A Distance Learning Power Electronics Laboratory

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Abstract

This paper describes the proposed power electronics laboratory offered in conjunction with power electronics course, ENGR 455, to senior or high junior Electrical Engineering students in the School of Engineering, San Francisco State University. The focus of this laboratory is to enhance students' understanding of power electronics circuits by conducting a series of laboratory exercises, design exercises, and computer simulation exercises using PSPICE or SABER©. In order to finish all assigned lab projects, students must be able to use various measuring equipment such as Curve Tracer, Spectrum Analyzer, Digital Storage Oscilloscope, Voltage and Current Transducers, etc. Familiarity with PSPICE, SABER©, LABVIEW and MATLAB are also required in order for students to carry out all assignments. One laboratory exercise, *DC Motor Speed and Torque Control using Single Phase Controlled Rectifier Circuit*, is designed for distance learning such that students can conduct this experiment through Internet using a browser like Netscape Communicator. The necessary hardware and software for this distance learning laboratory is discussed.

Introduction

A four-unit power electronics course, ENGR 455 is one of the four power courses offered in the School of Engineering, San Francisco State University. Three units are for the lecture and one unit is for the laboratory. The objective of the lab session is to help students understand the theory of power electronics circuits. A NSF-ILI grant provides the major instrumentation upgrade for this power electronics laboratory. It also enable us to integrate the design, simulation, and prototype building of power electronics circuits together for students so they can maximize their learning on this important enabling technology: Power Electronics.

With the explosion of Internet Access and the need to have more students to access the university facilities, distance learning becomes very effective teaching tool for some engineering subjects. One of the difficulties of conducting distance learning of engineering courses is how students can conduct experiments remotely in an effective way. With new Internet Development Software and LabView program from National Instrument, the distance learning laboratory becomes a reality. We will discuss the requirements on both hardware and software for distance learning laboratory course. We will also use one project, *DC Motor Speed and Torque Control using Single Phase Controlled Rectifier Circuit*, to demonstrate that students can conduct the experiment through Internet using commonly available browser like Netscape Communicator. Not only they can control the speed and output torque of the DC motor, they can also observe relevant waveforms such as armature voltage an current, speed and torque of dynamometer online over the internet. Actual numerical data can also be downloaded to local computer so students can incorporate those in laboratory report they have to turn in later.

Philosophy of Our Approach:

Practical aspects and hands on experience are the two most important elements in the power electronics laboratory we try to implement. We believe that in order to enhance students' learning on power electronics subjects, the best way is to let them apply the knowledge they learn in lectures in actual design and see to it that their designs actual work. Our teaching philosophy is to teach students to design power electronics circuit based on circuit theories first. Then they simulate and improve their designs using commercial simulation software like PSPICE or SABER. After that, they build prototype(s) in the laboratory, and finally they test their design and prove that all design criteria are met. The design of our power electronics laboratory follows the proposed philosophy closely.

Characteristics Curve of Switching Devices

Since all power electronics circuits or systems consist of various semiconductor switching devices, we ask students to use a Curve Tracer, Tektronix 370 specifically, to study switching characteristics for Bipolar Junction Transistor (BJT), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor, Silicon Controlled Rectifier (SCR), etc. A typical characteristic curve for MOSFET IRF150 is shown in Figure 1. Most controllable switches (BJT, MOSFET, IGBT, etc.) used in power electronics circuits are either fully ON or completely OFF, i.e., they are used as switches. Turn on and turn off characteristics such as voltage drop across switches when they are fully ON, minimum voltage to turn on MOSFET, minimum gate current to trigger SCR, etc. are important parameters for students to identify. Students are asked to study characteristics of all semiconductor components they will use later in the semester to build actual power electronics circuits such as SCR, BJT, MOSFET, and IGBT.

