Power Electronics Research Experience for Undergraduates

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ABSTRACT

On the first half of the 20th century many of the electronic devices and machinery used were very expensive, inefficient, unreliable, and robust. With revolutionary advances in semiconductor technology much of these barriers are being improved. A new and very important field within Electrical Engineering was born with the purpose of improving the quality of electronic devices and machinery. Power Electronics is the field that deals with the control and conversion of electric power by semiconductor devices wherein these devices operate as switches.

SINOPSIS

Durante la primera mitad del siglo 20, muchos de los aparatos electrónicos y maquinaria usada era muy costosa, ineficiente, poco confiable y muy recia. Con los avances revolucionarios en la tecnología de semiconductores, muchas de estas barreras fueron mejoradas. Un área nueva y muy importante dentro de la ingeniería eléctrica nació con el propósito de mejorar la calidad de los aparatos electrónicos y de la maquinaria. Electrónica de potencia es el área de la ingeniería eléctrica que trata con el control y la conversión de la potencia eléctrica mediante el uso de semiconductores, donde dichos componentes operan como interruptores.

I- POWER ELECTRONICS & CPES

As we already know, Power Electronics refers to the control and conversion of electric power by power semiconductor devices wherein these devices operate as switches. The invention of the silicon-controlled rectifier (SCR), led to the development of a new area of application called Power Electronics. Before the SCR, mercury-arc rectifiers were used for controlling electric power, but applications with these devices were limited. When SCR became available, the application area spread into many fields such as drives, power supplies, aviation electronics, and high frequency inverters. The main application of power electronics is to control and convert electric power from one form to another. There are four types of conversion which include rectification referring to conversion of ac voltage to dc voltage, dc to ac conversion, dc to dc conversion, and ac to ac conversion. Due to great improvements in semiconductor devices, power electronics has expanded greatly in applications that include portable and consumer electronics, energy efficiency/ environment, productivity, transportation/ environment, utility applications/ environment, etc. As technology grows potential advances in power electronics emerge. These advances are: system solution, integration, improved semiconductor devices, improved passive components, and improved topologies and control.

If you drive a car, use a computer, cook with a microwave, talk on any type of telephone, listen to a stereo, or make holes with a cordless drill, then you come in contact with power electronics. Thanks to power electronics, the electricity needed to run the things you use everyday is processed, filtered, and delivered with maximum efficiency, smallest size and minimal weight. Due to the importance of this field, the Center for Power Electronics Systems organization was established [24].

The Center for Power Electronics Systems (CPES) deals with the improvement of the competitiveness of US power electronics industry by developing an integrated system approach via integrated power electronics modules (IPEMs). CPES consists of five national universities, Virginia Tech, University of Wisconsin, Madison, North Carolina A&T State University, Rensselaer Polytechnic Institution, and University of Puerto Rico Mayaguez, and 77 industry partners. Its main goal is to improve performance, reliability and cost of power electronics systems. Many of the research that CPES is involved include: electronic devices, control and regulation, power converter circuit design and work with various topologies for converter circuits, magnetic components, electronic circuit packaging and manufacturing, and control of electrical motors [1, 10].

The IPEM area led by Professor Dushan Boroyevich of Virginia Tech, provides system integration between the demonstrative program and technology development so as to link the enabling technologies to actual applications by developing rigorous design methodologies. In the motor drives department, CPES goal is to develop and apply IPEM technology to motor drive systems in order to achieve major improvements in cost, reliability and performance, consistent with the CPES global mission. More specifically, the motor drive area pretends to take advantage of new IPEM concepts, components and techniques that are developed as part of the CPES technology development areas [1].

II- RESEARCH EXPERIENCE FOR UNDERGRADUATES

In the summer of 2002, the first research experience for undergraduates (REU) program began. The program, sponsored by CPES, consisted on bringing two undergraduate students from the Polytechnic University of Puerto Rico to the University of Puerto Rico Mayaguez campus to have the opportunity of learning how to do research and work on a project that involved power electronics. The main goal of the program is to promote graduate studies in power electronics.

