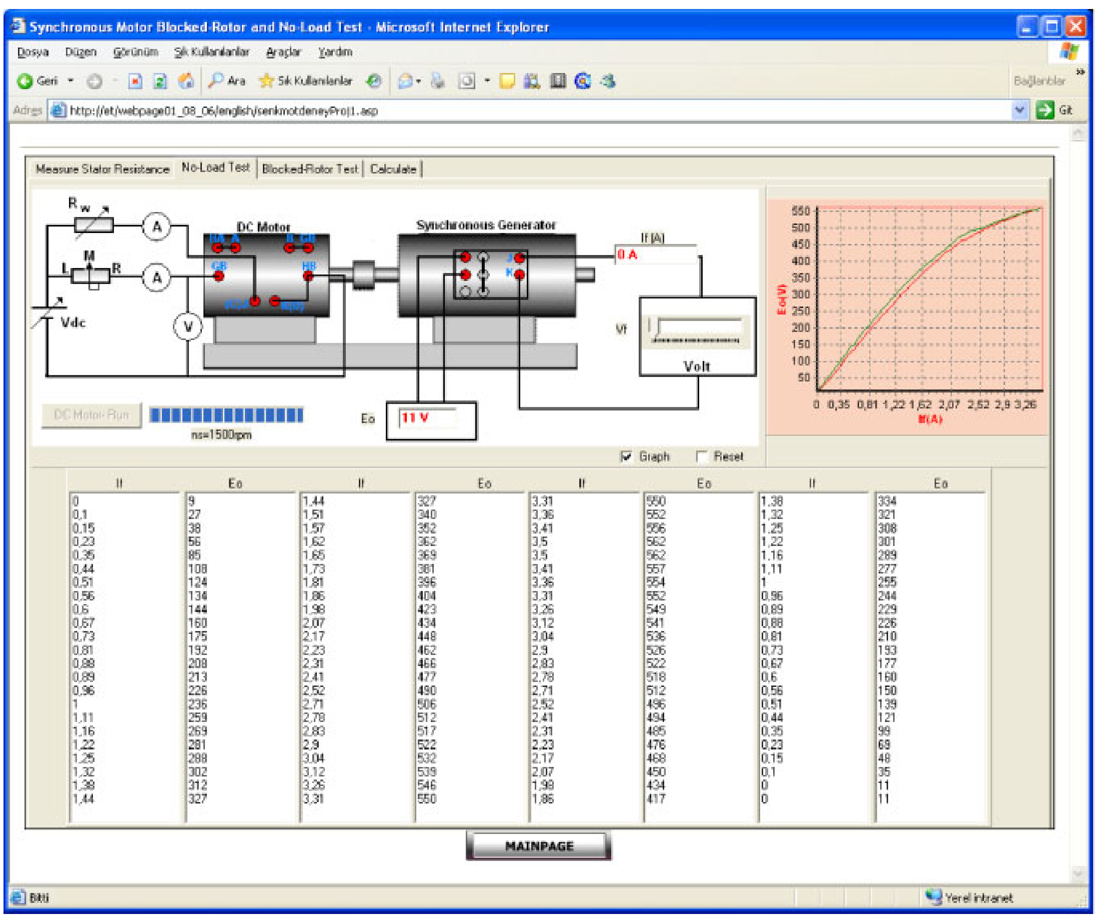

Figure 4 Appearance of the application page of open and short circuit experiment of synchronous motor. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