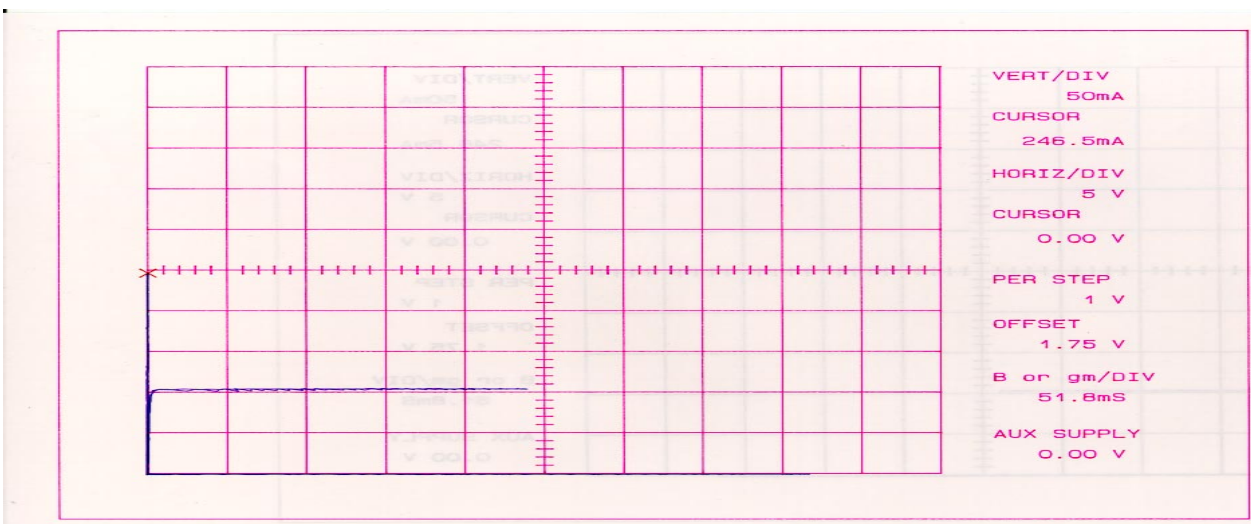

Figure 1: Typical Switching Characteristic Curves of MOSFET IRF150

Basic Switching Characteristics of Switching Devices

After characteristics of individual switching devices are obtained with the help of Tektronix 370 Curve Tracer in the laboratory, attention is turn to getting the basic switching characteristics of various switching devices (BJT, MOSFET, IGBT, etc.). The objective of this exercise is to obtain voltage across the switching device, current through the switching device, during the switching from

ON to OFF and vice versa so actual switching losses of the switching device can be estimated as practically as possible.

In order to have meaningful estimation of switching losses and switching speed of switching devices used in actual application circuits, it is essential that switching testing circuit shall emulate as close to actual circuit as possible. Important factors to consider are actual voltage across the switching device, current through the switching device, and driver circuit for the switching device. For example, if it is desired to examine behaviors of MOSFET in a basic DC to DC Step Down converter (28 VDC to 5 VDC) with input current of 3 ADC, the switching circuit shall allow 23 VDC (28 – 5 = 23) to be developed across the MOSFET when it is OFF and there shall have 3 A of current flows through the MOSFET when it is ON. Furthermore the switching frequency of the testing circuit shall be the same with that of actual power electronics circuit that the switching testing circuit is emulating. Since driver circuit for switching device has paramount effect on how fast the switching devices can be switched, the actual driver circuit shall also be incorporated into the switching testing circuit to yield as practical results as possible! Figure 2 shows a typical switching circuit for MOSFET IRF150 to be used in DC to DC Converter (28 VDC to 5 VDC with input current of 3 ADC). Switching frequency used is 50 kHz although it can be much higher if desired. The values of resistor *R* and inductor *L* are chosen to yield a current of 3 ADC when MOSFET is fully turn ON.

