New Era in Engineering Experiments: an Integrated and Interactive Teaching/Learning Approach, and Real-Time Visualisations*

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A computer-based and interactive laboratory system is described, and the implementation details of the system are given in this paper. The work was designed and implemented for the undergraduate electrical machines and drives teaching laboratory. The changing status of the experimenting in engineering education are discussed, and the problems identified in the conventional method of delivering the experiments are studied together with the proposed solutions. It is shown here that the alternative and cost-effective solution can overcome most of the problems that academic institutions are facing in the area of experimental work, and prepare the academic institutions to the new era of computer-based teaching and learning. Some sample front panels of the experiments are also given and the planned major future developments are highlighted.

INTRODUCTION

THE EMERGING issues in universities are how to educate the students, how to provide the cross-disciplinary knowledge (such as in electrical, electronics, computer and mechanical engineering) within a limited number of contact hours, and how to make the students aware of the problems faced in advance practical systems without their having an opportunity to analyze such devices in detail.

In addition to these, specifically in the area of laboratory practices, the very rapid rate of change in the fields of electrical, electronic and computer technology poses special problems for the academic institutions. There is of course a continual need to update and augment the content of the lecture courses to keep pace with this change, but it is in the area of experimental work where major concerns arise. The challenge was to provide the students with meaningful, up-to-date and relevant practical experiences while not being limited by the finite resources in the provision of laboratory hardware and infrastructure. One of the solutions is to use computer-based techniques to interface the students with the physical world, with suitable user interfaces to provide increasing sophistication and to provide increased flexibility for potential extensions in the future.

Furthermore, since the engineering subjects are very much involved, it will be very beneficial for the students if the experiments demonstrate functional interaction between other engineering topics. Specifically in Electrical Engineering, it is

often late for the students to understand and to solve the problems related to the complex systems unless it is supported by the relevant laboratory practice. It was experienced that fresh theory supported by the real-time data and the use of advance tools during the coursework, are the two principal keys for success especially in Electrical Engineering.

Moreover, the laboratory environments in engineering should provide common practical experiences to cater for students who are coming from increasingly diverse backgrounds, and whose learning is best achieved in a contextual setting.

Although a number of computer-based customized test systems [1] have been developed within the past ten years to replace the conventional engineering experiments, commercially available computer-controlled systems suitable for educational institutions have many limitations.

- Inflexible and unfriendly programming structure, which do not allow the users or designers to implement subject or department oriented experiments.
- Usually not compatible with the existing experimental systems in the laboratories, which may be very expensive to convert.
- Normally designed in a modular structure, having a certain number of inputs/outputs that may be surplus in some applications.
- Hardware generally contains small-scale testing devices, which do not usually represent the practical systems operating in real-life conditions, where the major learning practices originate.

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* Accepted 28 July 1998.

- Usually housed behind a panel that prevents the students experiencing real-life devices and the visual benefits of direct experimentation.

However, due to recent advances in computer technology and software, it is now feasible to implement even more advanced, more efficient, highly interactive and very user-friendly systems at optimum cost without using the commercial custom-written software and tools.

In this paper, the laboratory course, Electrical Machines and Drives, modified and equipped with PCs and LabView® virtual instrumentation [2] workstations in the Department of Electrical and Electronic Engineering, the University of Adelaide, is described. The system has the following key benefits: elimination of pre-practical tutorials, less time in each session (means more sessions to handle the large number of students and/or advanced study), saved resources (student time and demonstrator time), and accurate measurement for detailed and dynamic analysis (such as starting, acceleration and braking) which was not available before.

It is intended in the paper to mitigate the limitations of the current experimental practice, which is believed to be common in similar academic institutions, by introducing a cost effective, long-lasting and flexible real-world experimental system, and by providing advance hands-on experiences to the students during the undergraduate level of the engineering education.

INTERACTIVE LABORATORY CONCEPT AND THE OBJECTIVES

From the technical point of view, all the teaching laboratories deal with some physical quantities such as temperature, speed, position, current, voltage, pressure, force, torque, etc. A computer equipped with the suitable interface circuits, data acquisition systems and software, can give a visual look to these quantities, and can process the acquired data very quickly for further analysis. It is also possible to use the data later, and/or to transfer the data in real-time to a remote area user via Internet link.

However, all these physical quantities in the real-world should be converted to digital data to be processed by the computer. As is well known, the data acquisition cards can perform such conversion if they are linked to the suitable signal conditioning circuits. Also, such systems can be used to output the desired data to the outside world for control purposes, such as for an emergency shutdown of the device under test and to vary the rotor resistance of a slip-ring induction motor. Furthermore, a variety of information can be stored in the computer for report-writing purposes. The exact *repeatability* of the information stored in the computer, regardless of the tutor and the time of the session, is the principal benefit. In addition to this, the inter-action possibilities in such system are unlimited when they are equipped with a suitable custom-written software. In Fig. 1, the components of an interactive experimental system, which was also implemented in this work, are shown.

As stated previously, in engineering laboratories, the emphasis should be placed in engineering fundamentals supported by the real-life applications. These real-life applications which capture the relevance of the fundamentals should not be left to the students to disseminate later. As will be demonstrated later in the paper, a computer-based interactive experimental approach can allow the students to visualize and disseminate the real-life data on the electrical machines and drives, which was not possible before with the conventional testing systems.

