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

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Abstract. IEEE PES sponsors a panel session in the summer power meeting in Seattle on laboratory education in power engineering. Six short papers and one full paper summarize the opinions of the panelist. This paper contains the summary of the four 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 operation can be improved using a simulation laboratory. The available simulation tools and the assessment of their values 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.

I. Laboratory Experiences for Undergraduates in Electric Power Engineering

Significant percentages of the graduate students in electric power engineering are working in industry. Many times these students are supported by industry. To meet with the students' need, WEB based and distance learning techniques are used increasingly for graduate education. The laboratory education in the case of a WEB course or distance learning course is difficult. At the undergraduate level, the increasing investment cost hinders modernization of machine laboratories.

The main objectives of the panel presentation are:

1. Identification of typical laboratory experiences in electric power engineering.
2. The advantages and disadvantages of a 'virtual laboratory' experience.
3. Typical laboratory specifications.
4. Identification of the needs for specialized equipment.
5. Identification of the potential continuing education and graduate education utilization of a power quality laboratory.
6. To discuss advanced simulation equipment, instrumentation, and sensors.
7. To conjecture and discuss some advanced concepts for an education power engineering laboratory.

A. Need for a Discussion of these Topics

Contemporary power engineering is a topical area within electrical engineering in which laboratories and measurement form a key component. Education at the undergraduate level in power engineering should include some exposure to AC circuit measurements, three phase circuit measurements, fundamental measurement concepts such as the two-wattmeter method, measurement of power factor, event recorders, digital fault recorders, digital oscilloscopes that can calculate the fast Fourier transform of a signal, and new instrumentation techniques and systems such as the LabView® system. Table 1 presents the topics for laboratory education. The educational value of these areas relate to:

- the development of basic AC circuit measurement skills,

Table 1. Main Topics

Topic	Implementation	Comments
Institutional issues	Competition for laboratory space	Methods of integrating specialized equipment into existing laboratories, time multiplexing laboratory use
Circuits topics	AC circuits measurements	These are basic skills that students should master in the area of voltage, current, and power measurements. The area includes three phase circuit measurement techniques.
Relaying applications	'Relay benches'	[redacted]
High voltage engineering	High voltage topics in the undergraduate program	[redacted]
Computer and software issues	Software needs	PSpice®, LabView
	Limitation of virtual laboratories	Many phenomena are second order and can not be seen with simple instruments
	Familiarity with computational packages	Matlab®, Mathcad®
Projects	Senior design projects	Examples of power quality project work
Transformers	Transformer modeling	[redacted]
Standards	Exposure to IEEE and other standards	[redacted]
Sensors	Advanced topics	Integrated sensors, instrument limitations, digital signal processing and measurement, optical measurement systems
Power quality topics	Basic measurement of voltage and current waveforms including expression of those signals in the frequency domain	Power quality topics may be used to illustrate concepts of modeling, bandwidth, digital signal processing, power electronics, and the consideration of nonlinear effects.
Power electronics	Power electronic projects	Used to illustrate the basic circuit types and also to build motivation among the students.
Solar related studies	Instrumentation needs	[redacted]
Graduate versus undergraduate laboratories	[redacted]	[redacted]
Cost issues	[redacted]	[redacted]
ABET requirements	Does a virtual laboratory give hands on experience?	[redacted]

- appreciation of voltage and current levels in power circuits,
- bringing together of digital signal processing, an excellent example of modeling, and practical application of instrumentation techniques.

There is also an element of motivation in including topics in power quality laboratory experiences to educational programs. This area offers a real opportunity to expose students to specialized instruments and state-of-the-art measurement techniques. Typical examples are listed in Table 2.

Table 2. Some potential innovative topics in an electric power engineering laboratory experience for undergraduate students.