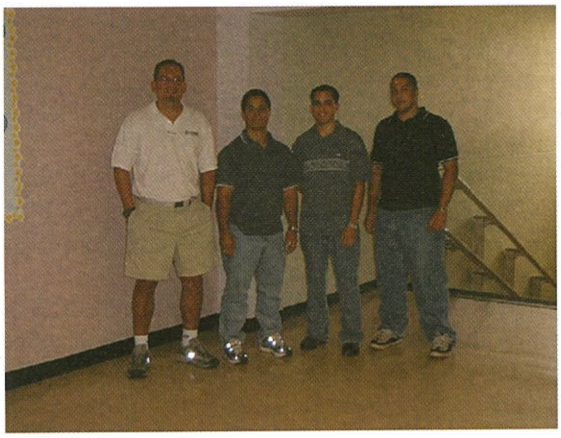

Figure 1: *From left to right: Milton Concepción, Dr. Efraín O'Neill, Eric Nieves(student), and Luihomir Santos(student).*

During the eight week of the program the two students were submitted to several workshops, presentations, etc. On the first day, Dr. Efrain O'Neill, program coordinator, gave the students a tour of the Mayaguez campus and started with the presentations about CPES and the goals of the REU program. He talked about CPES, its collaborators, its vision, the IPEM, the Center Overview, UPRM Personnel, UPRM Infrastructure, energy systems instrumentation laboratory, the development of electro thermal models for IPEMs, etc. Dr. Efrain O'Neill also talked about trends in power systems, power quality events such as: sags, swells, outages, transients, spikes, and harmonics.

On the second presentation the program coordinator talked about power systems, power quality, about issues in distribution systems, DVRs, static condenser, distribution static compensator, solid state transfer switch, and many others.

The students also got a prattle on communication skills, presentation skills, and cooperative learning. Finally the coordinator gave the students information on graduate studies, he talked about the different opportunities in the Mayaguez campus and the other universities that are working with power electronics as well.

III- PROJECT

One of the objectives of the REU program was to get the undergraduate student involved on a project that had involved power electronics. The two students involved in the program worked on separate projects. I was assigned to work with DC Motor Control.

Modern electric drive systems are used increasingly in such high-performance applications as robotics, guided manipulations, and supervised actuation. In these applications, controlling the speed is only one of several goals; others include controlling the starting, speed, breaking, and holding of the electric drive system. Recent advances in the design of electric drives have resulted in low-cost, lightweight, reliable motors; improvements in power electronics have resulted in a level of performance that was not possible a few years ago.

An electric drive is a system which performs the conversion of electric energy to mechanical energy or vice versa for running various processes. About half of the electrical energy produced is used in electric drives. Electric drives have a wide range of industrial applications:

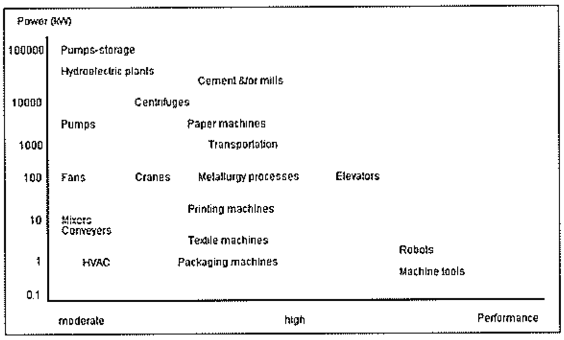

Figure 2: Applications of Electric Drives [22].

The drive systems have various forms: line shaft drives, single-motor, single-load drives, and multi-motor drives. The line shaft drive is the oldest form of an electric drive system. The system consists of a single electric motor that drives equipment through a common line shaft or belt. The single-motor, single-load drives are the most common form of electric drive. Here a single motor is dedicated to a single load. In the multi-motor drives several motors are used to drive a single mechanical load. This form is usually used in complex drive functions such as assembly lines, paper-making machines, and robotics.

