Role of Laboratory Education in Power Engineering: Is the Virtual Laboratory Feasible?

Part II

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Keywords: Laboratory, education. virtual laboratory, electric power

Abstract. IEEE PES sponsors a panel session in the summer power meeting in Seattle on laboratory education in power engineering. Six short and one full paper summarize the opinion of the panelist. This paper contains the summary two of the presentations.

The objective of the panel is to discuss the roll of laboratory education in power engineering at both the graduate and undergraduate level. The question is what type of laboratory courses is needed? Power electronics, electric machines, system simulation, etc?

The second objective is to assess the status and value of computer-based virtual laboratories. This includes the presentation of experience with virtual laboratories and a list of available tools.

The teaching of power system operations can be improved using a simulation laboratory. The available simulation tools and the assessment of their value will be an important topic of the panel.

Last, but not least, the last presentation will give opposing views, arguing for the traditional laboratory use. This paper contains the summary two of the presentations.

I. Modernization of Classical Electric Machine Laboratory

A. Introduction

One of the major problems of electric power education is the lack of hardware knowledge. The students concentrate on the use of computers and writing programs. The lectures concentrate on the theory and the development of problem solving ability. There is no time to teach the hardware.

Simultaneously, industry expects basic hardware knowledge from the young engineer. It is very disappointing when a graduate engineer is unable to distinguish between an induction and synchronous motor or can not recognize the three-phase system.

The laboratory exercises together with site visits are the major sources of the hardware knowledge. Traditionally the power laboratory has large, several horsepower machines. The operation of these machines requires special skill and is not without danger. Consequently, the laboratory requires constant supervision. The fashionable open laboratory method, where the student selects the most convenient time for work, can not be used because of safety problems. We found that old-fashioned 5 – 20 hp rotating machines make students uneasy, and these machines convey a message of obsolescence.

The industry uses digital data acquisition systems. Even the modernized university laboratories use old fashioned analog meters. The students must read the results and make notes. This creates a constant source of errors that has been eliminated in the industry by the use of digital data acquisition systems. Unfortunately, the state-of-art digital data acquisition system is expensive.

The laboratory exercises are found to improve practical knowledge. However, this requires the use of real motors and transformers. Is it important that the students assemble the circuits to obtain a hands-on experience? The computer-simulated motors are useful economical tools to teach concepts; however, the student should see and handle the hardware that he or she tests.

Another aspect of the modernization of the laboratory experience is to increase students' interest in electric power. A student using modern equipment realizes that electric power engineering is not an obsolete subject. Electric power uses new technology and modern computer based equipment.

The objective of this paper is to propose the modernization of the classical power laboratory.

B. Laboratory Modernization

Most universities have replaced the old large machines by small modern 50-100W machines. The most frequently used are Canadian manufactured laboratory units [1]. Figure 1 shows a typical unit. The upper part has six slots, which is suitable to accommodate different experiments. In this case Figure 1 shows the test of a capacitor start single-phase induction motor placed in the middle of the test set up. The left side of the motor is the power supply, the right side contains the capacitors used to start the motor. The upper row shows the analog volt (left), current (right) and watt (middle) meters. This is a versatile and friendly set which pleases the students. The only problem is that the motors operate with 120V or 208V, which can be a safety problem. ASU is experimenting with the reduction of the line-to-line voltage to 60V. This would results in a line to ground voltage of around 35V. The low voltage would eliminate the safety problem and permit the use of the open laboratory.