Topical area	Innovation
Measurement equipment	Virtual laboratory
	Distance measurement
Sensors	Optical
	Integrated sensors
	Faraday and other polarized wave phenomena
Power electronics	PWM technologies

II. Mixed-Signal, Mixed-Technology Circuit and System Simulation Expertise in the New "Multi-dimensional" Power Engineer

As the influence of regulatory policy and technology innovation drive electric power systems to ever increasing levels of engineering complexity, it is prudent for power engineering academicians to re-evaluate the prospective employee skill set desired by the electric utility industry. It is clear that the electric power industry will continue its trend on the integration of information technology–computers, controls and communications–into their systems. Someday, the electric power system might even be described as a complex, "macroscopic" high-power integrated circuit (IC). The introduction of these technologies into the power system will change the way academicians view the role and scope of a power system engineer. To successfully compete in a very competitive industry, electric utilities will have to ensure that future power system engineers be conversant in the design and analysis of mixed-signal, mixed-technology (MSMT) systems. A MSMT system is a generic classification used to describe those electrical systems containing both analog and digital circuits while possessing interfaces to mechanical, chemical, biological, optical, or electromagnetic systems or subsystems.

When electrical engineering students are seeking advanced technical degrees (i.e., M.S.E.E.), many choose a technical path in either the microelectronics or computer engineering areas. Both of these specialization areas have extremely good job markets, pay well, are technically challenging, and are perceived to be "glamorous" by the rest of society. Thus, it is not surprising that power engineering is left "holding the door" as potential students seek advanced degrees in these areas. However, for those who do seek out the power engineering area, it is important that they experience a curriculum which adequately reflects the direction in which technology is flowing.

The so-called classical "power systems" engineer must be replaced by a "multi-dimensional" power engineer who is capable of understanding the integration issues (i.e., hardware and software) associated with equipment at the device, circuit and system levels. Of course, this is in addition to all the "other" skills which the student is expected to have before obtaining permanent employment. Some of these skills include

1. Being able to work in a team environment,
2. Be able to work independently (i.e., self-motivated),
3. Be able to understand and negotiate contracts, etc.
4. Be able to manage a construction project,
5. Be able to speak a second language,
6. Be able to communicate effectively (i.e., written and oral), and
7. Be able to identify every piece of hardware in the field, know how they work, why they work, and how to connect and disconnect them from the system.

In this last point, this expectation is virtually impossible without the help of either a student co-op experience, through extensive laboratory experience, or lastly, via sophisticated MSMT simulators.

Before "real-world" integration issues can be addressed, it is necessary to have a complete understanding of electric power device, circuit and system theory. This is most easily handled via computer simulation versus a laboratory environment. The simulation of power electronics, circuits and systems is nontrivial. Classical circuit simulation software such as SPICE™ is inappropriate due to model-related issues. More advanced tools that enable modeling and simulation of coupled-energy systems and mixed continuous-time and event-driven devices are necessary. Some examples include Saber™ and Modelica™. To effectively simulate these types of systems, multi-disciplinary knowledge is essential (e.g., device physics, circuits, linear and nonlinear system theory, computer programming, control systems, analog electronics, digital electronics, etc.)

In this presentation, we will demonstrate representative MSMT systems that the new "multi-dimensional" power engineer could incur upon graduation from an ABET-accredited undergraduate electrical engineering program. The major assumption here is that few of these engineers will actually work for an electric utility due to the present trend in outsourcing engineering tasks to consultants. Some of these systems might include:

1. The design of an IGBT gate drive circuit,
2. Thermal analysis of an IGBT pulse-width-modulated voltage source inverter,
3. The analysis of an internal combustion vehicle ignition system, and
4. The electromechanical simulation of an electric vehicle.

III. Power System Hardware Simulator for Power Engineering Education in Japan

A. Analog Simulator versus Digital Simulator

Historically, first, analog artificial transmission lines and miniature generators were used for power engineering experiments at universities, and AC network analyzers at utilities. Since the 1960s, digital simulations have become very popular, and have played very important roles in power system studies such as power flow, dynamic stability, surge phenomena, and optimization. At the time when digital simulations became popular, analog simulators were small-sized and did not have sufficient accuracy. Thus, analog simulators did not prevail much. But one cannot say that digital simulators are better than analog ones. Especially today, when analog simulators can be large-scaled and have sufficient accuracy.

