Enhancing Electric Energy Conversion and Power Systems Laboratory Experiments Utilizing a Power System Simulator

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ABSTRACT

In 1993, the Engineering Technology Division of the University of Pittsburgh at Johnstown purchased and installed a Hampden Model 180 Power System Simulator. Funding was provided in part by a $100,000 National Science Foundation Instrumentation and Laboratory Improvement (ILI) equipment grant. The additional funding for the total purchase cost of $325,000 was provided from gifts of alumni and friends of the University and other resources of the University.

The simulator has been used every term in rotating machines laboratories for both electrical (EET) and mechanical (MET) engineering technology students and in power systems laboratories for the EET students. Student reaction to this new equipment has been very positive. Laboratory experiments are more efficient--requiring considerably less setup time than that experienced in previous rotating machines laboratories. Students are able to leave with a better vision of a "power system" rather than a sampling of pieces or components.

The simulator can be operated manually, utilizing switches and circuit breakers mounted on the equipment, or remotely, with an interconnected personal computer and associated software. This allows students to develop a "feel" for how electric utility operators control modern electrical power plants and electrical power transmission and distribution systems.

The paper gives examples of several specific laboratory activities which students undertake and the enhancement the activities provide for learning about power system concerns and problems.

INTRODUCTION

The equipment used in the rotating machines/power systems laboratories at the University of Pittsburgh at Johnstown (UPJ) had been in use for twenty years or more. Some of the equipment was becoming difficult to maintain in a reasonable state of repair. A decision was made to investigate alternative equipment possibilities. After studying equipment specifications and making visits to observe equipment installed in other locations, it was further decided to proceed with a "power system" rather than individual items of equipment. It was recognized from the beginning that this decision had two major disadvantages. First, it would be expensive, and secondly, because of this expense and also its size, it would only be possible and reasonable to purchase *one* such unit. This left us with the question of how to use it with 8-12 students in a laboratory class. In spite of these significant concerns or perhaps in the face of them, we continued with a determination to have a "power system" in the laboratory. Again, site visits were made to look at equipment supplied by several manufacturers. Quotations were obtained from each of these. A Hampden Model 180 Power System Simulator was selected as the preferred choice.

To help in overcoming institutional resistance to such expensive equipment, a proposal was prepared requesting partial National Science Foundation funding. Ultimately an NSF Instrumentation and Laboratory Improvement (ILI) equipment grant was made for $100,000. Additional funds were provided by various resources of the University including gifts from alumni and friends. This additional funding totaled $225,000. Thus the total cost including installation and training was $325,000.

The equipment was purchased in 1992 and installed in the spring of 1993. It was first used in regular classes starting in the fall of 1993.

HISTORICAL BACKGROUND

The programs in Electrical Engineering Technology and Mechanical Engineering Technology at the University of Pittsburgh at Johnstown have required courses in rotating electrical machines. The EET program also has a required electrical power systems course. An objective of the Engineering Technology program is to have a laboratory associated with every technical course. It is the faculty's opinion that the practical experience gained in the laboratory is one of the most distinguishing features and advantages of an engineering *technology* curriculum and program.

For twenty years our rotating machines and power systems laboratories used M-G sets in various configurations. The equipment used was from two different manufacturers:

1. Electrical Machines Laboratory model: EMT 180, manufactured by Feedback Instruments, Ltd., and

2. Universal Laboratory Machine (ULM) model: H-REM-120CM, manufactured by Hampden Engineering Corp.

EMT 180 Dissectable Machine

The Feedback equipment consists of a dissectable machine which can be assembled in a dozen or more configurations as either an AC or DC machine and to operate in a motor or a generator mode. During generator operation it is driven by a 1/3 hp DC shunt motor. While operating as a motor it is loaded with a Prony brake which measures load using a spring-loaded gauge.

The Feedback equipment has been very useful in providing students with a feel for machine design and construction. At the same time it has caused much grief. Assembly and disassembly by students week after week, and sometimes several times in a week when multiple labs were using the equipment, has been destructive. Personnel from the Engineering Technology (ET) Division mechanical and electronics maintenance shops have rebuilt, redesigned, and refurbished more than 50% of each machine, often numerous times. A second deficiency is that this assembly and disassembly, and in many cases the wiring connections required, are very time-consuming. When mistakes are made, additional time is spent trouble-shooting and resolving errors. There is some advantage to and pedagogical benefit derived from assembling , wiring, and trouble-shooting; however, as the frequency increases, even to the extent of consuming an entire 3-hour lab period, their usefulness becomes diminishingly small.

A third detriment with the dissectable machines has been that their machine characteristics (such as a shunt generator open-circuit characteristic or an induction motor speed-torque characteristic) are not of a high quality due in part to the machine's construction. Instrumenting has been problematic. The Prony brakes, for example, have been very troublesome.