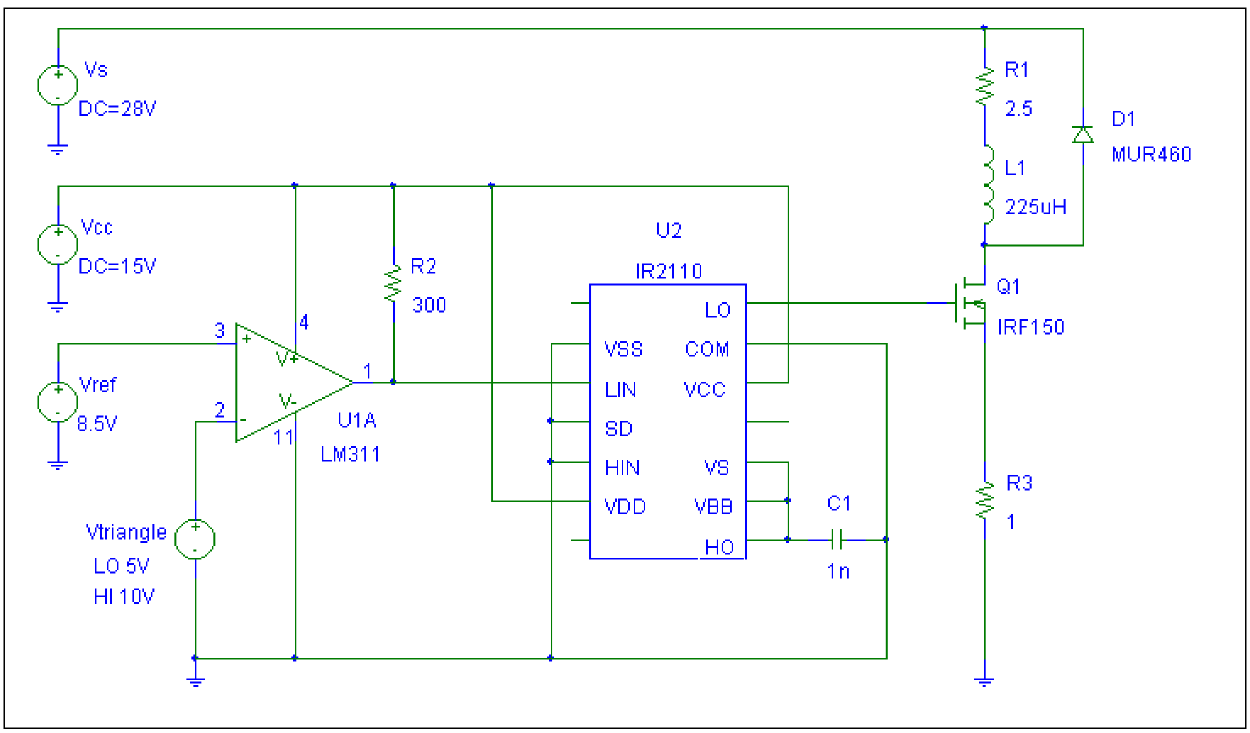

Figure 2: A Typical Switching Testing Circuit using MOSFET as the Switching Device

Introduction of Simulation Software

At this time, it is beneficial to introduce available simulation software such as PSPICE or SABER to students so they can get proficient with simulation software as early as possible. Obviously the objective of pushing students to use simulation software early is for them to concentrate on actual design issues later in the semester when they are assigned to design a complete power electronics system like DC to AC inverter. Learning curve for PSPICE is much shorter than that of SABER but SABER can do system simulation that PSPICE can not do easily. Figure 3 shows the simulation results (voltage across the MOSFET IRF150 and current through it) for the switching testing circuit under the same condition as depicted in Figure 2. Manipulation of the simulated results can be easily done to yield switching losses as shown in Figure 3. Actual driver circuit, IR2110 from International Rectifier, for the MOSFET is included in the simulation.

Prototyping the Switching Testing Circuit in Laboratory

The best way to verify simulation results is to build prototype in the laboratory and test it experimentally. To build a prototype in the laboratory is quite straightforward. Wire wrapping technique is commonly used. To avoid high frequency noises, it is much better to have some sort of printed circuit board (PCB) manufacturing machinery in the laboratory. The machine that uses milling instead of etching technique is a preferred one for waste handling consideration. In our lab, we have a plotter, Model 170 from LPKF, to help students make prototype PCB. Once prototype is built, actual waveform can be obtained through digital oscilloscope, TKS 754C from Tektronix. Actual voltage and current waveforms for the typical switching testing circuit as shown in Figure 2 are shown in Figure 4. Figure 5 shows the switching loss waveforms by multiplying acquired voltage and current waveforms together using the built in math function of TKS 754C Oscilloscope. Data collected in actual circuit can be used to optimize the model used in simulation if necessary.

The example of simple switching testing circuit illustrates our teaching philosophy completely. The actual design process evolves from the conceptual design stage to applying the simulation technique to optimize the preliminary design, from simulation results to building prototype circuit in the laboratory, and finally conducting testing with needed instrumentation to verify the design specification(s). We believe this approach mirror what industry is doing in their approaches of creating new power electronics circuits or system per design specifications. With this kind of training, students shall be well prepared to become an capable design engineer in short period of time in any power electronics company.

Typical Design Project

A half semester long project is assigned to groups of students. Each group can have up to three persons. A typical project is to design a variable frequency drive (VFD) for a 5 HP squirrel cage induction motor driving Air Handling Unit (AHU) in an Heating, Ventilation, and Air Conditioning (HVAC) system. Design specifications are as follow:

Input System Voltage:	230 V line to line, 3 phase AC
Input System frequency:	60 Hz
Motor	5 HP induction motor at 60 Hz and 230 V
	4-pole, Y-connected, rated slip s = 4%
DC link voltage ripple ΔV:	5% of average DC link voltage
DC link current ripple ΔI:	5% of average DC link current
Heatsink temperature rise	50 degrees Celsius above ambient