B. Importance of TNS

Students who might go to power engineering fields in the future should be exposed to physical phenomena through hardware-simulator experiments in addition to theories at universities. Especially because power systems involve not only static phenomena but also dynamic and transient phenomena, real feelings would not be understood by numerical simulations only. Also skills dealing with experimental equipment are necessary in addition to numerical simulation techniques. Thus a systematic power engineering education system combining software and hardware simulations is necessary at universities, especially for graduate studies.

C. Components of TNS

Experiments for up to a 3 machine system can be performed with TNS at Waseda University. Basically the TNS is comprised of two blocks, one is a power system block and the other is a digital control block. An overall view is shown in Fig.1. The infinite bus, transmission line, and generator models are shown in Figs. 2, 3, and 4, respectively. Transmission lines and transformers are made with passive analog devices. OLTC's are also included.

Generators are made with active analog devises using electronics circuits.

Harmonics can be generated from the infinite bus system.

Loads are hybrid systems comprising with passive and active analog devices. AVR and GOV can be adjusted with programmable controllers. The constants can be changed using graphic display on the CRT screen.

Fault sequences and programmable controllers can change CB switching. 5V-peak/phase-system voltage and 100mA-peak/phase current are used. Thus there is no need to worry that students could be electrocuted by accidents. Monitors and recorders to observe and record various phenomena.

D. Experiments Using TNS

For undergraduate students:

1. U-1 Power flow analysis (including controllers)
2. U-2 Fault analysis (balanced and unbalanced)
3. U-3 Transient stability analysis
4. U-4 Surge phenomena analysis

For graduate students:

1. G-1 PSS for damping oscillations
2. G-2 Voltage instability phenomena
3. G-3 Harmonic analysis
4. G-4 Load frequency control

E. Transient Stability Experiment Using TNS

As an example the transient stability experiment is shown here. Transient stability is one of the most important subjects, which deals with the effects of transmission line faults on generators. With this experiment, students can learn the following phenomena: fault occurrence, CB actions (including re-closure), and controller behaviors. Students are asked to do the things listed below.

1. Before the experiment, understand the theory fully.
2. During the experiment
   a. Check power flow and AVR and GOV actions.
   b. Observe transient phenomena of the 3 phase circuit. See the phenomena (waves) of 50 Hz for about one second.
   c. Confirm the effects of parameter changes such as AVR gains, inertia constants, and fault clearing times.
3. After the experiment, analyze the phenomena using the recorded data.

Remarks expressed by students are as follows:

1. Interactions among P, Q, V, and f are clearly observed by their eyes, which are very impressive.
2. Phenomena of ms or sec order can be observed on the spot with wave memory displays, which are very interesting.
3. Post-fault analyses can be done easily with the recorded data, which seem very efficient.

F. Conclusions

Importance of hardware simulation has been addressed for power engineering education. An example at Waseda University has been shown. A systematic approach combining software and hardware simulations would be desirable and necessary for power engineering experiments.

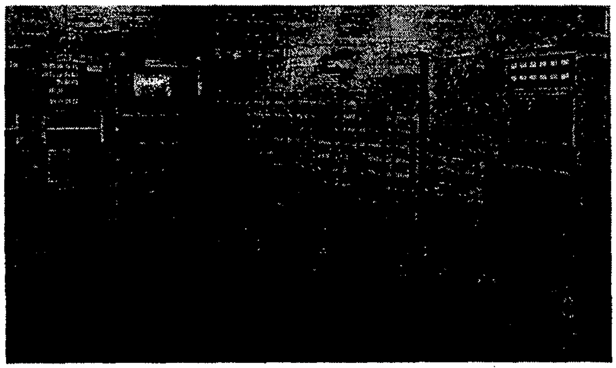

Fig.1 Overall view of TNS.

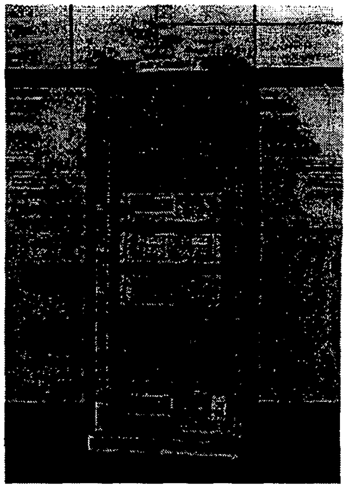

Fig. 2 Infinite bus.

