Students' Perspective on a Student-Designed Energy Conversion and Electric Drives Laboratory

Justin Morrill, Stephen Bostrom, Joshua Olson
Students
&
Steven Hietpas
Member of ASEE, Associate Professor
Electrical Engineering
South Dakota State University
steven_hietpas@sdstate.edu

Abstract

In September 2002 South Dakota State University's Electrical Engineering Department opened the doors to its new state-of-the-art energy conversion and electronic drives laboratory. The automated features, computer instrumentation and monitoring components of the laboratory provide students with a working demonstration of electrical engineering in the areas of energy conversion and electronic drives. However, the most extraordinary aspect of the new lab is that it was designed, constructed and tested by thirteen undergraduate students, one graduate student, and a professor over a period of five years. This paper provides an overview of the laboratory, describes the educational benefits students gained throughout design and construction of the facility, and recounts the challenges and lessons the students learned throughout this process. The student perspective will provide considerable insight to those interested in employing students in the design of a new laboratory.

New Laboratory Overview

The concept of the new energy conversion and electric drives laboratory was birthed in the fall of 1997 with an original estimate of $275,000 to replace essentially all existing equipment. The proposed layout for this laboratory is shown in Fig. 1. Three components were identified for design and fabrication through senior design and student design projects: 1) automated load banks (ALB), 2) power processing station, (PPS) and 3) power workstation benches (PWB). The new student laboratory was designed around the PWB, which obtains access to power and load resources located in the utility room via a PC with a National Instruments Data Acquisition Card and LabView control interface. These resources include 208 and 240 Vac 3-phase utility power, 0-250 Vdc power, battery banks, solar panels, and the DC/AC (single or 3-phase) 10 kW ALB. The PPS enables interconnection between the PWB and these resources. The first PWB was constructed in the summer of 2000 and the second in the summer of 2001 (Fig. 2). The first PPS prototype design [1] was fabricated in the summer of 2001 (Fig. 3), while three separate design teams [2-4] worked on the design and implementation of the ALB (Fig. 4).

Final Design Phase

The final design phase began in the summer of 2002, with one of the three students having fabrication experience and a working knowledge of the project. The lack of experience coupled with the daunting task of finalizing a long running project led to apprehensions over whether or not the laboratory could be completed in time for classes the following fall. Following is the process followed by the design team that ultimately resulted in a completely functional laboratory by the fall of 2002.

Dr. Hietpas, acting as the project manager and chief engineer, assigned tasks to each student, based on his assessment of each student's talents and abilities. The project Gantt chart, with each major task and its timeline, was drawn on a whiteboard (Fig. 5) in the laboratory so that the design team would be continually aware of each major design milestone. Design constraints and critical design paths were identified and their importance made clear to ensure a successful design. This gave the design team the foresight to order parts well ahead of time and to assist one another when one stage of the project was at a standstill.

The final design phase of the ALB was completed by Hietpas with the assistance of Morrill. Though Morrill had not yet taken any of the junior level electronics courses, his military avionics technician experience and troubleshooting skills were important for the final ALB design phase (Fig. 6). Morrill was also assigned the layout and assembly of the PPS. To ensure that all components fit properly into the large electronics cabinet, Morrill constructed a 3-D AutoCAD model of the entire PPS (Fig. 7), making immediate use of an AutoCAD class taken the previous semester. This approach helped to ensure the successful operation of the PPS by the beginning of the fall semester. Morrill also served as the lead technician and provided guidance to the other students when it came to fabrication issues.

The PCB layout of the ALB and PPS circuitry was assigned to Olson. Olson did not have any previous experience with the PADS PCB layout software, but did have experience with CAD and was known to be an excellent independent learner. He was able to learn the software using the bundled tutorials in two weeks, just in time to begin laying out the first PCB for one of seven control and data acquisitions boards. Olson also designed and fabricated an instrumentation interface between the ALBs and the National Instruments data acquisition and control card. When PCB layouts were completed, Olson and Bostrom performed a pin for pin, connection for connection comparison with the prototype schematics to ensure all components were properly placed and connected. Their attention to detail resulted in only six missed connections out of hundreds, for a total of 31 fabricated PCBs. When the PCBs were returned from the manufacturer, Olson and Bostrom were also tasked with populating and soldering all components. While neither Olson nor Bostrom had any prior soldering experience, their skills were greatly improved after completing an estimated 10,000 solder joints (Figs. 8 and 9).

