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Recent Experience with Directed Mentoring and Laboratory Development in the Electric Power Area

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Abstract

A Directed Mentoring program was developed during the past two years at New Mexico State University (NMSU) with local electric utility support of committed internship positions and academic-year support for students. The program's objectives and progress were described in a paper presented in 2003. The mentoring program consists of a carefully-coordinated program of activities in which students work with faculty and receive financial support during regular semesters, with the opportunity of employment with sponsoring companies during summer or co-op phases.

A key component of the mentoring program this year has been directed student participation in the technical development of a new **Electric Power Systems Laboratory**. The basic components of this laboratory were assembled and have been used in both required and elective classes in electric power systems, and updated continually, beginning in the Spring 2002 semester. The students are also developing experiments, which include hardware and associated computer control, for teaching and exploring more advanced power-systems concepts, including network operation and control using power-electronic devices. These are discussed.

This paper describes the development of this laboratory capability, illustrating in particular how such a Directed Mentoring program benefits the students, their industry sponsors, and the University

1. Introduction

As indicated in a previous paper [1], a Directed Mentoring Program was established at New Mexico State University to increase the visibility of electric power engineering and attract students (primarily undergraduate) to the power area. The program was designed to address challenges that such programs face in attracting quality students, which often results from the power industry's lack of visibility among freshmen and sophomore engineering students. A year ago, after the program had been in operation nearly three semesters, initial successes were reported [1], confirming to us the validity of the approach.

A major component of the mentoring program over the past year has centered about the development of a new fractional-horsepower machine and power-systems laboratory facility for use in undergraduate and graduate courses. The primary thrust of this laboratory has been toward our first, required junior-level course in electric power systems and machinery. This laboratory has reached a nearly-satisfactory development state (as far as the required junior-level course is concerned) with a total of thirteen experiments (seven computational and six with actual equipment) plus a field trip to a transmission substation.

The primary purpose of this paper is to describe this laboratory in detail and to illustrate how its development, conducted almost entirely by undergraduate and graduate students, met and exceeded the primary needs and expectations of the mentoring program. Indications of future activities of the mentoring program are given as well.

2. Fundamentals of the Directed Mentoring Program

It may be helpful to review briefly, in this paper, the fundamental goals and methodology of the mentoring program as presented in [1]. The mentoring program was actually initiated in the Fall semester of 2001. Its goal has been to encourage students to consider power engineering as a career choice. Identifying students as early as their freshmen or sophomore years, and engaging them in power engineering, is seen as the path to accomplishing this goal. A major incentive (from the student's point of view) is financial support and the near-guarantee of a summer or co-op position. Students who elect to participate in the program have the following *opportunities*:

- Work with faculty during regular semesters while they take power area classes
- Work with a sponsoring member company during the summer or co-op phases
- Have these opportunities available to them through their graduating semester.

At the same time students are made aware of the following *responsibilities*:

- Maintain interest in power engineering by following the sequence of power and related area classes.
- Participate in education and research activities.
- Actively participate in student activities, in particular as IEEE members, and seek leadership positions
- Seek employment opportunities in the power industry
- Participate in outreach activities

Students in the program have been exposed to a range of projects, as indicated in Section 4 below. The continued development of the undergraduate course laboratory has been the most emphasized of these projects in terms of numbers of students and resource expenditure.

A key challenge in the continued development of the mentoring program has been to provide challenging on-campus opportunities for the students in a way that supports their academic endeavors. Students have worked with faculty and advanced graduate students on their research programs, and have assisted with laboratory maintenance and instruction. Perhaps the most rewarding on-campus activity, as discussed below, has been the involvement of these students in laboratory development, primarily through senior design classes (Capstone projects).

3. The Laboratory

Beginning in 2000, the faculty began a concerted effort to develop and equip a new laboratory in the Energy Systems area. The focus of the efforts was to create a modern laboratory that would allow us to explore concepts at a system level and then gradually expose students to the details of individual pieces of equipment, including design, testing and operational issues. The "Systems" approach, outlined in Table 1, is consistent with our recent curriculum review. It was also considered critical that the planned laboratory present a modern and realistic image, while allowing flexibility of use. Thus elements of power electronics and computer-based control, as well as the use of automated test equipment, were considered important. These developments were supported by a generous contribution from the El Paso Electric Company, and a grant from the Department of Defense Air Force Office of Scientific Research.