The principal objective of the method implemented in this work was to provide a visual educational experience while retaining the conventional laboratory techniques. A number of additional educational benefits of this method can also be identified as: encourage independent learning, analyzing deficiencies, and allowing students to experience advanced laboratory techniques [3, 4]. This method will develop students skills in making correct measurements and understanding the operational principles of advanced instrumentation in an interactive environment.

It may be true to say that among the experiments in electrical engineering, electrical machine experiments including the drives are probably the most time-consuming experiments in the collection of data. They are also expensive both in terms of
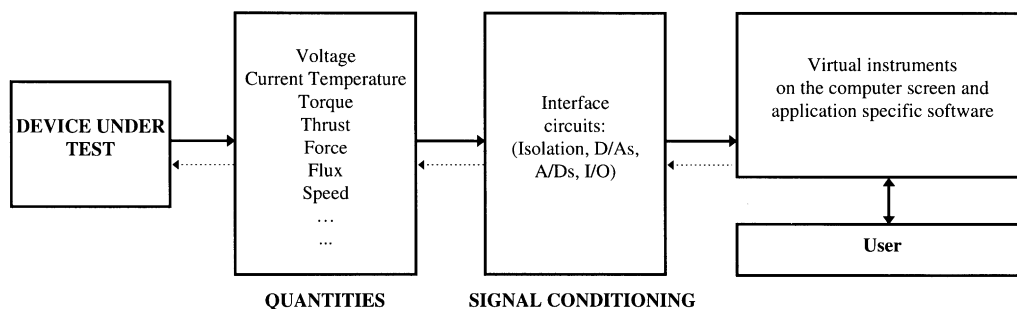

Fig. 1. The components of an interactive experimental system.

human and financial resources whether performed in educational institutions or in industry. Moreover, it should be emphasized here that an effective computer-based experiment should not overshadow the benefit of hands-on experiences, such as wiring. Therefore, to facilitate an effective experimental and learning process, the previous practices are also included in the new method.

In this work, the experiments were designed in such a way that the valuable insights into the process of controlling data and controlling electrical machines via computers are achieved. The application-specific software helps the students to learn the necessary skills to understand electrical machines, electromechanical devices and drives.

It was expected in each experiment that using images and real-time signals instead of steady-state analogue measurements greatly increases student learning. The prominent purpose of real-time signals is to disseminate certain information through the presentation of graphical images since the graphical images are linked to the specific experimental setup. Therefore, this technique helps the students to understand the experiments in detail, to experience real-time signals and controls, and to observe the limitations of the theory delivered in relevant courses.

The additional objectives of the method are: to use the experimental time more effectively, to introduce more and advanced analysis aspects (such as signal processing, power measurement, harmonic analysis, etc.), to reduce time in each session (currently 6 hours per session), and finally, to save demonstrators' and students' time.

SYSTEM ARCHITECTURE AND THE HARDWARE IMPLEMENTED

The layout of the laboratory is shown in Fig. 2. There are ten identical workstations in the laboratory. The essential part of each workstation consists of four principal units: the electrical machines/drives sets, the transducers, PC/data acquisition card and the software [4].

In total, there are 10 Pentium-based PCs running Windows NT, LabView full development software and HiQ software, two laser printers networked to the computers, 10 custom-built torque transducers to measure the instantaneous shaft torque in the machines, 120 custom-built current transducers, 120 custom-built voltage isolation amplifiers, 10 benches and switchboards, 10 static starting circuits and interfaces for the slip-ring induction motors, and wiring required for the power supplies and the signal conditioning circuits.

The layout of the workstations

As stated earlier, the main purpose of this experimental setup is to use the existing experimental systems to avoid the excessive cost. Therefore, the rotating machine setups and the switchboards were fully utilized and the system was designed around this existing structure. Each machine set in the laboratory consists of one DC machine (generator or motor), one slip-ring (wound-rotor) induction motor and one salient pole synchronous machine (generator or motor). These machines are mechanically coupled so that they have a common shaft which allows the