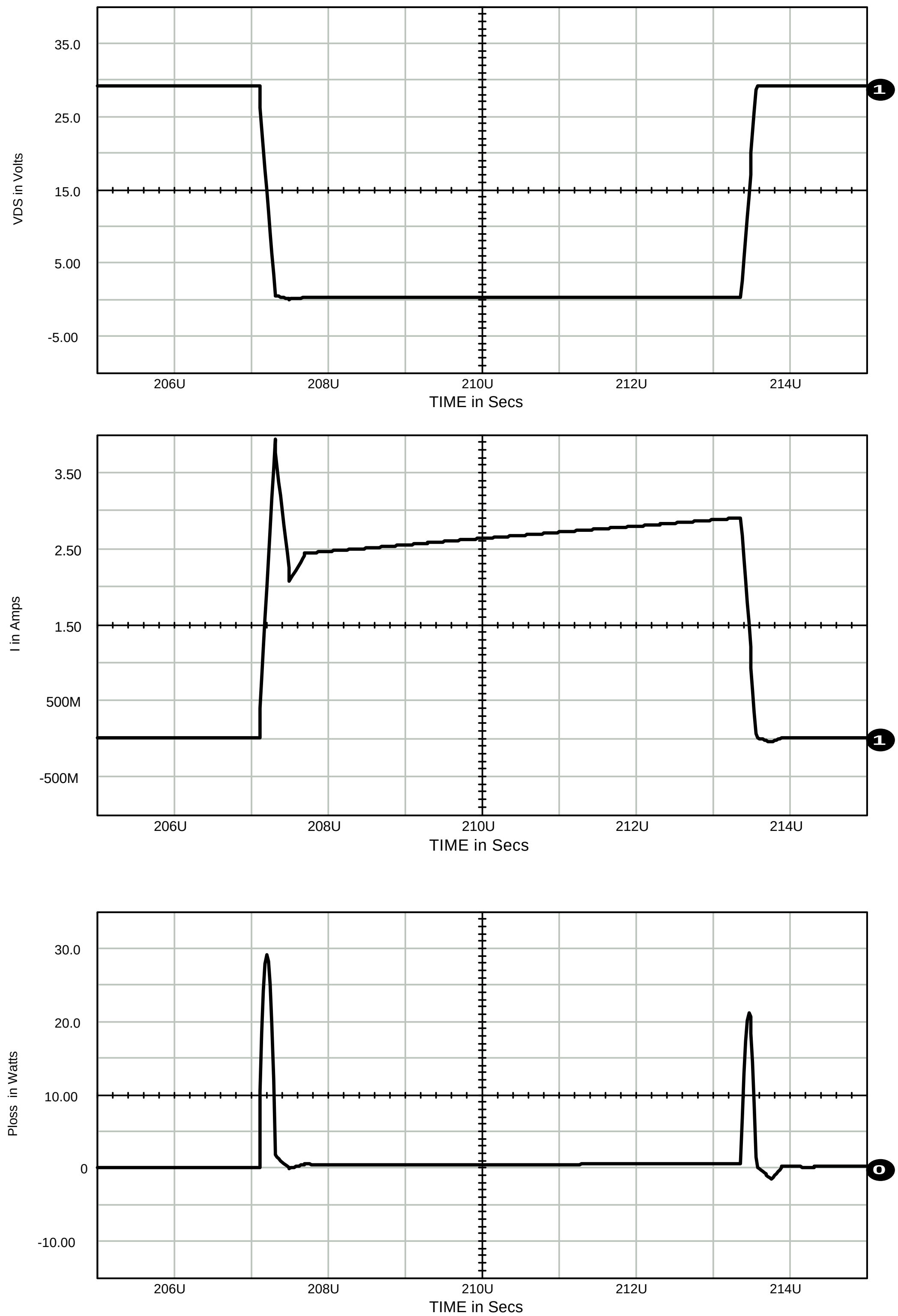

Figure 3: Simulation Results of Typical Switching Testing Circuit for MOSFET

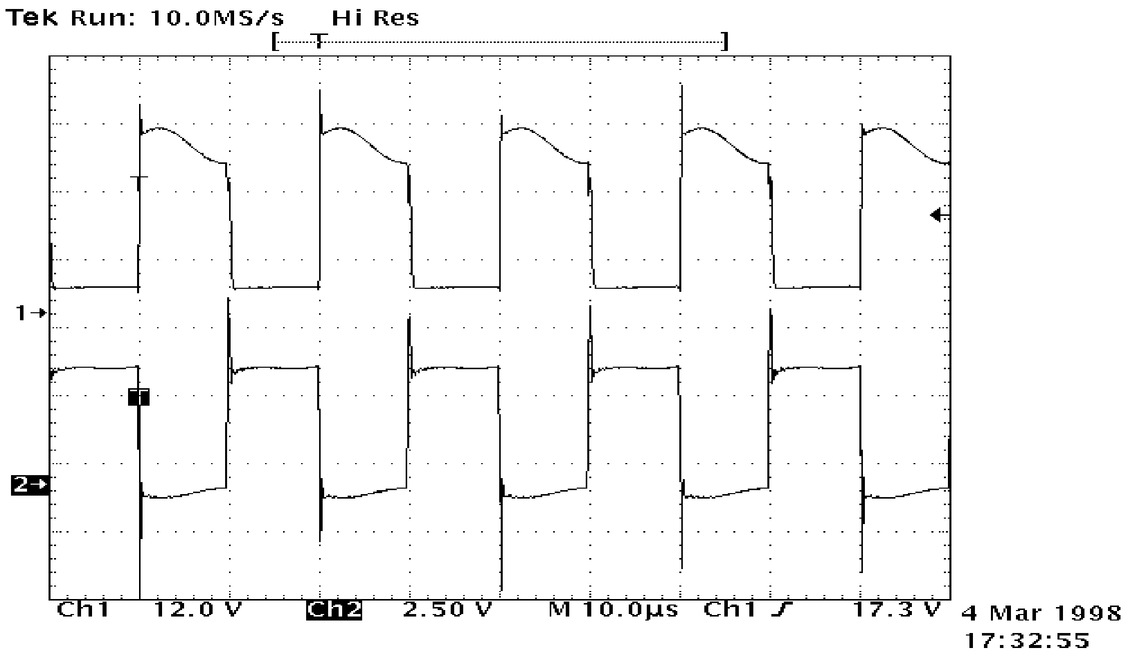

Figure 4: Experimental Voltage and Current Waveforms of MOSFET for Switching Circuit

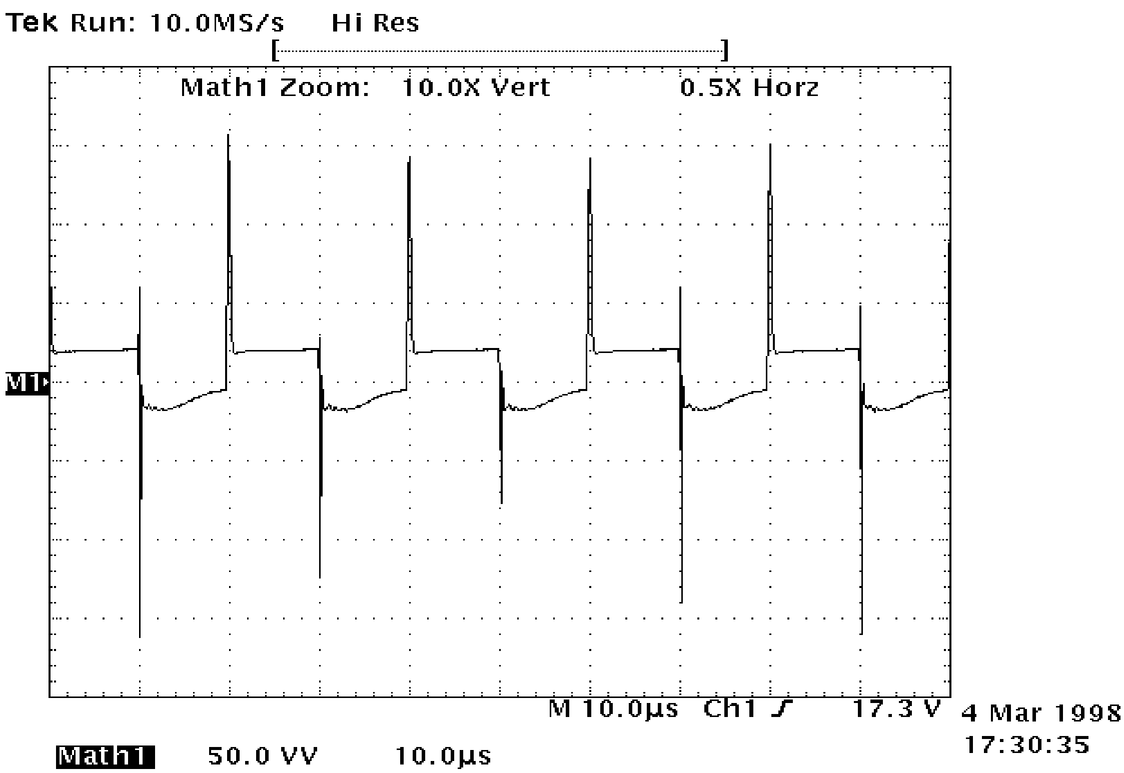

Figure 5: Actual Switching Losses Waveforms of MOSFET for Switching Circuit

In lecture, two papers[1,2] have been given to students and we discussed those two papers thoroughly so students can understand the approaches used by authors of those two technical papers. Students must follow the procedures identified in those two papers to find out the peak current, root mean square (rms) current, and averaged current through the switching devices (IGBTs) and diodes in the inverter module. They also have to identify how big a capacitor value they shall use in the DC link per voltage ripple specification. For the selection of inductor in the DC link section, current ripple specification must be used. Switching losses calculation for all six switches (combination of IGBT and anti-parallel diode) can be carried out and appropriate heatsink can be chosen for this inverter.