Laboratory Concept

Figure 1 provides an overview of the desired energy systems laboratory according to our present goals[1]. The equipment in the laboratory consists of commercially available consoles or 'workbenches'. Each console is essentially a test-bed where students can connect and instrument different types of energy-systems. Each console has a local, computer-based, instrumentation system. The workbenches can be tied together to create an interconnected power supply and utilization system. The interconnected system is monitored through a centralized system, similar to industrial supervisory control and data-acquisition systems. Although model transmission lines lines are commercially available, a complete transmission system with SCADA controls is not.

Table 1 encapsulates the type of laboratory exercises that are or will be utilized. In each instance we start at the system level and work toward component details. Thus the proposed laboratory enhancement will provide a complete capability to meet our goal of enhancing education across the curriculum and providing an early introduction to the relevant hardware. We believe the latter is important to increasing student interest and involvement, which directly impacts recruitment and retention. Of particular benefit will be the inclusion

[1] We have a separate computer laboratory for simulation-based studies.

of laboratory experiments in the Electrical Engineering service course for non-majors and, perhaps, in Mechanical Engineering design courses.

We expect to channel a number of student design efforts into the laboratory since it is developing a reputation for providing a fertile ground for cross-disciplinary capstone projects and research. Some examples of relevant projects are as follows:

- Selection and design of protection for a transmission line or transformer
- Design and implementation of a scale-model hybrid propulsion system.

- Design and implementation of a distributed generation interface.
- Advanced dc-ac conversion design or FACTS design for power control

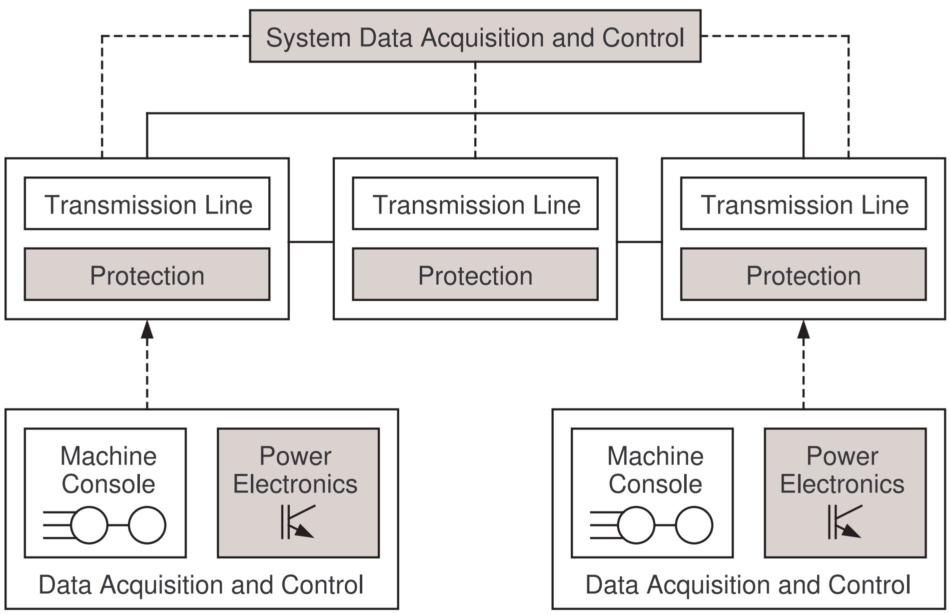

Figure 1 Laboratory Concept.

Table 1 Typical Laboratory Exercises for Regularly Scheduled Classes

Class(es)	Laboratory Exercises
Power Systems Core course and three elective classes	Assembly and testing of a mock power system Rotating Machines experiments System Operation and Control Power Electronic Applications Power Systems Protection Specialty Power Systems
General Lower Division EE	Dc and ac circuits Power Systems
Service class for non-EE	Dc and ac circuits Basic electronics Control-system fundamentals Motor control
ME Design classes	Electromechanics, Interfacing, Digital control

Although our primary focus is on undergraduate teaching enhancement, the Laboratory will have a major impact on graduate education as well as research. *It is important that both graduate student research and general research be supported by hardware implementation.* The proposed laboratory will allow hardware implementation and testing.