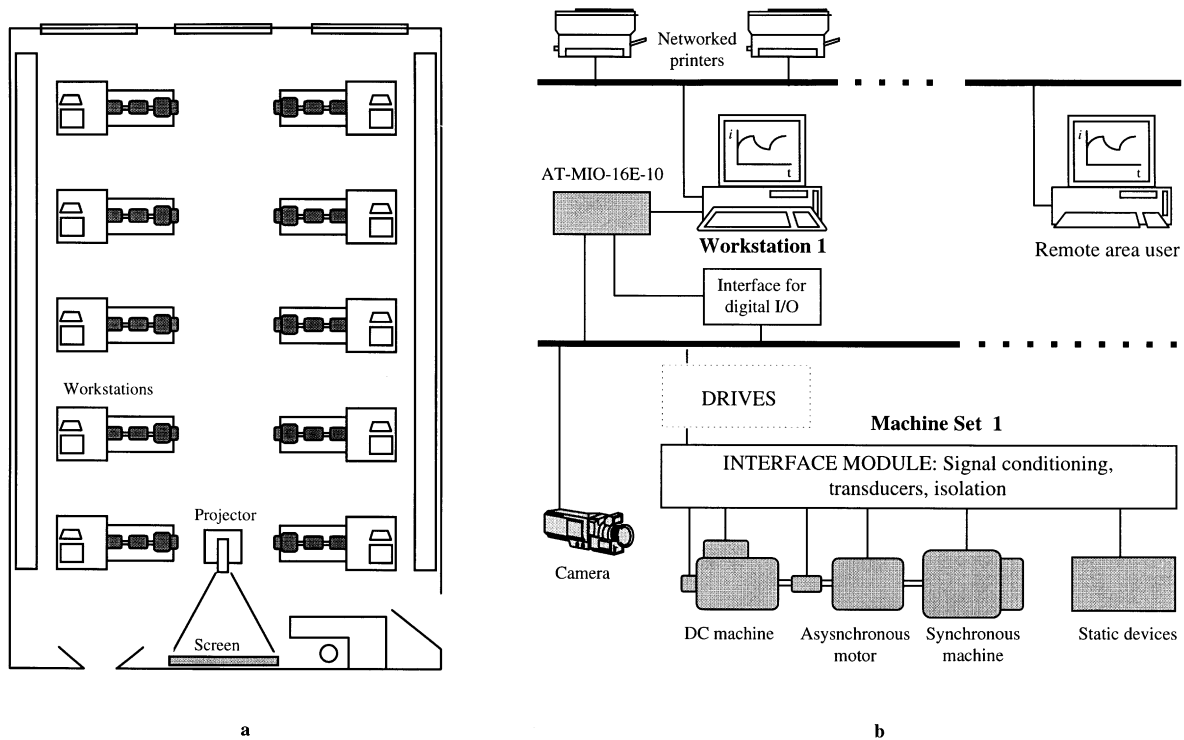a   b

Fig. 2. The layout of the Electrical Machines and Drives Laboratory, and the system diagram of networked workstations.

Table 1. The ratings of the electrical machines available in each workstation

Machines	Specifications
3 phase Slip-Ring Induction Machine	415 V, 5.5 kW, Y-connected, 50 Hz 11 A, 1410 rpm, $\cos \phi$: 0.85 Rotor: 170V, Y, 22 A
3 Phase Salient-Pole Synchronous Machine	415 V, 8 kW, 50 Hz 10.5 A, 1500 rpm
DC machine with series and shunt winding	220 V, 5.5 kW, 27.6 A 1250 /1500 rpm Field: 210 V, 0.647 A

measurement of shaft speed via an AC tacho-generator and the instantaneous shaft torque via a custom-built torque transducer. This coupled machine configuration allows the operator to use any machine either as a motor or as a generator. The ratings of these machines were provided in the Table 1.

The rotating machines are pre-wired to the terminals on the switchboard via custom-built voltage and current transducers. The static devices for the test (such as power electronic converters, single-phase transformers and other electro-mechanical devices) are supplied on the bench associated with the main switchboard of each machine set, where the connections to the voltage and the current transducers can be made. A schematic view of the workbench showing the machines, the workbench and the PC are given in Fig. 3.

In the new computer-based method, the existing instruments on the switchboard panel are used as indicators only for additional checking and/or confirmation of the calculations which are performed in the custom-written software.

The interface circuits design

As it was discussed earlier, the significant aspect of the computer-linked experimental setup is the interfaces which should be designed to operate the system safely and accurately. The accompanying hardware design is highly flexible, and can also deliver suitable output signals for control purpose.

The unique future of the system is that multi-phase high voltages and large line currents at reasonable high frequencies should be observed to perform the experiments. In addition to this, the low-voltage computer-side must be totally isolated from the power-side and should have one common ground. However, it was found out that insulation via differential input channels of the data acquisition card in such laboratory environment, where multiphases high voltages/ currents are measured, is not suitable for safety reasons. Although the conventional isolation transformers can be used to isolate the high-voltage sides from the user and PC, it was not preferred in this application due to the impos-sibility of measuring high-bandwidth voltages, such as in the inverter controlled electrical machine experiment. Therefore, to achieve total isolation, twelve high-performance isolation amplifiers (1000 V rms, 50 kHz) for voltage measurement and twelve high-performance Hall-effect current transducers (50 A and 100 A, DC to 100 kHz) for current measurement were employed (Fig. 4). In total, 24 current/voltage transducers are used in each workstation.

In the voltage isolation section, the voltage dividers are used to attenuate the high voltages, maximum 340 V. The attenuated voltages are isolated by using isolation amplifiers, type ISO122P. Each isolation amplifier is also powered from a separate DC/DC converter (Fig. 4a).

These transducers are housed inside a box, and located behind the main switchboard inaccessible to the students. Each group of three transducers (current or voltage) in the interface unit is equipped with its own floating power supply for additional safety and to achieve the common ground on the PC end of the system. The voltage transducers' boards are also physically guarded against the potential danger which may occur due to an arc.