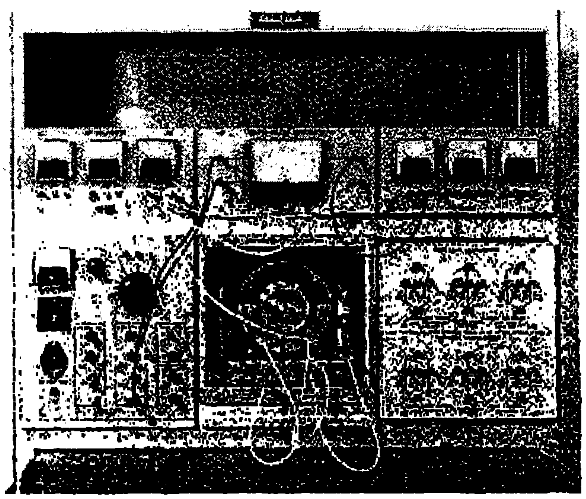

Figure 1. Motor test setup [1].

Considering the basic energy conversion course, the laboratory should support the lecture. We recommend two hardware exercises and eight experiments.

The purpose of the hardware exercises is to teach the construction of a transformer and motor.

1. Transformer technology. The students receive a bunch of iron core laminations, winding holder and wire. First they make a winding with 50-80 turns and assemble the transformer with, and without, overlap. This is followed by the measurement of magnetizing current and turns ratio. The third part is the calculation of the magnetizing current from the dimensions.
2. Induction motor technology. The students disassemble a single-phase induction motor and identify the parts and measure the dimensions. The flux induced voltage is calculated from the measured values.

The recommended tests are:

1. Three phase power, VAR, VA, power factor measurement.
2. Transformer test (Open, short circuit and load test).
3. Three-phase induction motor test.
4. Single-phase induction motor test.
5. DC shunt motor test.
6. DC series motor test.
7. Synchronous generator test.
8. Synchronous motor test.

The concept is that in each case the students perform the open circuit and short circuit, or blocked rotor tests and calculate the equivalent circuit parameters. After that, they load the motor or transformer and measure voltage drop, speed variation, torque, input power, etc. The same values are calculated from the equivalent circuit and the measured and calculated values are compared. This method assures that the students see a practical use of the test.

C. Measuring Method

In industry most laboratories use digital data acquisition systems. It is suggested that the hand held digital and analog meters be eliminated entirely, and replaced by digital data acquisition systems. We developed a LabView® program [2] based system, but other hardware/software combinations may be used to interface the primary sensors with lap-top computers, PCs, and base station computers in the laboratory.

The basic system consists of three current transformers (CTs) and three voltage dividers. The clip-on current transformer provides 0.05-5V voltage between 0.1-10A. A LabView card placed in a PC digitizes the voltages generated by the CTs and voltage dividers. Figure 2 shows the simple LabView program used for this test.

Figure 3 shows the appearance of the test results on the screen. These test results are stored in an Excel file. The test results include the power in watts and the rms. current and voltage values. In addition, the student can save 2-3 cycles of the digitized voltage and current waveform.

Digital techniques permit more elaborate tests and collection of data. It should be recognized that the laboratory exercises must be upgraded to utilize the advantages of digital data acquisition. Some software may be provided to the students to accomplish more complex calculations and tests. At ASU the students use the Mathcad® program to evaluate the test data. As an example, the digitized waveforms permit the calculation of harmonic content by FFT analysis and the calculation of the total harmonic distortion (THD) factor. The students like to use the digital data acquisition system.