All detailed analysis procedures can be found from those two technical papers. Students probably find out that MATLAB might be the best software for the analysis part. Simulation is an integral part of this design process. Students are required to use PSPICE to do simulation of the whole circuit excluding the control part, due to the complexity involved. Because of the time it takes to make the prototype, a commercially available variable frequency drive from IDM, Inc. is used in the laboratory to demonstrate how VFD works.

To have the VFD drive an induction motor and dynamometer gives students a multimedia sense of industrial process since there is noise from the VFD, motor, and dynamometer; and various voltage and current waveforms to look at from oscilloscope. Students always enjoy this particular laboratory assignment.

There are other projects students must experiment with. These projects are uncontrolled AC to DC rectifier, controlled AC to DC rectifier, DC to DC converter, switching mode power supply, six step voltage source VFD, etc. These standard projects do not involve design, analysis, simulation, and prototype building at this moment. We are in a process to apply the same philosophy (design, simulation, build, and test) to these modules to maximize students' learning in power electronics.

Distance Learning (Remote) Laboratory of DC Motor Speed and Torque Control with Single Phase Controlled Rectifier

We also design a laboratory project that allows students to conduct experiment through the Internet using standard browser like Netscape's Communicator. With the explosion of Internet access, we believe it is a good idea to explore the possibility of conducting experiment through the Internet and what kind of hardware and software are needed in order to implement this distance learning laboratory. Thus this is a pioneering project just to test the concept and explore the potential of this idea. Many issues are premature and unsettled at this moment. We choose not to go into these issues now.

Figure 6 shows the hardware setup for this remote laboratory. It consists of a host computer connected to network (eventually to Internet), a data acquisition board and an IEEE 488 control card plug into the host computer, a single phase DC motor controller RG500UA and speed controller module PCM4 from Minarik, an 1-hp permanent magnet DC motor from LESSON, an HD-710-8 dynamometer and dynamometer controller 5240 from Magtrol. Also used are voltage and current transducers LV-25 and LA-25 from LEM for voltage and current waveforms acquisition.