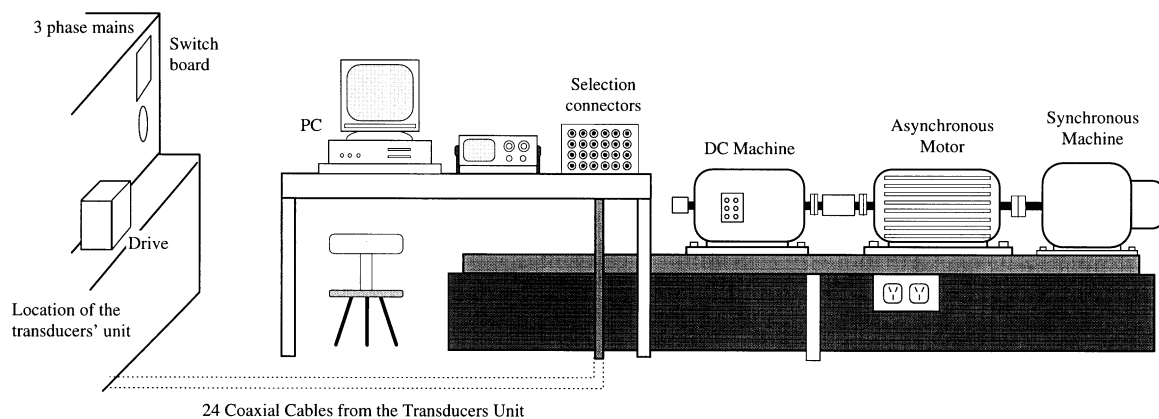In order to create a buffering circuit and to take
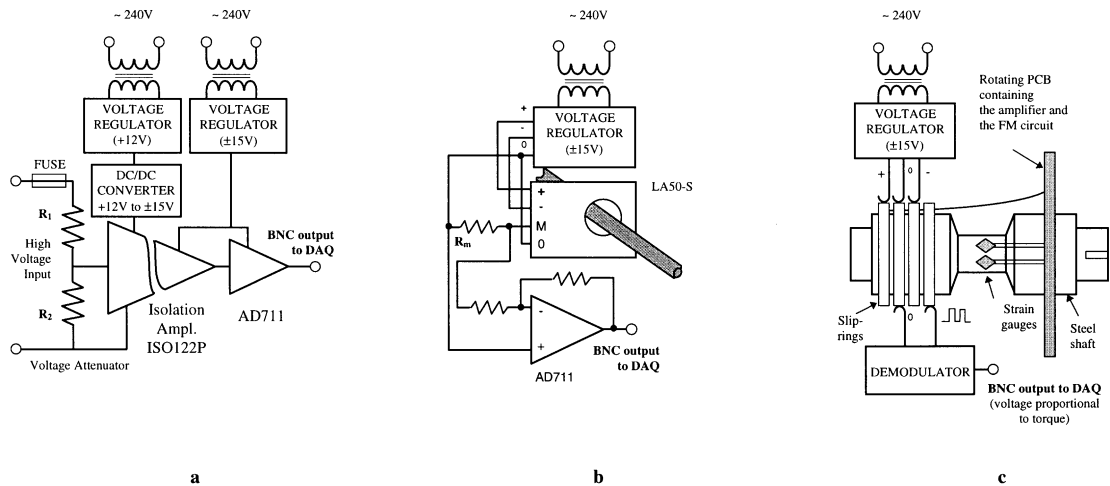

Fig. 3. A view of the workstation.

Fig. 4. The block diagrams of the custom-built transducers: (a) voltage transducer; (b) current transducer; (c) torque transducer.

full advantage of the resolution of the A/D conversion, additional amplifiers, AD711, are used to amplify the signals obtained via the Hall-effect current transducers (Fig. 4b) and the isolation amplifiers.

The instantaneous torque is observed by reading the output of the torque transducer in real-time (Fig. 4c). To achieve the torque measurement, the strain gauge torque transducer is designed specifically for the machine set, which is capable of measuring high starting torque as well as the torque in steady-state operation. Therefore, a variable gain control was included in the design, which is software configurable. The shaft speed of the rotating electrical machine is obtained from a tachogenerator. The tachogenerator output was also isolated and a signal conditioning circuit was built to convert the frequency and the amplitude modulated output signal of the tachogenerator into a DC level that is proportional to the shaft speed. This was done to reduce the processing time of the speed calculation in the software.

Data acquisition and the software

Every experiment in the laboratory requires some signals to be measured on specific channels. The selection of the channels are based on the requirements of the particular test. In the system designed, a maximum of eight parameters can be measured in real-time. This number was determined by the maximum number of parameters to be measured to perform the most complex experiment in the laboratory. For instance, to perform an induction machine test, three phase voltages, three line currents, the speed and the torque should be measured.

AT-MIO-16E-10 data acquisition cards from National Instruments were used in this project that have specifications suitable for both data acquisition and data output in control applications. Each of the data acquisition card has 8 channels, 12-bit resolution, 100 kHz sampling

rate (not simultaneous), two analog outputs (for 12-bit D/A conversion) and 8 Digital I/O. The data is captured by this card, scaled and translated into a suitable form by LabView software, and then it is manipulated to perform a specific experiment with the aid of the custom-written software.