For example, there is great interest in electrochemical-capacitor applications in high-power domains. These capacitors promise a small footprint and high specific reactive power. We are investigating several applications for such capacitors in conventional power systems, as energy storage media associated with distributed generation, etc. The Laboratory will allow us to easily prototype and test such applications. Other areas of current research include subtle dynamic vulnerabilities in power systems, advanced dc-ac power conversion schemes, and the operation of distributed generation clusters.

We began the development of this laboratory by installing two power system and transmission line consoles. Two additional consoles were added subsequently. A typical console (manufactured by LabVolt, Inc) is shown in Figure 2, and consists of:

- A test bed in which motors and generators can be installed,
- Controllable power supplies,
- Metering and a computer based data acquisition system
- Additional consoles containing transmission lines.

These consoles have the capability of creating a complete, conventional electric power system as illustrated in Figure 2. The existing laboratory thus has the capability of supporting our introductory power system class. It can also serve lower-division circuits classes, as well as classes in engineering technology. It was found that additional consoles were needed to serve the fairly large enrolment in these classes. The presence of additional consoles and equipment will, of course, allow larger-scale simulations and thus more realistic investigations of electric power systems in more advanced, single-group laboratory experiences as well.

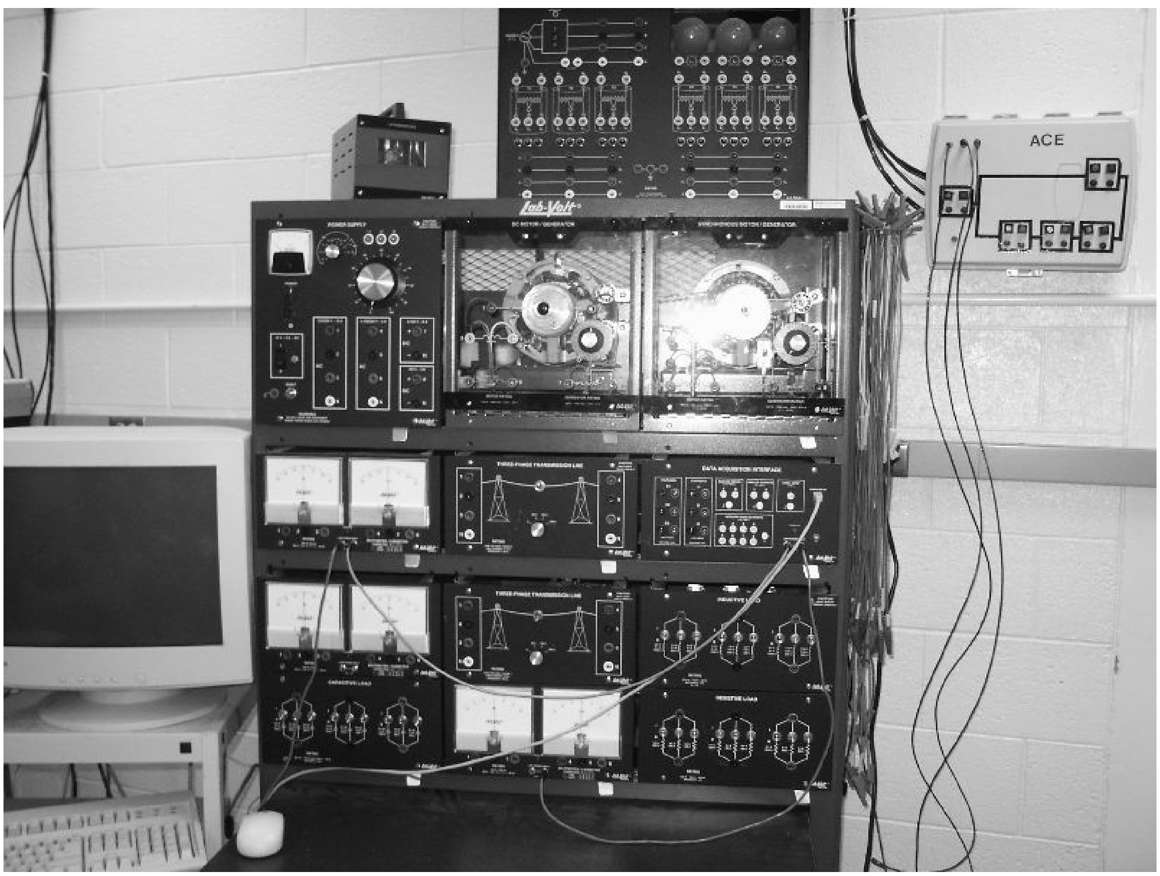

Figure 2 Machinery and Power system Console

Two additional consoles with capabilities described previously, but augmented with power electronics modules were recently purchased from a commercial vendor (LabVolt, Inc.) This increases the number of laboratory stations to a total of six. A set of these modules is shown in Figure 3.

The Power Electronics modules consist of high-voltage SCR, Diode and IGBT bridges, as well as synchronizing, firing and protection circuits. As such most desired forms of power electronic systems can be implemented by matching High Voltage circuits with pre-built or student-designed controllers. The modules readily support the basic classes in power electronics by providing hardware demonstrations of ac-dc, dc-dc, and dc-ac conversion. Their advantage is that basic concepts can be implemented in hardware without undue effort in wiring, programming or debugging. The experience gained will allow students to build their own hardware in a project setting.

Figure 3 Consoles with Power Electronic Modules