A modern electric drive is made up of an electric motor, the power electronic converter, the electric and motion sensors, the drive controller, and the command interface. The drive controller, which is what is of interest, is made of a motion, speed or position controller, the same for all types of electric drives. Motor speed and torque control systems for most adjustable speed drives in the past thirty years have been dominated by the SCR and TRIAC converters, but are being replaced rapidly by converters based on IGBTs. Power devices such as high performance transistors in the mid seventies introduced chopper drives to accomplish the same task for lower horsepower machines [2].

There are many different models of drive controllers that are being worked on for the past 10 years. Some of the models involve PI or PID control types [8]. The PID controllers have been the most widely used and well known controller in the industry for over 50 years [21]. The classical method of tuning of PID controllers is that of Ziegler-Nicols which is based on the open loop response of system, but an adaptive control technique has been developed which can be used as self-tuning regulators, since they are able to self-tune PID gains and adapt to changes in the system states. Therefore, tuning methods developed for PID controllers can be classified into two groups: fixed PID gain tuning and adaptive PID tuning. From simulations that were performed we see that the PID learning controller outperforms the conventional PID controller in tracking, robustness to parameter uncertainty and load torque variation and disturbance rejection [17].

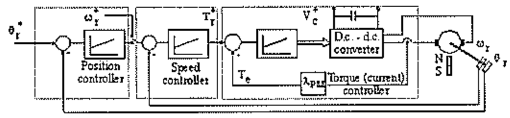

Figure 3: Cascaded Motion Control [22].

Conventional control strategies are of fixed structure, fixed parameter design, therefore the tuning and optimization of these controllers are a very difficult mission, particularly the ones that involve variations in load conditions, parameter changes, abnormal modes of operation etc. Many other technologies such as rule based, expert systems, fuzzy logic and artificial neural networks started to emerge during the last decade and promise to simplify and improve the robustness of speed and position control designs [11, 18, 20].

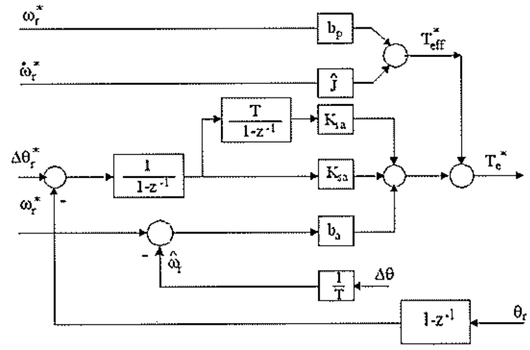

Figure 4: State-Space Motion Control [22].

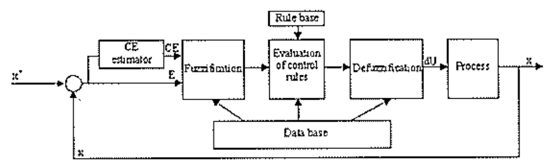

Figure 5: Fuzzy Systems Motion Control [22].

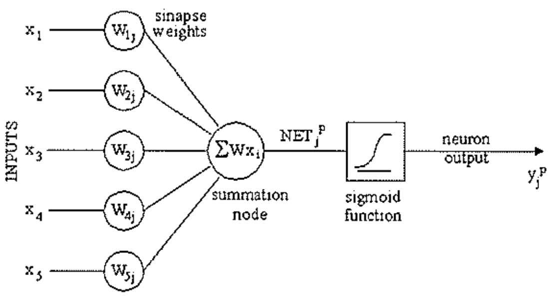

Figure 6: *Neural Networks [22].*

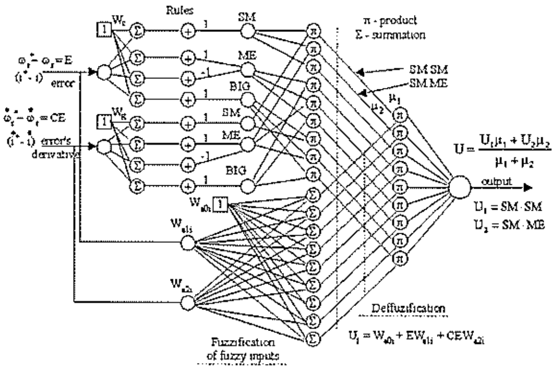

Figure 7: *Neuro-Fuzzy Systems [22].*

The next development is achieving full torque at zero speed without use of a sensor. Reduced or zero harmonics is another area almost certain to be realized within the next generation of drives. Starting with 12 pulse bridge technology as standard on all drives automatic phase displacement will lead to improvement in control of high inertia loads such as the use of mains regeneration as opposed to the current norm dynamic braking [3].