The object-oriented programming tool, LabView has been chosen in this work due to its 'next generation' look and its highly mature technology. It is a virtual instrument environment, complete with software drivers that operate a wide variety of embedded and connected boards and GPIB instruments, and allows possible extensions in the future. This object-oriented program permits the user to design and develop very complex experiments and virtual devices that can mirror real objects or systems. The graphical interface of LabView can also allow the designer to create data acquisition control, analysis and graphing programs by connecting acquisition routines, buttons, displays, built-in functions and libraries in flow diagrams.

Although the system described here has 10 LabView full development systems installed on PCs, there is no need to purchase multiple copies of LabView software to develop a multi-user system. The custom-written software can be duplicated by another National Instrument Product, 'Application Builder' that is an add-on software package for LabView. Application Builder can convert custom-written software into a standalone application, and hence the application can be distributed freely.

In addition to this, another software package, HiQ (National Instruments), is installed on each PC. HiQ software is also an interactive analysis environment where linear algebra, data-fitting interpolation, optimization, statistics, differential equation solving, nonlinear analysis, integration, differentiation, can be performed to produce a technical report that can be embedded into a Word document.

Table 2. Typical formal laboratory experiments and topics covered in the laboratory

Title	Remarks
Preliminary practical session	Prepares the students for the laboratory, discusses safety issues, and measurement procedures in general.
An electromagnetic device: solenoid	Demonstrates the principle operation of an electromechanical device, and measurements of hysteresis loss, flux linkage and force.
Characteristics and losses of rotating electrical machines	Examines the losses and measures the moment of inertia of the rotating electrical machine.
Three-phase induction motor tests	Determines the parameters of the exact equivalent circuit, analyses the speed control principles. The starting of a slip-ring induction motor is also examined here.
Synchronous machine tests	Determines the parameters of the exact equivalent circuit, and examines the speed control principles.
Single-phase transformer tests	Determines the parameters of the exact equivalent circuit, and examines the initial switching.
DC choppers in speed control of DC motors	Covers the principles of the speed control using a single transistor step-down DC converter.
Phase control by thyristor and triac	Covers the principles of the phase control at different loading conditions (such as with resistive, inductive and AC motor loads).
Real-time temperature measurement and analysis	Covers the heatsink design in high-power switching devices; demonstrates the temperature variation visually (with and without forced cooling) and analyses the impact of temperature variations on electrical circuit parameters.
Synchronization	Demonstrates the principles of synchronization, the measurements of frequency, rms, and phase sequence on three-phase power lines.
Principles of phasors and rotating fields in AC machines	Demonstrates the likeness between the three-phase real-time signals and phasors at different loading conditions, and the concept of rotating fields.

CONTENT OF THE EXPERIMENTAL METHOD

The formal and the future experiments

Five experiments have already been implemented by using this method: three-phase induction motor, characteristics and losses of machines; relays and solenoids; transformers and synchronous machines. The material covered in the laboratory is given in Table 2. The table also includes the experiments under development.

The developments on the overall system will proceed to utilize the system more efficiently and effectively. Some of the possible extensions of the system are also summarized in the table. Other potential developments of the experiments include: inclusion of synchronization principles of synchronous generator, dynamic simulation and demonstration of the rotating reference frame in the induction motor experiment, temperature measurement and analysis in real-time, controlling the start-up and stopping procedures of the electrical machines, varying the power sources (AC and DC) via LabView, and implementation of visual and audio communication through the Internet for distance experimenting.

In the new method, the experiment will be delivered fully via a computer/software/interface system. The experiment is divided into three stages as shown in Fig. 5.

The self-studying tutorial

The previous system in the laboratory depended heavily on detailed written instructions and an associated tutorial session that is delivered by a lecturer.

In the developed system, however, the information about the experiments (handouts) are provided on the computers either as a LabView file or a MS Power Point file, which the students can access before the experiment. The information presented in these files can easily be modified when it is required with minimal cost and time.

The theory of an experiment, procedures to follow, technical details and relevant circuit diagrams, specifications of devices and machines, channel assignment to carry out the experiment—all are available to students as software on the network or in a diskette for self-studying. The students are required to study the details and the procedures of the experiment on these tutorial files before they attend to the laboratory session. The information provided in these files include the photos of the devices under test and the main switch board, and the name-plate data together with the related theory. Two sample windows given in Fig. 6, demonstrate the possible format of the self-studying tutorial file.
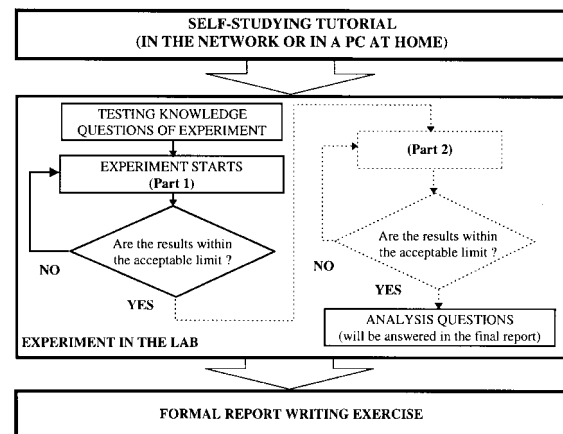

Fig. 5. The block diagram showing the order of the delivery of an experiment.