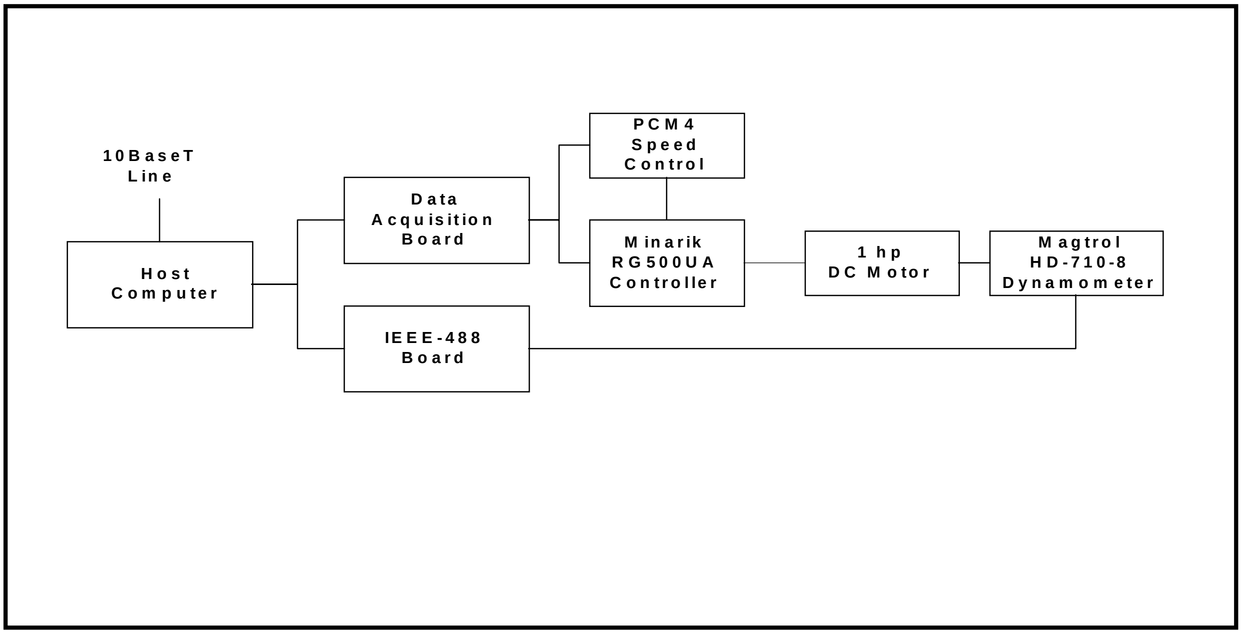

Figure 6: Experimental Setup for Distance Learning (Remote) Laboratory

To receive command from user and download data and waveforms to users located remotely through Internet, an Internet Development Kit from National Instrument is used. LabView is also used by the host computer to control various instrumentation. As far as user is concerned, he/she is looking at LabView User Interface. Once the program is initiated (after checking the privilege), a menu is shown on the screen on the user’s computer. He/she can input the command speed in rpm, torque in NM, a time period for experiment in second, and where the data files shall be stored. Figure 7 shows the screen user will be seeing. After user issue the start command, host computer will interpret the speed command value and issue an analog signal between 0 to 10 V through the data acquisition board to Speed Control Module PCM4 to control the averaged output voltage from the single phase controlled rectifier controller RG500UA. Host computer will also issue control signal through IEEE 488 bus to Magtrol 5240 Dynamometer controller per torque command signal specified by user. Actual speed and torque from the Dynamometer are sent to host computer running LabView through IEEE 488 bus. Voltage across and current into the DC motor are fed to the data acquisition board through LEM transducers. These signals are sent to LabView running in the host computer to display. LabView also calculate electrical input power by multiplying measured voltage and current together. Mechanical power can be obtained by multiplying measured torque and speed together. Thus, efficiency can be calculated and displayed easily with waveforms of voltage, current, torque, and speed on the same screen. User can also specify where data files for all waveforms shown on the screen can be saved so they can use them in other program like Excel to facilitate the report writing. This is essential for any remote laboratory experiment, we believe!

Judging from the outcome, this remote laboratory is a success since we have achieved our goals of testing the concept of conducting experiment through Internet. We have proven that it is feasible to conduct a remote lab and receive and download actual data of the experiment. For students using a slow modem accessing the Internet, response time might be slow but this can be improved by reducing amount of graphic information on the screen. Other major issues are security and how much time each dial in user can have. Since only one student can use one station at any given time, if we keep the procedure as straightforward as possible, this might not be a constraint. As far as whether this will deprive students of their actual hands on experience, we believe this shortcoming can be corrected or mitigated and we are currently working on this problem.

Conclusions

Based on the experience we had so far, we can draw the following conclusions:

(1) Because the power electronics lab requires many measurements that can only be made with various equipment such as spectrum analyzer, digital oscilloscope, curve tracer, voltage and current transducers, tachometer, multi-meter,. it might be beneficial for students to have some basic training in how to use all these equipment before they conduct their first lab project

(2) The philosophy we proposed, i.e., design, analysis, simulate, build, and test is a good approach. Students generally learn more and have a sense of accomplishment after they finish testing their very own product. This experience can stimulate their interest and expand their imagination. Both of these are essential in their engineering careers.

(3) The distance learning (remote) laboratory is a good tryout. We have learned a lot how this can be accomplished. It also raises a few important issues. We will try to address these issues later. Nonetheless, this distance learning laboratory requires some hardware and software for it to happen. IEEE 488 in each instrument and a data acquisition system are indispensable. Also LabView and Internet Development Kit are also needed.

(4) Power electronics circuits involve high voltage and high current, when equipment is used in the lab to conduct any voltage and current measurements, it is critical that the voltage and current waveforms can only be monitored through the voltage and current transducers. If this practice is not followed carefully, not only a short circuit through the common ground lead of measuring equipment will surely happen, there is even a potential danger of electrical shock to the person who is conducting the experiment.

(5) Instructor should remind the students that power electronics is very different from all the other electrical engineering lab projects, especially the digital or electronics lab students are so accustomed to. Not only the wire size for the hook up wire are far bigger, all the passive components, resistor, capacitor, and inductor should have enough voltage and current ratings in order to work properly in the experiment. Most of the students never saw the power resistor before. They are amazed at the size of the power resistor when they first encounter it. They should be taught about how to check whether the components or devices they find in the lab have high enough rating to be inserted into their testing circuits.