Universal Laboratory Machine

The second equipment type, the Universal Laboratory Machine (ULM), can also be used in a number of different AC/DC, motor/generator configurations. It is fundamentally higher quality equipment and thus considerably more costly. These machines are also physically larger with a maximum capability of approximately three kilowatts. The downtime has been comparatively low, resulting in low maintenance and repair costs as well as time. The machines are designed and constructed so they are of a quality comparable to industrial-type equipment. The resulting operating characteristics are of similar quality. The instrumentation used in taking measurements has a more negative impact on the quality of the resulting characteristics than the machines themselves do.

The biggest frustration with this equipment, as with the former, has been the time required to make the necessary connections and in setting up the requisite instrumentation. This was especially so when in the power systems course, for example, the students were required to interconnect two of these machines to operate in parallel and then use an RLC load bank and/or a third ULM operating as an induction motor as loads forming a miniature power system.

LABORATORY REQUIREMENTS

In each of the rotating machines laboratory courses (EET 1142 and EET 1151) at UPJ, 10-12 laboratory assignments are required per semester; all require either a formal written report or a formal oral presentation (usually two or three each semester). In the three power systems courses (Power Systems I, EET 1152 is required; Power Systems II, EET 1153 and Industrial Power Systems, EET 1154 are elective courses) the laboratories have for many years been (1) a combination of work in the laboratory using the equipment previously discussed, (2) field trips to the local electric-utility company (GPU Energy) facilities and industrial plants, and (3) computer assignments such as short-circuit current calculations or protective-relay coordination. In their paper in 1995, DeWitt and Skvarenina indicate they arrived at a similar laboratory curriculum when developing a power distribution course at Purdue[1].

Various software packages have been used with the power systems courses, some written by students (as term projects or as a senior-year or capstone project) and others written and marketed commercially. Currently we are using ETAP, a commercial package developed by Operation Technology, Inc., of Irvine, California.

THE POWER SYSTEM SIMULATOR

Purchasing Decision

After reviewing the departmental objectives and past experience, alternatives for new power systems/rotating machines laboratories were considered. The following observations were made:

1. First, cost for this type of equipment is high, a major expenditure of funds (a once-in-twenty-years commitment).

2. This type of equipment has a long life (expected to be in excess of 20 years).

3. The University would live with the decision and be constrained by it for many years.

4. The possibility always exists of a major technological paradigm shift, causing the equipment and techniques to become obsolete.

We proceeded through the evaluation process and arrived at a decision to purchase the Hampden Corp. equipment. We continue on with an expectation and hope that the equipment can be maintained in a reasonably viable state with minor periodic equipment upgrades (such as replacement or upgrading of the personal computer used to control and operate the simulator). Our experience with other Hampden equipment gives some confidence that the equipment maintenance would be minimal.

Purchasing, manufacturing, and installation required most of a year.

Simulator Configuration

The simulator consists of seven panels or sections as follows:

Section 1 represents a generating station with two alternators. These are connected to a ring bus which supplies two parallel overhead and two parallel underground transmission lines.

Section 2 represents a generating station with a single alternator, master instrumentation, and station service loading.

Section 3 represents a substation and residential-type distribution and loading.

Section 4 represents typical industrial loads with varying power factors. Emergency generation, power factor correction capacitors, and voltage regulating equipment are available.

Sections 5 & 6 represent commercial distribution and substation operation such as is typical of a city or large metropolitan area electrical distribution.

Section 7 contains provision for interconnecting the simulator with the local utility company system. This might be considered an intertie with an adjacent power system [2].

Additionally there is metering and protective relaying associated with equipment in each section. Provision has been made to interject faults at seven locations within the power system, allowing protective relays to be set, and then tested.

All simulator functions can be performed manually utilizing switches mounted on the simulator face or remotely from a computer with supporting software.

STUDENT REACTION

The First Experiment

We were pleasantly surprised and pleased with the initial student response. They were awed by the obvious complexity and physical size of the equipment, intrigued with the possibility of using it themselves.

We have found that the students can be adequately prepared after an hour of hands-on demonstration to continue on their own. Two people are stationed at the simulator and another pair at the computer. They "walk through" start-up procedure of a generator, then on to the interconnections with the transmission and distribution systems and finally the application of loads, residential or industrial , in about an hour. Every ten or fifteen minutes individuals are rotated so that at the end of an hour all are comfortable with all aspects of the simulator operation, both manual and from the computer console. They are left on their own to develop one or more observations, such as voltage or frequency regulation at the generator, voltage regulation at the load, or system voltage spread profile [3,4]. These topics would already have been introduced in reading assignments and/or discussed during lectures, so the students are able to proceed quite independently.

Subsequent Experiments

A second visit with the simulator might be used to parallel two alternators. The requirements for parallel operation or synchronization are reviewed: "(1) same phase sequence on both generators, (2) same frequency of generation, (3) same magnitude of voltage, and (4) same voltage phase angle at instant of closing the [synchronizing] switch." [5] The simulator has both a synchroscope and lamps for using "the three-light-bulb method" [6] to establish that the synchronizing requirements have been satisfied.