PART 5 No Load Iron Losses vs. Speed

From the set of graphs of power losses versus speed for different values of If, we can now plot the no load iron losses versus speed for those values of If. To achieve this, we subtract the curves for those values of If by the curve for If = 0.

i.e.

$$Ploss_{(\text{If not equal to zero})\text{friction + windage \& no load iron}} - Ploss_{(\text{If=0})\text{friction + windage}}$$

In this section of the experiment, we will calculate the no load iron losses based on the function determined in the previous section.

Therefore, select the type of function and enter the coefficients into the relevant areas. where:

LINEAR   : $Ploss = a_0 + a_1 n$

POLYNOMIAL : $Ploss = a_0 + a_1 n + a_2 (n)^2 + a_3(n)^3$
$\qquad\qquad\qquad a_4 (n)^4 + a_5 (n)^5$

EXPONENTIAL : $Ploss = a_0 + a_1 \exp (a_2 * n)$

Type of Fit
✓ Linear
Polynomial
Exponential

Coefficients for Ploss (If not equal to zero)

$a_0 =$ 45.599E+0
$a_1 =$ 20.139E-3
$a_2 =$ 134.343E-6
$a_3 =$ 0.000E+0
$a_4 =$ 0.000E+0
$a_5 =$ 0.000E+0

Coefficients for Ploss (If = 0)

$a_0 =$ 43.036E+0
$a_1 =$ 548.658E-6
$a_2 =$ 136.881E-6
$a_3 =$ 0.000E+0
$a_4 =$ 0.000E+0
$a_5 =$ 0.000E+0

CONTINUE   DONE

Torque / Speed Test - Procedures

The aim of this test is to obtain data and calculate the Torque versus Speed characteristic of the d.c. machine and then comparing it with the measured torque. In this test, you are required to find the torque for two different values of load. Whereby the synchronuos generator is used as a load.

Having connected the circuit below, start the d.c. machine with the resistor bank set to its maximum value and adjusting the field current (If) to one of the values used in the steady speed test.

The load can be varied by adjusting the exciter field current of the synchronous generator. In this test, you will choose these currents to be 13A and 6A. As in part two of this experiment, capture the speed (N), the armature voltage (Va) and the armature current (Ia). Having obtained these data, calculate the input power (Pin = Va*Ia) and the armature resistance loss (= Ia^2*Ra). While the friction + windage losses and iron losses can be read from the graphs obtained in Part 5. Therefore the torque can be calculated from

$T = (60*Pout) / (2*pi*N)$ where Pout = Pin - Ia^2*Ra - Ploss(friction+windage and iron)

DONE

Fig. 6. Two sample front panels in self-studying tutorials section.

The experiment

The experimental section of the method is divided into two main sections: the Testing Knowledge and the Practical Experiment sections. A very short form of the self-studying tutorial described above is also made available in the computer (in the laboratory) for a reference only.

Each experiment starts with asking a certain number of the Testing Knowledge (must-know) questions. The questions are linked by a menu called Tutorial Questions. These questions are selected randomly from a group of questions (from a question bank) by the personal computer allocated to each workstation. The questions are designed around the material supplied in the self-studying tutorial files, and are in the form of multiple-choice (Fig. 7) covering the safety issues, measurement procedures, instrumentation, meanings of the name-plate data of the machine under test, the number of parameters to perform the relevant experiment, and even the basic circuit diagrams. The students must answer all the questions correctly to carry on the experiment. In the case of wrong answer(s), students are allowed to repeat the Tutorial Questions section two more times. Students can be assessed in this section to award their preparation effort.

As stated above, the practical tests in the laboratory start following successful completion of the initial phase, Tutorial Questions. In the main part of the practical experiment, the first window in the experiment, following the University's logo, asks the students to enter their name. The data entered into this window are displayed at the bottom of each front panel together with the time and the date of the experiment. This data is printed out

together with the relevant graphs or files and is used as a proof of performing the test.

The first front panel of each experiment has a very similar layout. The front panel indicates the title and the subsections of the experiment. Any subsection can be selected from this window. The first front panel is shown in Fig. 8a for the Characteristics and Losses of Rotating Electrical Machines Losses experiment. There are six major sections in this experiment (Fig. 8b), and a save button that can be used to store the data in a diskette for further analysis and formal report production. Each of these sections contains a few subsections highlighting the experimental procedures and the practical test itself.

The custom-written software includes circuit diagrams, virtual control boxes, buttons, graphs, and even custom-designed control icons. A very user-friendly and similar structure was followed in every experiment to select the subsections, simply by double clicking the display sections. In Fig. 9a, a sample front panel is given, which contains a variety of control boxes. Each control box in this figure either has direct connection to the data acquisition routine or has a manual control to be entered by the student. Fig. 9b shows the basic block diagram of this section.

After the successful completion of the experiment, each group of students gets a certain number of questions: Analysis Questions. Similarly, these questions are also selected randomly by the computer in each workstation. However, the questions are printed out in the laboratory and their answers are included in the final report to analyze the results obtained during the experiment.

TUTORIAL QUESTIONS

QUESTION 10 of 10

Using the recommended ranges on the nameplate, What is the maximum available Torque in the DC machine ?