After analyzing these advances some general conclusion were made on them. The Physics-based approach to state variable control design methods promotes creative and insightful drive controls. State observers are very useful sensor replacements for drive control. Self-sensing methods for torque and motion control have the potential for substantial cost and reliability benefits and can operate at sustained zero and low speed. Fuzzy logic and neural networks provide control enhancements [4].

Many of these technologies are being testes in different softwares like for example, PSPICE, Matlab/Simulink, KREAN, etc. Some of the softwares are very useful for some applications than others that is why there are many different softwares you can work with [6]. Matlab is a computation engine with a full suite of mathematical functions, integration routines and numerical solvers. Simulink is a graphical interface that provides a way to use Matlab's functionality for simulation of dynamic systems [5, 7, 14, 16].

These are some of the simulation that is being done using softwares presented:

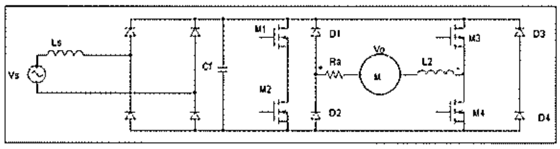

Figure 8: *Detailed circuit diagram of the DC drive system [9 - 19].*

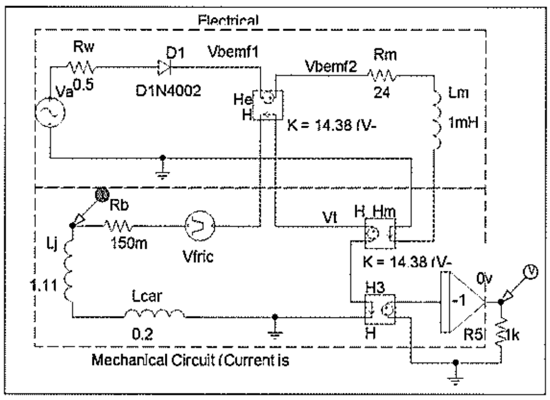

Figure 9: *DC MOTOR*

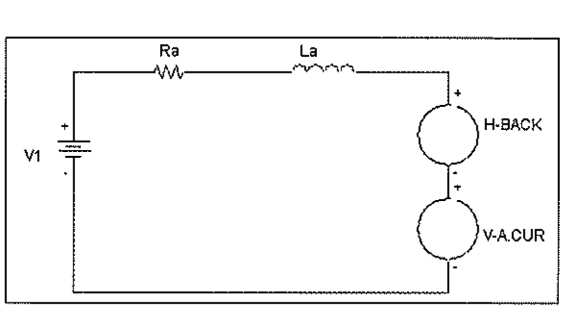

Figure 10: *Armature Circuit Model [13].*

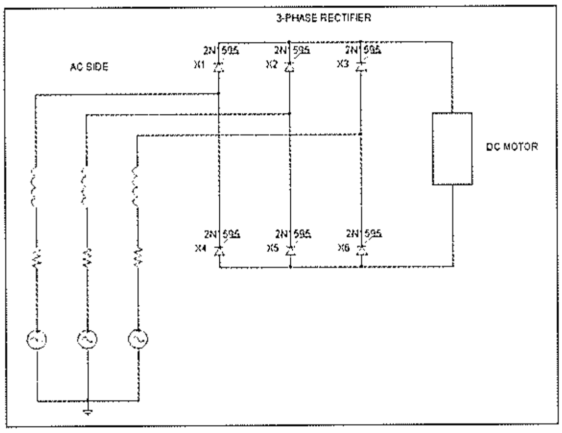

Figure 11: Complete Schematic entry of the Rectifier Motor Speed Controller [12].

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