Again this instructor-assisted introduction requires approximately an hour and then the students are left to pursue a variety of additional topics such as power factor correction, voltage regulation with transmission lines of differing lengths (the simulator has provisions permitting the instructor to select several different lengths for the transmission lines), or the system effects of paralleling transmission lines with differing impedances.

In subsequent laboratory sessions these continuing investigations can be done with limited instructor involvement. The students gain confidence rapidly and are particularly enthusiastic about operating the power system from the computer control console.

System Protection--Protective Relaying

When Professor Stevenson was preparing the fourth edition of his classic text, he sent questionnaires to many of us requesting suggestions for the new edition. In his subsequent preface he notes: "The most popular suggestion was for a chapter on system protection, and accordingly that subject has been added to the other four main topics of load flow, economic dispatch, fault calculations, and system stability" [7]. This was a great addition to the text. System protection is a very unifying topic and crucial to a comprehensive understanding of a power system design and operation. For this reason in particular I, for one, was saddened by the elimination of this topic in Grainger's [8] rewriting of the text.

It has always been difficult to include this significant topic in the lab. The simulator has a variety of protective relays which the students can set and test with respect to current magnitude and time. For a third time, this requires some instructor involvement. We are currently using the Glover/Sarma text [9] which has a chapter on system protection. After or while covering this chapter, we can begin using the simulator. Once the students have developed some familiarity with relays and how to modify their settings, they again quickly gain self-confidence and proceed to different circuit configurations and fault problems.

The ability to demonstrate system protection concepts has been one of the most satisfying experiences with the equipment. This seems to be true from both the students' as well as the instructors' point of view. The students do see a "**power system**."

SUMMARY

The power system simulator has been in use for seven semesters; it has been a principal component of the laboratory exercises associated with 10 courses (this represents about 20 lab courses, since we usually have two laboratory sections per lecture class). It has been used for one or more periods in labs associated with other courses (such as the first circuits lab to introduce the need for and uses of electricity in a general way and to provide an overview of the EET curriculum). Modifications were made to access the power system and do power system quality assessments. This was done as a senior project (capstone project) by a student team. Other lesser individual student projects have been accommodated by the simulator.

The power system simulator illustrates a variety of electrical principles and equipment being used in a practical setting. Besides the obvious rotating machines, transformers, and power system elements there are examples of analog and digital electronics, microprocessors, computers, communications, control systems, and electromagnetic fields.

Benefits

The positive results from having purchased the equipment include the following:

1. The labs are fast-paced such that the students are quickly involved in testing or experiencing principles and concepts that have been discussed in lectures.

2. Considerably less lab time is lost due to equipment failure and none caused by wiring errors.

3. Student interest and curiosity is considerably enhanced.

4. Complaints about this equipment are almost nonexistent, which reduces complaints concerning any lab where it is used.

5. The amount of time required of the ET Division maintenance personnel to service the labs involved has been reduced.

6. Topics such as power system protection and protective relaying issues can be treated that were not possible previously.

Students now see the simulator for several semesters before they have the opportunity to use it. Anticipation increases with time, like the plot in a well-developed mystery story. Students have a heightened sense of accomplishment and can relate what they are doing to "real world", day-to-day activities of practicing engineers. The depth of the course content is greater, both in lecture and lab, since more time is spent on principles and concepts.

An adjunct benefit has been publicity. The simulator has been featured in local newspaper articles and in several college publications. This has brought positive attention to both the EET Department and the ET Division. It is a great "show piece" for visitors, such as politicians and business and industry representatives. But perhaps of a more practical benefit to us is when potential students and their parents visit and want to tour our facilities.

Concerns

From the outset there was concern about how to use a single piece of apparatus with 10 or 12 students in a lab. Because of present enrollment trends the lab sections have tended to be less than this. We have been able to keep 9 or 10 students involved and occupied by effectively "directing traffic"--this consists primarily of rotating activities such as operating the computer, making readings, recording data, etc.

However, the optimal student complement seems to be four to seven. The ideal number is more a function of the students and their ability to work cooperatively than the particular activity being undertaken.

The other earlier concerns are still extant--potential early obsolescence and potential significant maintenance costs. We proceeded on the assumption that neither of these would materialize and continue with this same expectation. Nothing new has developed to cause additional concern.

CONCLUSION

The faculty are still learning how to effectively utilize the simulator. There are many more possible activities (experiments or labs) than time permits. Being efficient and effective are probably our most significant challenge. As of this writing we are more confident and satisfied with the decision to buy the simulator than when it was initially made.

Rotating machines labs where the power system simulator is used are more effective. The effectiveness in power systems labs is even more obvious. The students are clearly more satisfied and, we think, better served. We have concluded that it was a good decision for us.

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BIOGRAPHICAL INFORMATION

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