OPTIONS

(A) 38.2 N.m.
(B) 45.8 N.m.
(C) 5.5 N.m.
(D) 66 N.m.

Select   Help

Fig. 7. A window sample of multiple-choice must-know questions.

**Characteristics and Losses of
D.C. Machines Experiment**

Please enter the information requested below:

Operator's Name

Nesimi Ertugrul

Start   Exit

Tuesday, October 28, 1997   4:37:51 PM

THE UNIVERSITY OF ADELAIDE
Department of Electrical and Electronic Engineering

Characteristics & Losses of DC Machines

PART 1 Armature Resistance Test
PART 2 Steady Speed Test
PART 3 Retardation Test
PART 4 Power Losses Against Speed Graphs
PART 5 No Load Iron Losses versus Speed
PART 6 Torque / Speed Characteristic

Select   Done   Save all
data to Disk

Nesimi Ertugrul   Tuesday, October 28,   4:42:43 PM

THE UNIVERSITY OF ADELAIDE
Department of Electrical and Electronic Engineering
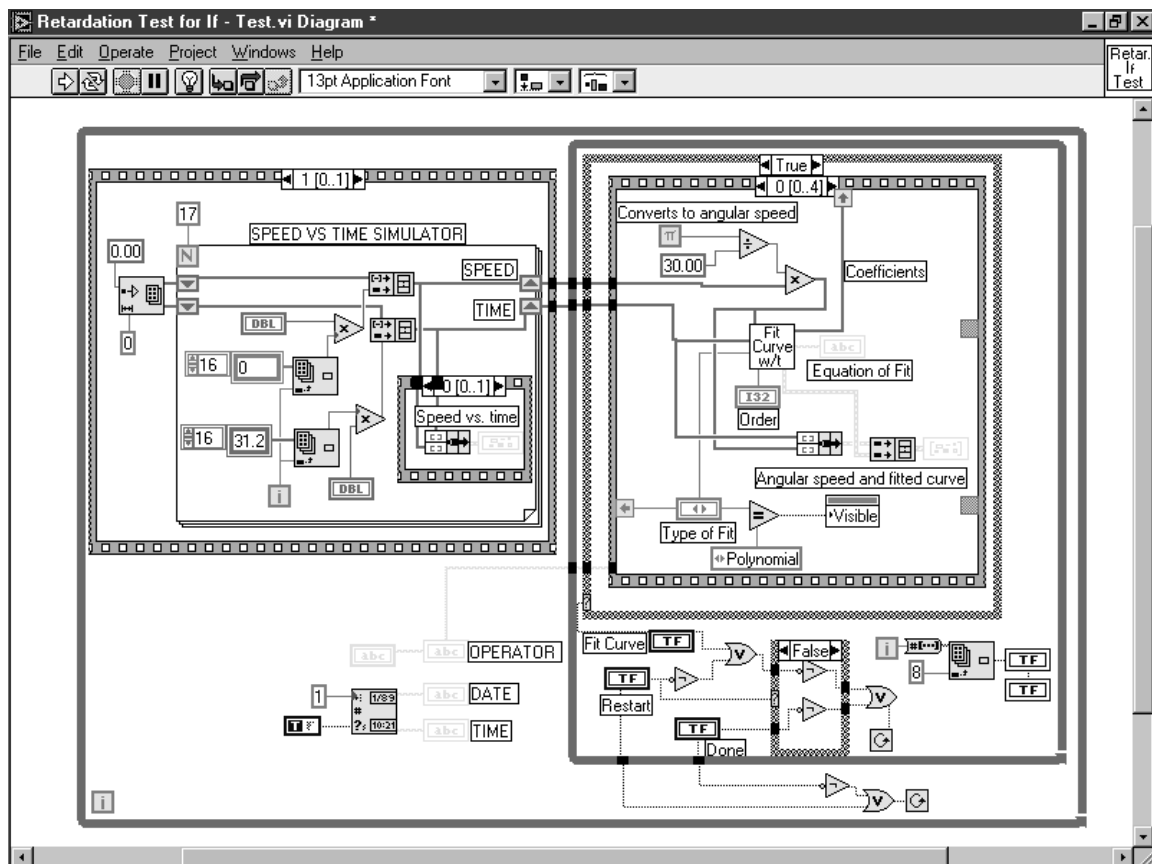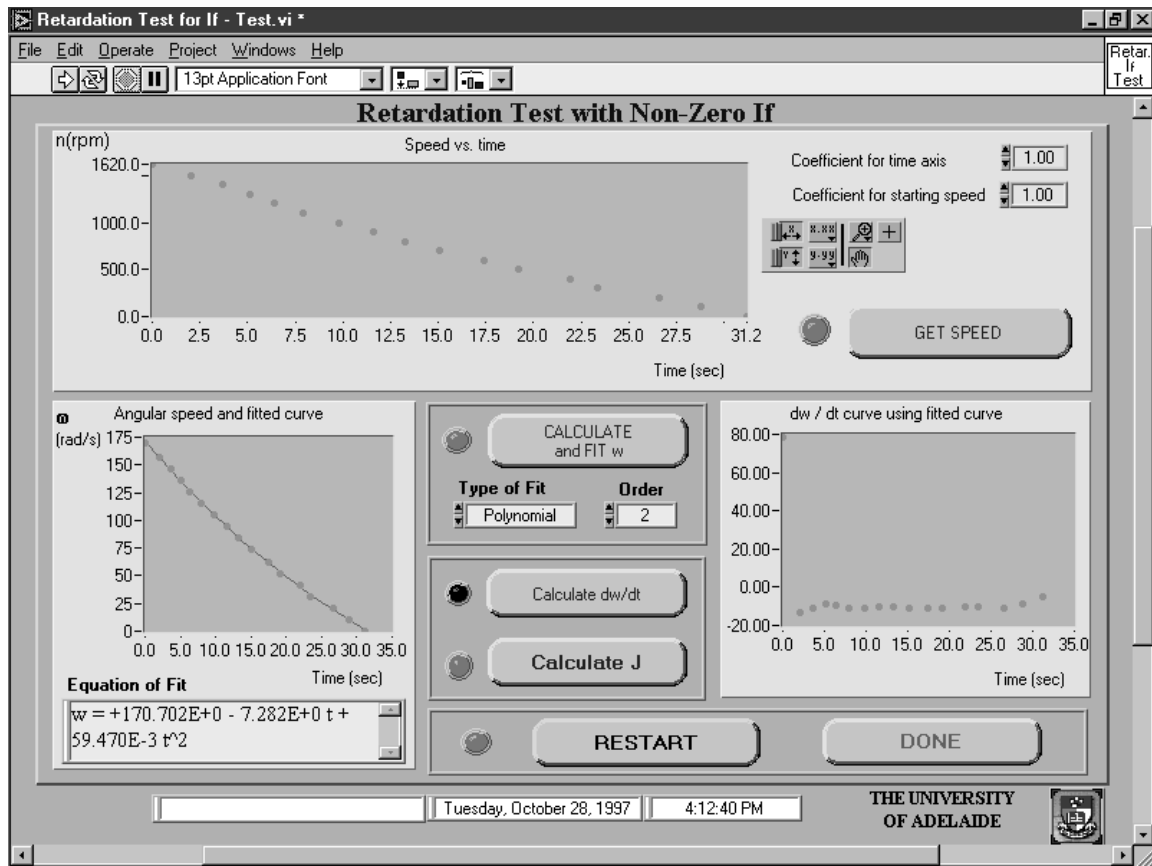
Fig. 8. Two sample front panels.