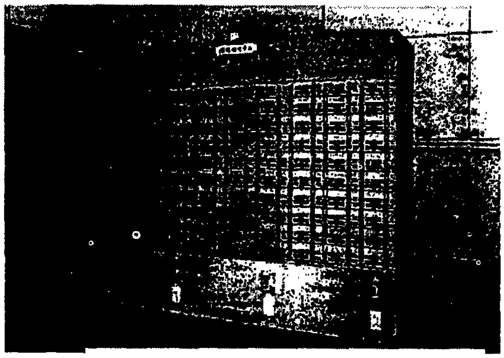

Fig. 3 Transmission line model.

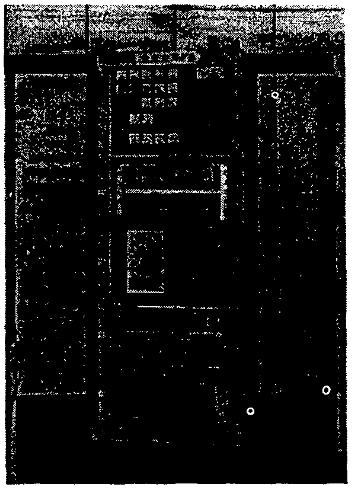

Fig. 4 Generator model.

IV. ENOUGH IS ENOUGH WITH SIMULATION

The widespread availability of powerful computing lures many science and engineering students to rely purely on computer simulation for design and analysis. Thus, students subsequently do not develop essential laboratory skills, nor do they gain insight on the advantages and limitations of using computer-aided design (CAD) for hardware. Computer simulations are only as accurate as the underlying mathematical model. Most models are developed to capture behavior under a pre-described set of circumstances. These circumstances may range from temperature standards, an electrically noise free environment, or ideal coupling to name a few. However, many of the problems that occur at the production stage of a product are due to non-ideal effects.

Frequently, problems that lead to delays in the design cycle arise at the hardware prototype stage. Many of the problems encountered at the hardware stage are due to non-ideal effects, such as electromagnetic interference, acoustic noise and/or vibration, or thermal management that are not predicted by a computer model simulation. Without sufficient laboratory experience, engineers are often at a loss to systematically counteract these difficulties, or over-design a retrofit at considerable cost to the company and/or customer.

Competence and confidence in the lab is essential for students pursuing an industry career. Industry needs engineers that can transform a paper design into functioning hardware that meets specifications and cost requirements, and who can anticipate and compensate for the limitations of the models, CAD tools, and analyses employed in the design process. Further, industry needs engineers that can develop a realistic plan and schedule for producing a functioning prototype from a paper design. Ultimately this intuition and knowledge results from laboratory and hardware experience in their coursework. Knowledge of manufacturing and production limitations gained, as a result of hardware and laboratory experience, is an extremely desirable skill in a highly competitive marketplace.

One of the objectives of an engineering program should be to provide a laboratory experience in which students develop the skills to integrate theoretical and practical aspects of their curriculum. Lack of hands-on laboratory experiences fosters a loss of intuition about the physical meaning and physical magnitude of system outputs. For example, using a computer simulation may lead a student to design a feedback controller using states which are attainable in a computer simulation, but which may not be physically measurable (observable). Without the intuition obtained through actual hands-on experience with a system, this scenario may become increasingly prevalent. Students need to be educated in how to verify simulated behavior and the possible shortcomings of computer-aided design and simulation. This experience can only be gained in the lab.

Laboratory and hardware experience is also advantageous for graduate students pursuing an academic career. Students in the classroom respond very positively to hands-on demonstrations and to "real-world" applications. Faculty with hardware experience are better able to correlate theoretical background with concrete examples of the material, which increases students interest and promotes material retention. On the research side of academia, there is a tremendous amount of funding available from industry sources for research that has direct applications to product development. Many federal funding programs are becoming more oriented toward engineering applications, or requiring experimental or hardware validation of concepts and modeling. Junior faculty that have hardware and laboratory experience can more easily attract industry support. For faculty, the ability to attract industry funding can be the key to developing a growing and productive career path that includes a thriving research program.