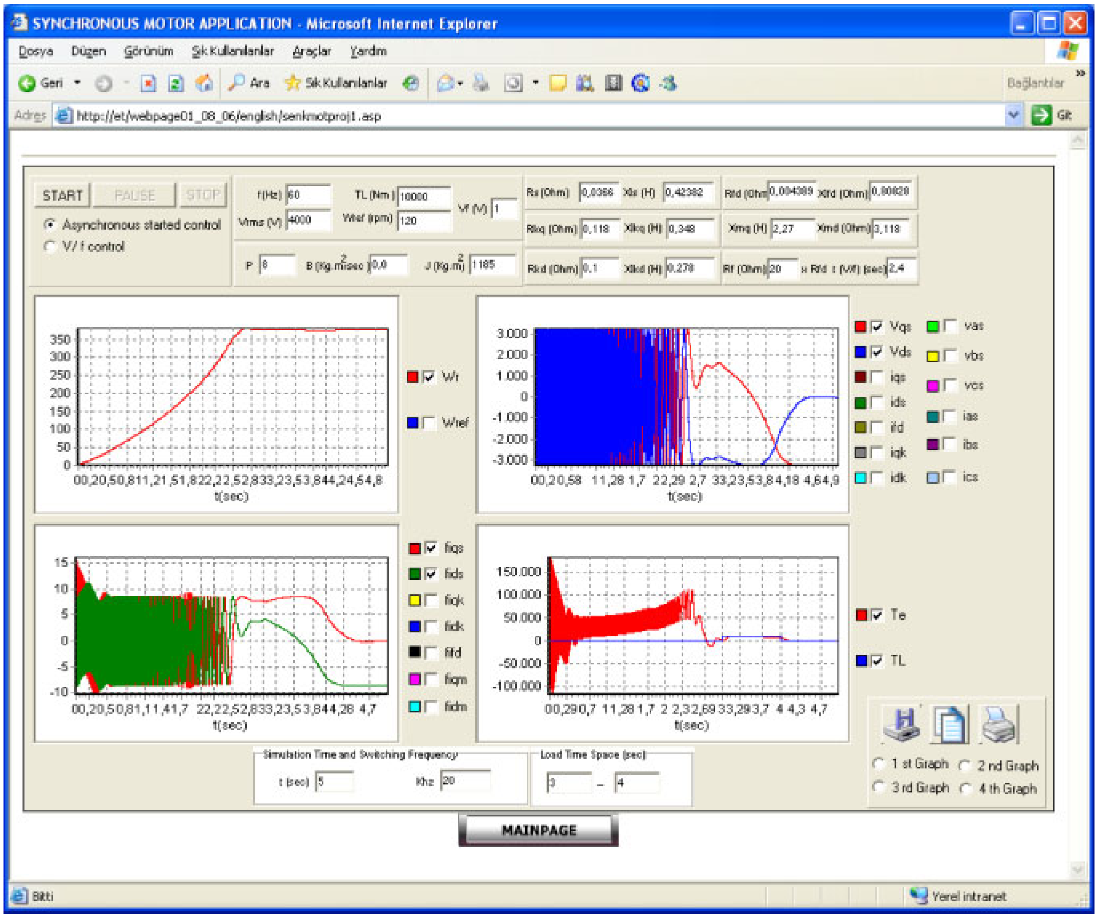

Figure 5 Appearance of the application page of V/f control experiment of asynchronous drive synchronous motor. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

copied or printed out (Fig. 7). In this way the user can use the results of different applications later. The students can analyze their experiments and discuss the results. By doing so, student can measure his or her success and complete the insufficiencies by studying the subjects he or she failed.

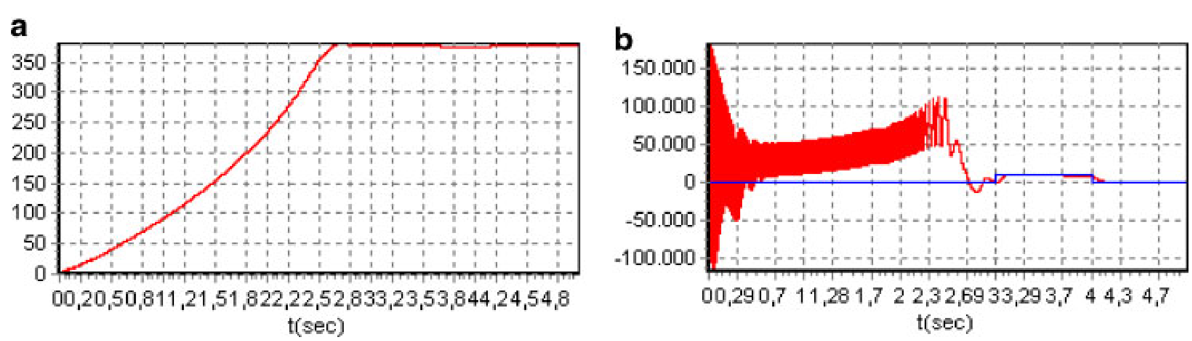

Figure 6 Graphical results of the applications of synchronous motor, (a) speed graphical results of the applications of synchronous motor, (b) torque. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

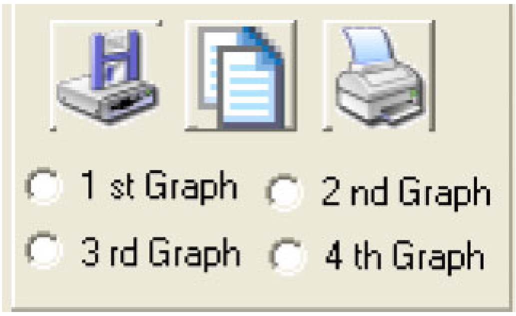

Figure 7 Window of recording, copying or printing of the results of the simulation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Findings and Discussion

The statistical findings and discussions belonging to this study are given in this section.

Effect of Virtual Lab Environment on the Success of Student. The success graphics of pre- and post-tests of the experiment and control groups are given in Tables 1 and 2 after applying independent group *t* test. While there is not any difference in the pre-tests of control and experiment groups in successfulness, the success of the experiment group is clear in post-experiment tests as can be seen in Table 2.