Assembly of the PWBs and overall parts database management was assigned to Bostrom. Combining features from two existing PWBs, six additional benches and corresponding electrical and electronic hardware was placed on order, with an expected delivery of June 15. However, the benches did not arrive until the first week of July, delaying the schedule by approximately 2½ weeks. With other manufacturing errors on the connection panels, adjustments were made in the schedule allowing Bostrom to use his experience with Excel for better organizing and tracking all purchase orders. Fabrication of the PWBs was quite extensive, involving wood work, wiring, and considerable stages of assembly (Fig. 10). Fortunately the PWBs, PPS and ALB systems were completed (Figs. 11 and 13) by late August leaving approximately three weeks of system integration and testing, making the laboratory ready for the fall semester classes, which included Circuits I and II and the Energy Conversion and Electric Drive course.

Educational Benefits

Throughout this project students were given the opportunity to exercise and sharpen skills they had learned in the classroom, such as circuit design, fabrication, troubleshooting techniques, selecting and evaluating components using datasheets, and component and system layout using software tools such as AutoCAD and VISIO Professional. Students were also exposed to new skills and tools such as sheet metal work, which included cutting, drilling, and painting, as well as electrical work such as soldering, wire and cable selection, and proper wiring and termination techniques. The students also gained invaluable software experience including PCB layout with PADS, LabView programming, PLC and Touch Screen HMI programming [5], and database management. In addition, students were exposed to project management techniques, learned how to function as a team in an industry environment, and were required to consult with manufacturers about project component requirements. The students were required to place orders in a timely manner, work under budget and under time and design constraints, keep records of designs in engineering notebooks, keep accurate schematics, and write and follow safety and calibration procedures [6].

Challenges and Limitations

Many of the challenges encountered during the completion of the laboratory stemmed from the fact that the students charged with the lab's completion entered into a project that had been under development for five years. Nearly all of the students who initially developed the project had since graduated. However, Dr. Hietpas had been involved with the project from its beginning and was able to provide the necessary direction to the design team. Previous designers had fortunately left well documented engineering notebooks [7-9], which proved extremely beneficial, and inspired the final design team to continue in the same manner. Other challenges stemmed from errors when transferring from prototype to final design. One particular error resulted when individual comparators on the prototype were implemented in a single IC on the PCB [6]. The problem actually existed on the prototype and was a design violation in that maximum input voltage levels were exceeded, yet problems did not surface until the final PCB was tested. This problem was remedied by cutting traces on the PCB and inserting a protective clamping diode at the comparators' inputs.

Another significant challenge was developing effective schedule changes when important components were not delivered on time, especially in the case of the benches. At other times, packaging layout along with PCB connector placement did not always coordinate, resulting in the need for innovative work-arounds.

The limitations involved with using students as a construction team included insuring that the wiring met building code. For this a licensed electrical contractor was required to route all wiring throughout the laboratory. Also, the manufacturing of the PWB benches and connection panels was outsourced, since onsite construction would have proved time and cost prohibitive.

Acknowledgements

Funding for this project were from MidAmerican Energy, the Russel Christianson Foundation, Black Hills Power and Light Company, Otter Tail Power Company, Cutler-Hammer Co., and members of the Center for Power System Studies, SDSU. To complement these funds, SDSU was awarded an NSF CCLI A&I grant (DUE-9952517), for developing new energy conversion and electric drive exercises, and purchasing lab equipment. The authors acknowledge the following individuals who took part in various stages of the design process: Tony Harrell '99, Scott Hoberg '00, Sara Horner '99, Matt Karlgaard '01, Jason Kautz '00, Andy Koob '02, Troy Metzger '02, James Ziebarth '02, Wade Ziegeldorf '99, and Vijay Kambhammettu.