Fig. 9. A sample of a front panel (a) and a block diagram (b) of an implemented experiment.

Assessment and report writing

In the laboratory work, it is important to record the complete details of the experiment for correct interpretation. The inclusion of the details on the printouts allow students to perform further analysis. However, as stated earlier, the data collected during the experiment can also be saved into a diskette to be processed later. The assessment of each laboratory session will be done based on the final report produced. To allow sufficient time for students to refine and assimilate the knowledge gained, students are required to submit a report on the following day. The written report should include the printed results of the tests, the answers of the Analysis Questions as well as the discussion and the conclusions.

THE BENEFITS OF THE DEVELOPED SYSTEM AND SUGGESTIONS FOR FUTURE DEVELOPMENTS

The principal benefits of the method are summarized below.

- To allow students to experience the multi-disciplinary and interconnected nature of an engineering discipline.
- To indicate the bridge between the theory, the simulation and the real-world in a well rounded way and in a practical environment.
- To use the experimenting time more effectively.
- To provide updated information to the students, in the fields which are developing very rapidly.
- To update and modify the system in the future with a minimal cost due to the common structure used.
- To provide a fully functional educational tool for similar implementations in other engineering disciplines.
- To make a system available to be used for distance education and training purposes.

Due to the completely visual approach to the teaching, the method has a clear advantage dealing with the people who are from non-English speaking backgrounds or whose learning is best achieved in a contextual setting. It is believed that this method also provides a common practical experience to cater for students who are coming from increasingly diverse backgrounds.

The software, LabView, and the developed system are also suited to distance-testing of large machines via Internet, potentially for remote area users and possibly for overseas students.

CONCLUSIONS

The interactive computer-controlled test system designed, implemented, and reported in this paper demonstrates that the accompanying hardware is highly flexible, and the potential applications of the system are unlimited. It was also found that programming with LabView drastically reduced the time spent in writing and modifying the software. At the same time, the efficiency of teaching and the understanding of some basic concepts of electromechanical systems in general, and power electronic converters are improved compared to the existing practice.

The key benefits of this computer-based instructions/learning/analysis system are: elimination of pre-practical tutorials, less time in each session (means more sessions to handle the large number of students and/or advanced study), saved resources (student time and demonstrator time), and accurate measurement for detailed and dynamic analysis (such as starting, acceleration and braking) which was not available before. Furthermore, the system is suitable for signal processing as well as power and harmonic analysis.

Considerable amount of support has been received from the University of Adelaide and National Instruments. It has been scheduled that the laboratory will be fully functional in 1999 serving approximately 400 students each semester.

It has also been planned that some open-ended projects using LabView programming will be included in the laboratory program to allow the students to develop projects involving data acquisition and simulation aspects of other Electrical Engineering subjects. The future plan also includes the implementation of visual and audio communication through Internet for distance experimenting in this laboratory.

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