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A second use of the Power Electronics consoles is in the teaching of the means by which power electronics is utilized in 'modular' power systems. Thus, we build a bridge to the future, from conventional power systems to specialty power systems, illustrating characteristics likely to be found in tomorrow's transportation systems, aircraft, ships, and spacecraft. Using the laboratory it is possible, for example, to create and explore an advanced propulsion system consisting of prime-mover, generators, transmission links and a variable- frequency motor drive.

4. Laboratory Development By Students

In the development of any academic laboratory, the acquisition and installing of hardware is usually the "easy" part. In contrast, the effort required to integrate the equipment and to develop instructional materials is very demanding. The availability of students in the directed mentoring program has proven to be very valuable in this regard. Conversely, these students benefited from working with state-of-the-art equipment and significantly advanced their knowledge in the power systems area.

In order to complete the development of the laboratory, a Capstone design sequence was created for a number of student teams. In this design class, teams were tasked with designing and fabricating a scale model transmission system. The general requirements given to the student teams were as follows:

A. Create a 5-node power transmission network into which the power system consoles could be connected to represent generating stations, loads or a combination of these.
B. Each node is to be implemented with circuit breakers with configurations such as a ring-bus or breaker-and-a-half scheme as typically found in a typical electric utility EHV switching station.
C. Breaker controls are to be provided locally at the consoles as well as from a standard rack as might be found in a substation.
D. Supervisory control and data acquisition capability is to be provided.

Starting with these general requirements, student teams developed a detailed set of requirements. The teams also created a power-flow and short circuit model for the proposed system. Using these models with appropriate analytical tools, students determined both the electrical and mechanical requirements for wiring and circuit interrupters. Control relays were used to mimic power circuit breakers; thus, additional design and development was needed to created breaker control circuit that would mimic the "Trip" and "Close" coil features of actual power circuit breakers. These mimic boards permit the interconnection of remote, manual and relay originated trip/close as is done in utility substations. Students also had to research code issues since 120V power cables had to be routed in standard cable gutters along laboratory walls and ceilings.