Figures

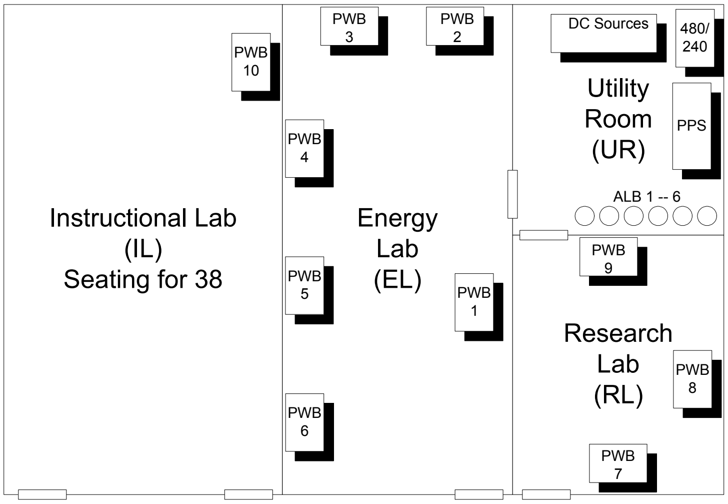

Figure 1. New energy laboratory facility

Figure 2. First prototype of PWB

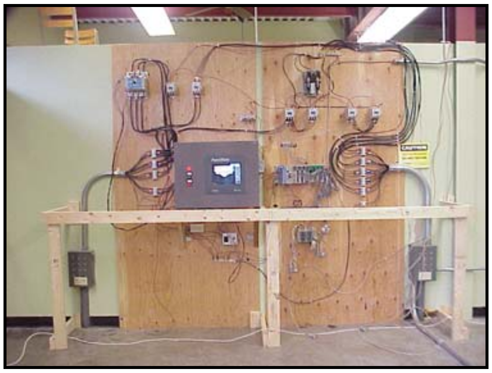

Figure 3. Prototype of PPS

Figure 4. First prototype of ALB

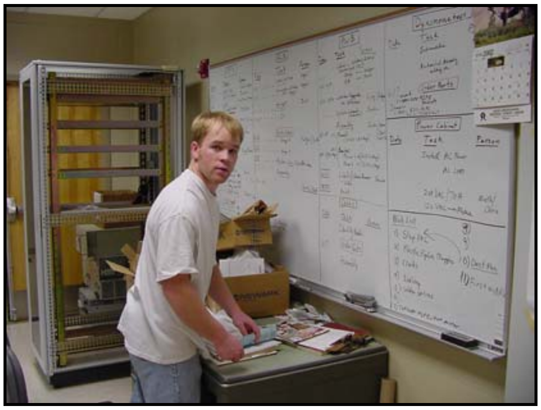

Figure 5. Whiteboard Gantt chart

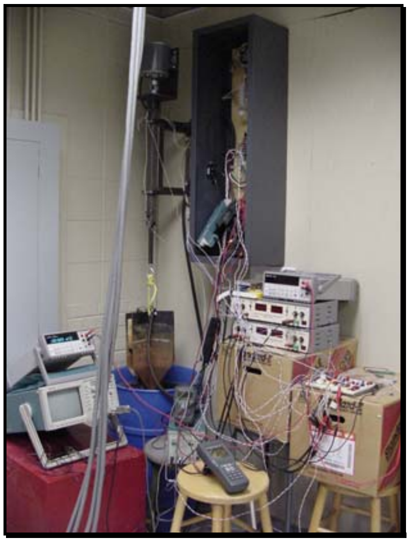

Figure 6. Design and troubleshooting ALB

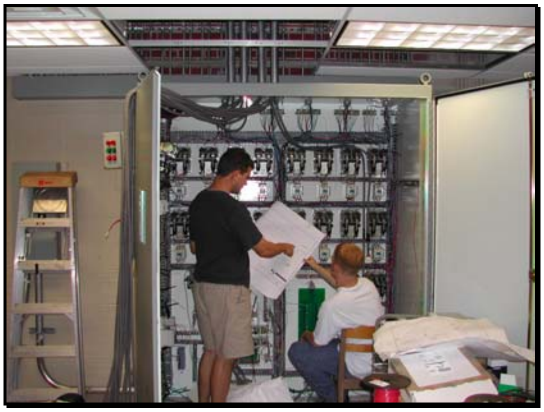

Figure 7. 3-D CAD layout of PPS used

Figure 8. Bostrom on PCB fabrication

Figure 9. Olson on PCB fabrication

Figure 10. PWB fabrication stage

Figure 11. Functional PWBs by fall of 2002

Figure 12. Completed PPS

Figure 13. Completed ALBs

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