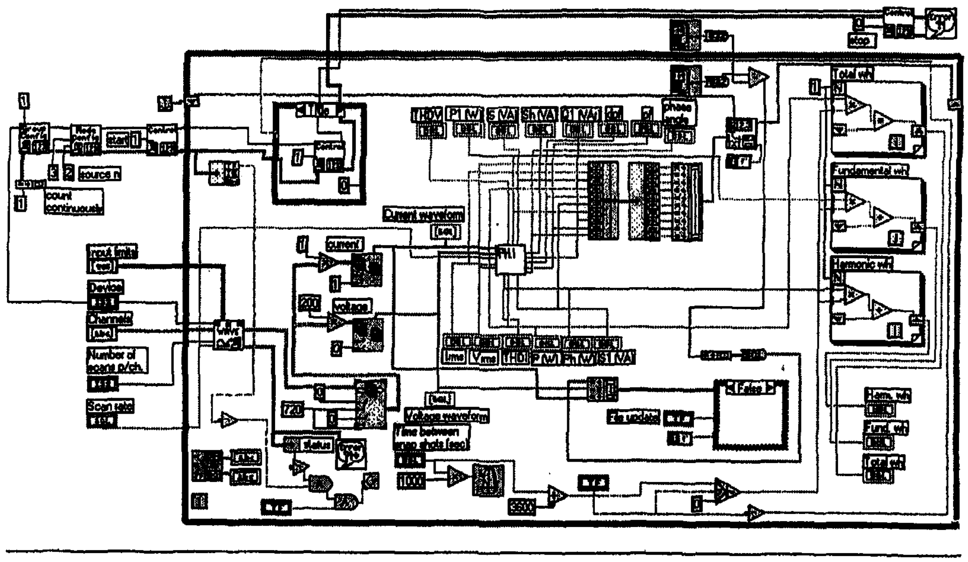

Figure 2. LabView program used for voltage, current and power measurement.

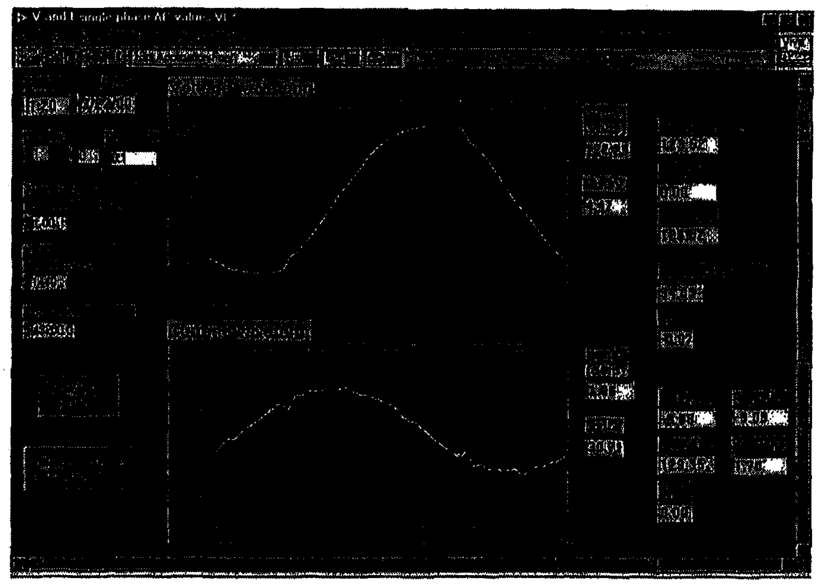

Figure 3. Test results of the PC screen [2].

D. Conclusion.

1. This paper presents an example of a modernized classical electric machine laboratory by using small modern low-voltage machines and digital data acquisition systems.
2. The introduction of simple technological exercises have improved student understanding of basic hardware.
3. The introduction of digital data acquisition systems has improved the students' evaluation of the laboratory.

E. References

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II. COMPUTER SIMULATION IN PLACE OF LABORATORY EXPERIMENTS

A. Introduction

One of the difficulties of teaching power engineering is the sheer size of generation-transmission-distribution systems. Indeed, the components of such power systems alone are large enough to fill specially equipped high voltage laboratories. How then, can the student be exposed to these large systems that can span continents and more importantly, be taught the fundamental principles of design, analysis, operation and control of such systems?

After the 1965 Northeast blackout, it became quite clear that the design and analysis of power systems could no longer be done by hand and even the transient analyzers available in those days were not scalable to the problem size. Digital computers were employed universally for the analysis of the behavior of power systems. Hence, the use of simulation has become an integral part of power engineering practice and also, power engineering education.

The main question then is not whether simulation should be used for teaching, because simulations have been used in power engineering courses for over 30 years, but whether simulation can be used to teach concepts that are normally taught in the laboratory. In other words, digital computer simulation has been used to teach analysis of power systems but can we now use it to teach the more 'hands-on' or the operational side of power engineering?