The final product of the Capstone is the ability to create a power system, as shown in Figure 4. Figure 5 shows the topology of the system. The part drawn in broken lines is still in progress. Apart from the numerous ways, described above, in which this system contributes to educational development of students, it also provides both students and faculty an excellent tool for research. **Once the additions that are currently in progress are completed, this system will possess almost every component that is present in actual power systems, and will be an excellent tool for demonstration of various dynamic and steady state phenomena in power systems, and possibly even for training practicing engineers.**

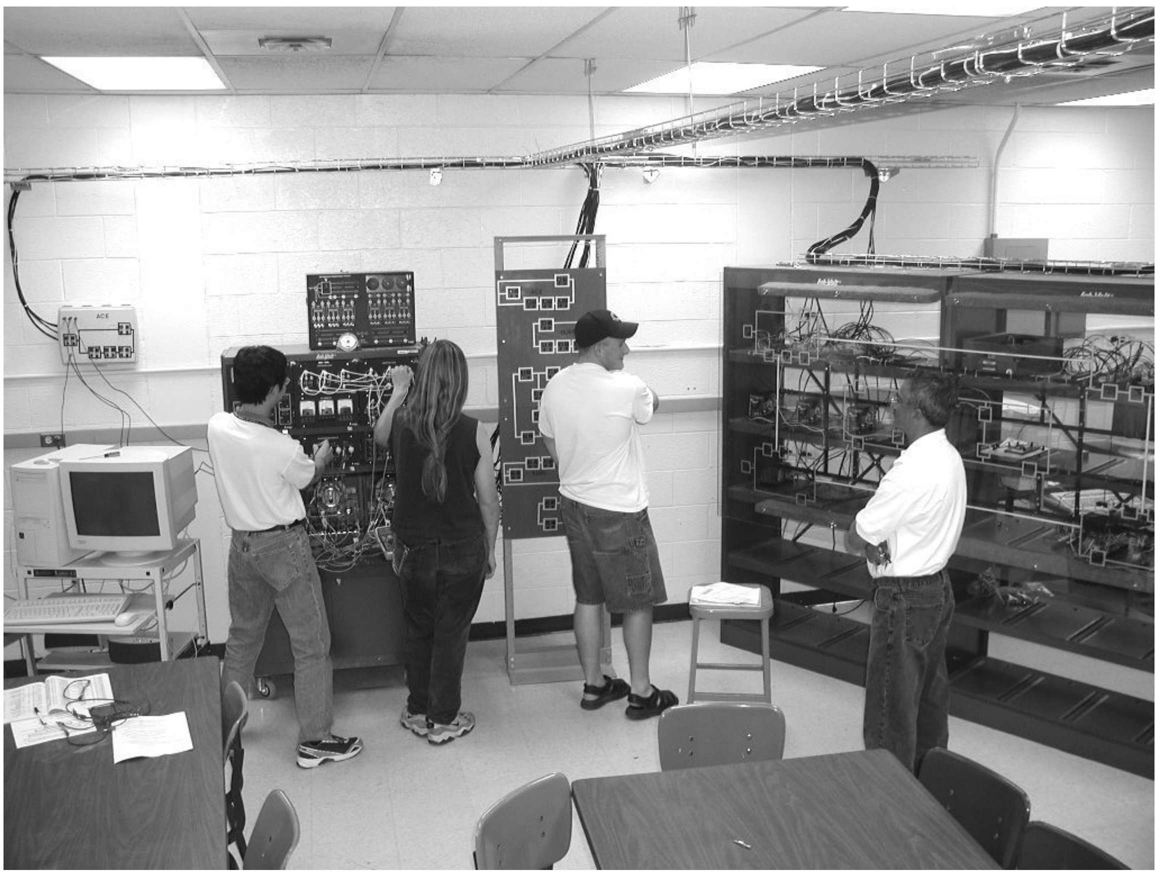

Figure 4 Transmission Network; In the center is a rack that mimics substation breaker control. At right is a mimic board showing the transmission system. Circuit breakers and transmission lines are housed behind the mimic board.

A second team of students was tasked with prototyping a SCADA system for computer-based operation of the interconnected power system. The students surveyed available SCADA hardware and software and recommended that a system be developed using National Instruments Field Point product line. Additionally, they recommended that standard digital metering, as used in the utility industry, be installed at all nodes and integrated into the SCADA system.

The SCADA system utilizes National Instruments hardware/software for two reasons. Firstly, this hardware is very commonly used in industry and research laboratories. Secondly we have already developed software useful for large scale monitoring as part of a project sponsored by the Electric Power Research Institute (EPRI).

The SCADA can mimic the System Control Center for a mock-up of a conventional power system. Groups of students can apply different types of control and automation schemes and study the response of the system.