Young engineers need a laboratory experience to develop the necessary problem solving skills to succeed on the job. Without this background, their ability to develop a systematic approach to a system design is severely compromised.

Computer simulation is a very powerful tool when used as a significant part of the development process, but ultimately, all designs must function within specifications in the real, non-ideal world. Engineers that have the background and intuition that comes from hardware experience can, in turn, develop better models for the computer-aided design process. Simulation and hardware must go hand in hand for successful and time-efficient product design and development.

V. REFERENCES

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VI. 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.

Gerald Thomas Heydt is from New York. He spent his early life in Nevada, and he received the BEEE (1965) degree from the Cooper Union. His MSEE (1967) and PhD (1970) degrees are from Purdue University, West Lafayette, Indiana. Dr. Heydt has industrial experience with the Commonwealth Edison Company in Chicago, and E. G. & G. in Mercury, Nevada. He also has worked with the United Nations Development Program in various positions around the world. In 1994, Dr. Heydt took a position as Center Director and Professor of Electrical Engineering at Arizona State University, Tempe, Arizona. His interests are in electric power quality, distribution engineering, and applications of computers in power system analysis. He is the author of two books, one on electric power quality, and the other on computer analysis of power systems. He is a Fellow of the IEEE and a member of the National Academy of Engineering.

Shinichi Iwamoto received his B.E. and M.E. and Ph.D. degrees form Waseda University, Tokyo, Japan in 1971, 1975 and 1978, respectively. From 1972 to 1974, he was at Clarkson University, N.Y. and received a M.S. degree. Presently he is full professor at Waseda University. From 1992-1993 he was at University of Washington as a visiting professor. His research interests are load flow, stability and AI applications to power system problems.

Kraig J. Olejniczak (S'85, M'91) was born on February 6, 1965, in Green Bay, Wisconsin. He received his B.S.E.E. from Valparaiso University, Valparaiso, Indiana, in 1987. He received the M.S.E.E. and Ph.D. degrees from Purdue University, West Lafayette, Indiana, in 1988 and 1991, respectively. Presently, Dr. Olejniczak is a professor of electrical engineering at the University of Arkansas where his research interests are in the areas of electric power quality, power electronics, and power electronics miniaturization and packaging.

H. Alan Mantooth (S'83 - M'90 - SM'97) received the B.S. (summa cum laude) and M. S. degrees in electrical engineering from the University of Arkansas in 1985 and 1987, respectively, and the Ph.D. degree from the Georgia Institute of Technology in 1990. He joined Analogy, Inc. in 1990 where he focused on the research and development of AHDL-based modeling tools and techniques. Besides modeling, his interests include analog, mixed-signal, and mixed technology design, test, analysis and simulation. In 1998, he joined the faculty of the Department of Electrical Engineering at the University of Arkansas, Fayetteville, as an Associate Professor. Dr. Mantooth has published numerous articles on models, modeling techniques, and modeling strategies. He is co-author of the book Modeling with an Analog Hardware Description Language by Kluwer Academic Publishers (1995) and has served on several technical program committees for IEEE conferences. Dr. Mantooth is a member of Tau Beta Pi, Eta Kappa Nu and numerous other academic honor societies.

Mariesa L. Crow graduated with her BSE (EE) from the University of Michigan and her MS and PhD (EE) from the University of Illinois. Her research interests have concentrated on developing computational methods for dynamic security assessment and the design and control of power electronic devices for bulk power system applications. She is a member of the IEEE Power Engineering Society System Dynamic Performance Committee, Power Engineering Education Committee, and the Dynamic Security Assessment and FACTS Planning working groups. She has been involved in research projects with the National Science Foundation, the Electric Power Research Institute, Ford Motor Co.,Sandia National Laboratories, Ameren Corp., Illinois Power Co., the University of Missouri Research Board, and the Missouri Institute for Instructional Development. Mariesa Crow is a registered professional engineer (Missouri).

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