The answer is that the technology is now well developed to be able to teach the operation and control of large power systems by digital simulation in laboratories. However, it is not quite correct to say that this implies the replacement of present laboratories with computers. Most of the present laboratories in power engineering education are used for teaching the behavior of components, mainly rotating machines and transformers but also protective relays, bushings, insulators and other such components. What the technology promises today is the ability to do laboratory type experiments on, and hence learn, the behavior of large power systems, something that has not been possible earlier. Thus the argument in this section is not to replace the present hardware laboratories but to enhance them with virtual laboratories that bring in a new dimension.

B. Simulations

The dramatic increase in the power of the digital computer has made simulation of larger systems and faster phenomena more feasible today than ever before. The real time simulation of electromagnetic transients for small power systems is possible today and so is the real time simulation of electromechanical transients of large power systems. Moreover the graphical user interfaces (GUI) of today are such that the simulations can be watched on the screen in so many ways that the understanding of these phenomena, and hence student learning, can be enhanced significantly.

The power flow simulation that shows the steady state operation of a large power system has been available for over 30 years and has been used extensively. It is more recently, however, that decent GUIs for power networks have become available. Moreover, standardization of power flow data has now made the data from real power systems available to people outside the traditional power companies. Thus, it is possible for a student to study the steady state behavior of the whole Eastern Interconnection by changing generation and load patterns, by disconnecting and connecting branches, etc.

This is invaluable hands-on experience available to students today, something that would take years of on-the-job exposure for engineers and operators only a few years ago. Are there phenomena that can only be seen on such large systems through an easy GUI? The answer is overwhelmingly yes. Unexpected parallel flows (known as 'loop flow' in the industry), voltage collapse without any contingency, unexpected limit violations after a contingency, are all very hard to predict for a large system and simulated exposure to such exposure is the only way to quickly familiarize someone with such phenomena. The GUI is important because the old-style tabular displays are not very conducive to quickly grasping behavioral phenomena.

C. Operator Training Simulators (OTS)

Operator training simulators are a more advanced version of power system simulation in which the steady state simulation is augmented with some real-time dynamic simulation [1,2]. In present day OTSs, the dynamics represented are that of the slow response of the power plants [3], as well as the uniform frequency behavior of the whole system in response to load changes. The decreasing price and increasing power of computers has now made it feasible to even simulate the electromechanical response of individual generators, but such an OTS has not yet appeared commercially.

In addition, the GUI is particularly designed to mimic that normally used by the operator in a control center. This is a significant difference from the usual power flow GUIs like in Figure 1, and the trainee/student can actually see another level of substation detail like breakers, transformers and generators in a substation as shown in Figure 2. This detailed view of the power system coupled with the changes reflected in real-time exposes the student to exactly the same environment as a system operator sitting in a real control center.