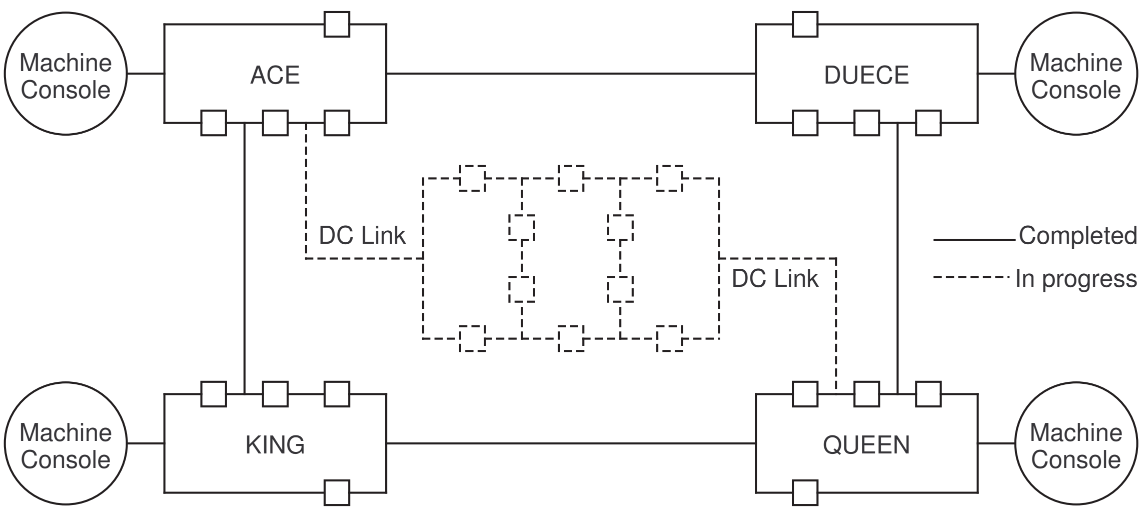

Figure 5 One-line Diagram of Station Interconnections

5. Summary and Conclusions

The Laboratory has already had significant positive impact on undergraduate instruction in our Energy Systems program. In particular, it has solidified the mentoring program discussed here and in [1] by providing a venue for both graduate and undergraduate students to exercise their talents in a directed setting. Our primary experience to date (Spring 2002-Fall 2003) can be summarized as follows:

1. Required undergraduate power course and laboratory:

   Approximately seventy students have utilized the laboratory in this class. A major impact of the new equipment is that the number of students per console has rarely exceeded two. This fact in itself makes the laboratory session more meaningful and useful to the students.

   A complete set of new experiments has been introduced and tested in the laboratory. As expected the "systems" orientation to power seems to be very well received.

2. Undergraduate "Capstone design experience". Three student teams have utilized the laboratory to successfully complete their 6-hour capstone design requirement. The following projects were completed:
   a. Supercapacitor charging system (2 teams)
   b. Solar car drive system (1 team)

3. Of particular note is that the laboratory also hosted a capstone design class entitled "Scale Model Transmission System". In this class a student group designed a scale model system to interconnect the six consoles into a "power grid". They further demonstrated the use of the SCADA components.

4. Two students have completed MSEE technical reports in the Power Electronics area using equipment directly acquired through a Department of Defense (DOD) grant.

As this development progresses, additional capabilities will be added to the Laboratory, addressed to specific advanced topics in the undergraduate and graduate course curricula. These will include electric power quality, power-electronic emphasis areas, and perhaps issues involving power-system security and reliability. ***It is anticipated that the mentoring program will continue to be the primary source of student effort for ongoing laboratory development.***

Overall, we find that this laboratory presents endless and exciting possibilities. This has not gone unnoticed by the industry. The laboratory has received tremendous praise and support from our sponsors and other industry representatives who have visited it. Progress in its continued development will be reported as time progresses.

6. Reference

[1] H. A. Smolleck and S. J. Ranade, "Directed Mentoring: A program of industry-university collaboration to revitalize electric power engineering education", Proc. Of the ASEE Annual Conference and Exposition, Nashville, TN, June 22-25, 2003.

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