A significant difference in favor of the experiment group was found in post-test points of the groups (see Table 2) and this was determined to be due to the learning environments. However, in testing the effectiveness of an environment, achievement points can be told to give more satisfactory and characteristic results. Therefore this test was also done and the results are given in Table 3.

By subtracting pre-test points of the students from the post-test points, achievement points were calculated. From the results, it was seen that there was not a significant difference in the achievement points of the students within the same group by using independent groups *t* test. On the other hand a significant difference was found in favor of experiment group in the comparison of control and experiment groups.

Students' Attitude to the Virtual Lab Environment. In order to determine whether there was a significant difference between pre- and post-test points from the attitude criterion (scale) of the experiment group who used the virtual lab environment, paired group *t* test was applied. An attitude scale developed by Aťiči [13] used in this study. The results are given in Table 4.

As seen in Table 4, a significant difference ($P < 0.05$) was determined among the points which experiment group got from the whole attitude criterion. This difference can be explained by the positive attitude of the students in the experiment group to the virtual lab environment.

The success of the experiment group was higher than that of the control group after the experiment done by the students and this is very important. In addition, learning effectiveness of the experiment group was seen better than the control group who used conventional learning path.

Table 1 The Results of Independent Groups' t-Test for the Pre-Test Points of Experiment and Control Group

Groups	Number	Mean score	Standard deviation	Degree of freedom	*t*-Value	Significance level
Experiment	40	15.20	4.01	71	−0.43	$P > 0.67$
Control	33	14.82	3.48			

$P > 0.05$.

Table 2 The Results of Independent Groups' t-Test for the Post-Test Points of Experiment and Control Group

Groups	Number	Mean score	Standard deviation	Degree of freedom	*t*-Value	Significance level
Experiment	40	24.28	4.25	71	−3.541	$P < 0.001$
Control	33	21.00	3.51			

$P < 0.05$.

Table 3 The Results of Independent Groups' t-Test for the Pre-Test Points of Experiment and Control Group

Groups	Number	Mean score	Standard deviation	Degree of freedom	t-Value	Significance level
Experiment	40	9.07	4.96	71	−2.71	$P < 0.008$
Control	33	6.18	3.96			

$P < 0.05$.

Table 4 The Results of Paired Groups t-Test of Attitude Criterion Pre- and Post-Test Points of the Experiment Group

Experiment	Number	Mean score	Standard deviation	Degree of freedom	Correlation	t-Value	Significance level
Pre-test	40	134.50	28.20	39	0.362	−3.459	$P < 0.001$
Post-test	40	150.08	21.16				

$P < 0.05$.

CONCLUSION

In this study, a virtual environment, which is a new and widespread technique in education, for electrical machines laboratory was created using Borland C++ Builder, CGI toolkit, HTML and ASP programming languages. The student can access virtual learning environment without any software installation, system configuration, or programming. In this virtual learning environment, the student will be able to join the study any time and try to solve the problems given and also transfer his/her opinions to the system. The student can submit system parameters and receive text or graphical results through a web browser. This virtual application and distance education pages is ideal for instructional use, and student learning, as well as for practical engineering applications. The laboratory prepared in this study provides a self-learning environment for the student. The use and application of the system is simple and friendly. Program can lead student from the beginning to the end and gives the opportunity of self-assessment. The ideas and principles presented in this article are applicable to many other areas of practical engineering applications. The application will dismiss a real laboratory need thus providing cost saving for a training institution in the field.

The system developed in this study has a big advantage since it eliminates probable safety problems and cost in electrical machine laboratories in electrical engineering departments. Students need synchronous motor, measurement tools, rheostat to be used in asynchronous drive and switch to turn from synchronous regime to asynchronous regime. There is always the possibility of hazards and danger during the experiments besides the cost due to the equipment and material needed. Same experiments are possible to perform in virtual labs under no risk. The lab developed in this study gives also the opportunity to face the risky and hazardous conditions in virtual environment without giving any harm to both students and equipments. It is also possible to repeat the experiments until the subject are learned well. The institutions suffering from the lack of a real electrical lab may also get benefited from the opportunities of this lab.

In the next step, the program will be developed and a much more comprehensive structure will be formed.

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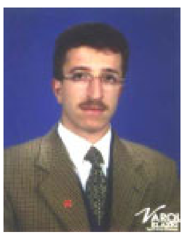
BIOGRAPHIES



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Ahmet Orhan was born in 1961. He joined Fırat University Electrical and Electronics Engineering in 1980. He graduated from this department in 1984. Next, he started to work as a research assistant in this department. Meanwhile, he continued his master study and completed in 1987. In 1999, he completed PhD study at Fırat University, Elazig.