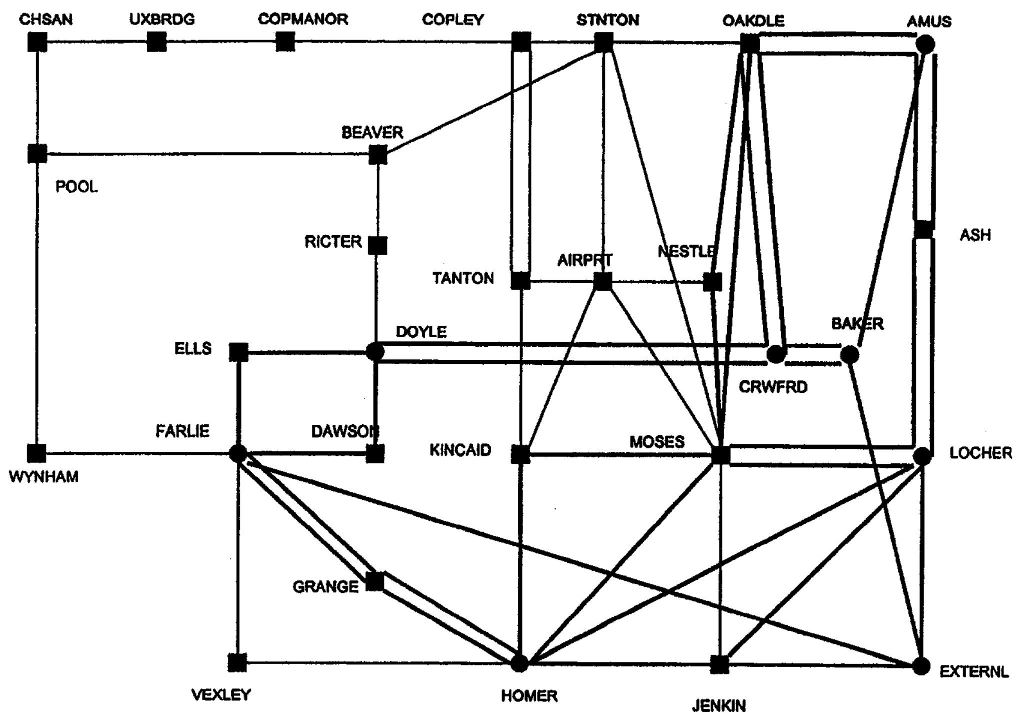

Figure 1. A typical one-line diagram of a power system.

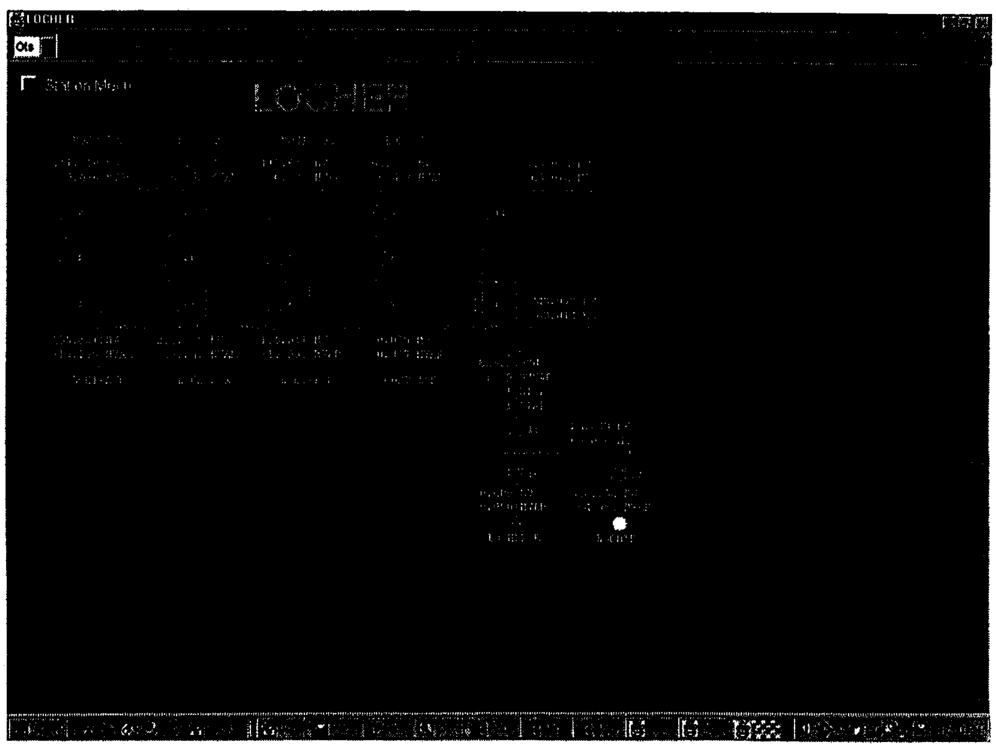

Figure 2. A typical substation diagram in a control center GUI.