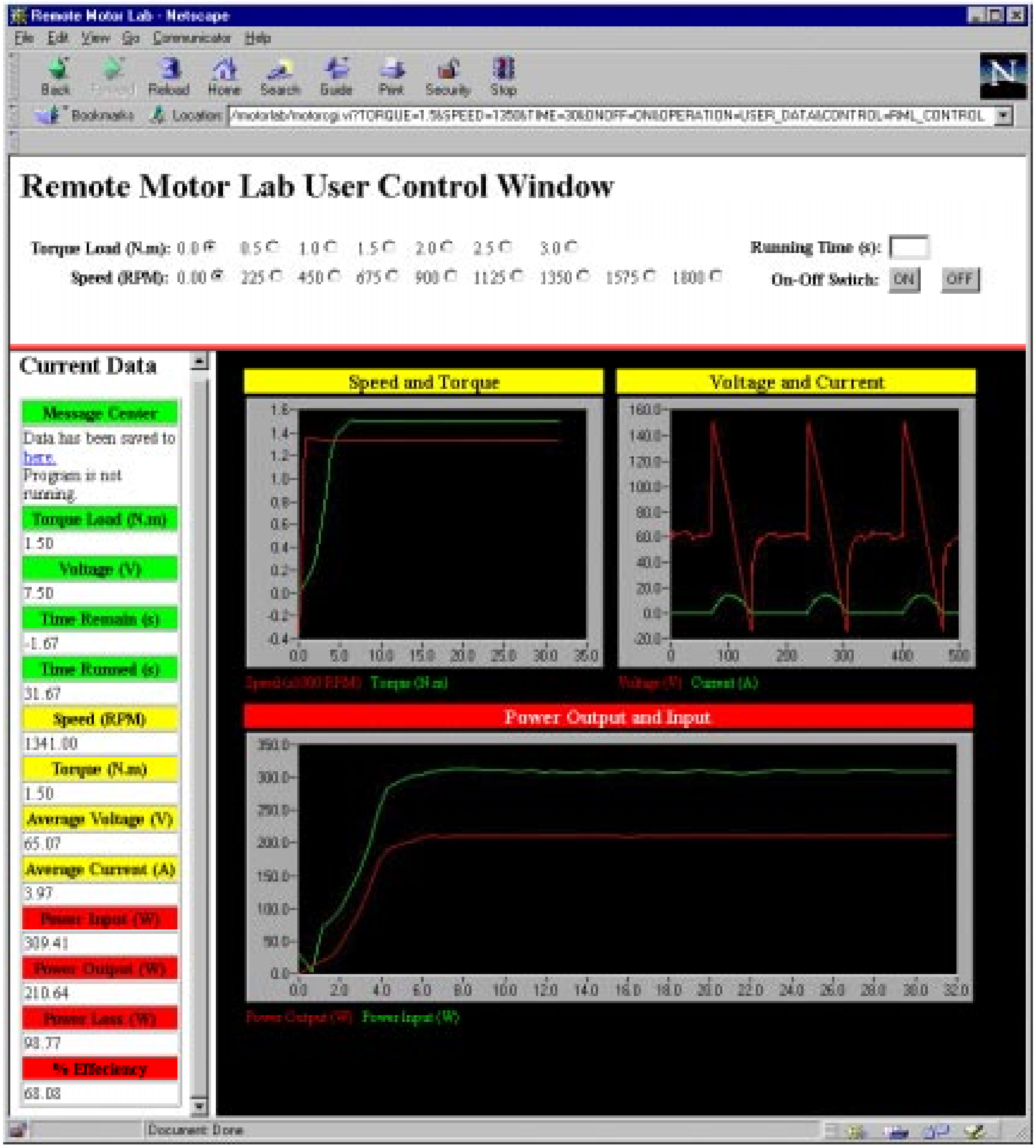

Figure 7: Initial Window for User of Remote Laboratory

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Bibliographic Information

[1] Phoivas D. Ziogas, Eduardo P. Wiechmann, Victor R. Stefanovic, "A Computer-Aided Analysis and Design Approach for Static Voltage Source Inverter," IEEE *Transactions on Industry Applications*, Vol. IA-21, No. 5, September/October 1985.

[2] K.S. Rajashekara, Venkatachari Rajagopalan, Anatole Sevigny, and Joseph Vithayathil, "DC Link Filter Design Considerations in Three-Phase Voltage Source Inverter-Fed Induction Motor Drive System," *IEEE Transactions on Industry Applications*, Vol. IA-23, No. 4, July/August 1987.

[3] ShyShenq P. Liou and Lawrence Vo, "Power Electronics Laboratory I in San Francisco State University," Proceedings, 1993 ASEE Meeting, April, 1993, Austin, Texas.

Bibliography

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