The main advantage of such a simulator is its teaching capability. Many scenarios can be rapidly presented to the student, something that may take years to encounter on the job, and particularly extreme scenarios can be presented that, hopefully, will never be encountered on the job. Most important, is that the scenarios can be made very realistic [4] by ensuring proper modeling and benchmarking against the real system.

At Washington State University, we have such an OTS available for student use. Although it has mainly been used for research, experiments are being developed to teach students the different phenomena that are otherwise difficult to teach. Automatic generation control (AGC) and voltage control are two areas that have been identified as particularly suitable for this environment.

D. Concluding Remarks

Although it is quite obvious that power system simulations are excellent tools to use for 'hands-on' experience, setting up this virtual environment requires a completely different set of logistics than a hardware laboratory. First, the maintenance of such a laboratory requires computer system analyst support rather than technician support. Although computer support is readily available in all Electrical Engineering departments today, the specialized knowledge required to maintain power systems software is not. Thus it falls to faculty and graduate students to maintain the rather complex set of simulation software that often includes GUIs and database managers not familiar to them.

Second, the software environment for these advanced simulators has not been very stable. Until recently, only the Unix environment has been capable of handling such software, and the absence of standardization in Unix on different platforms has created many porting difficulties. The present day NT environment, and the de-facto standardization of Linux, will largely solve this problem.

Third, the maintenance of the database for a large power system including all its substation configurations requires a lot of effort that is simply not available at universities. Again, standardization of the database has helped this situation. What will really simplify this is if industry makes their system data available to universities in standard formats, just as their power flow data is now available publicly.

Finally, these simulators are still so new that their potentials as teaching tools are not yet realized. It takes a lot of effort to develop scenarios, but more than that, it takes a lot of understanding to develop scenarios that are particularly suitable to teach certain concepts. Often, the faculty do not have the practical experience required to find the best scenarios and may need to partner with utility personnel more familiar with the particular power system to do so.

Nonetheless, the potential for the utilization of such simulators in teaching is almost endless. We are on the verge of developing more new simulators and the tools to make their use even easier. Without any doubt, these simulators will turn out to be better teaching tools for such large systems than the component based laboratories used today. However, there will always be a need for the present laboratories to teach the components.

E. References

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F. Biographies

George G. Karady received his BSEE and Doctor of Engineering degrees in electrical engineering from Technical University of Budapest in 1952 and 1960 respectively. Dr. Karady was appointed to Salt River Chair Professor at Arizona State University in 1986. Previously he was with EBASCO Services where he served as Chief Consulting Electrical Engineer, Manager of Electrical Systems, and Chief Engineer of Computer Technology. He was Electrical Task Supervisor for the Tokomak Fusion Test reactor project in Princeton. Dr. Karady is a registered Professional Engineer in New York, New Jersey and Quebec. He is the author of more than 150 technical papers.

Manuel Reta-Hernández (M '88) was born in Fresnillo, Zac, Mexico. He received his BSEE and MSEE from Universidad Autónoma de Zacatecas (UAZ), and Universidad Autónoma de Nuevo León respectively. He worked at UAZ in the Electrical Engineering Department from 1982 to 1993. In 1998 he received his Ph.D. in Electrical Engineering at Arizona State University (ASU). He is currently working in research and teaching as a Postdoc visitor at ASU. His areas of interest are power quality, power electronics, electric power systems, and renewable sources.

Anjan Bose received his B.Tech. from the Indian Institute of Technology,Kharagpur, in 1967, his MS from the University of California, Berkeley, in 1968, and his PhD from Iowa State University in 1974, all in Electrical Engineering. Dr. Bose has over 30 years of experience in industry, government and academe and his research is in the computer control of the electric power grid. At present, he is the Distinguished Professor in Power Engineering and the Dean of the College of Engineering and Architecture at Washington State Univversity