Embedding Remote Experimentation in Power Engineering Education

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***Abstract*—Engineering education by its nature is a costly program in university environments. Perhaps the most costly component is the laboratory facility, usually consisting of specialized equipment. Effective instruction of some topics in power engineering education requires experience with actual equipment, rather than small-scale replicas or simulation. In this paper, a new laboratory approach is described, as implemented in a virtual, Internet-based, experimentation platform. This virtual laboratory (VLab) utilizes real equipment distributed among multiple universities from which remotely located students can perform experiments. The software solution is a multiuser, client-server architecture developed in the LabVIEW environment. Implementation details including video, chat, archiving, and the hardware and software platforms are presented in the paper. An example presented herein is the study of current and voltage waveforms while controlling relays and low-voltage contactors. The applications have been tested with student teams enrolled in the electrical engineering department of Politehnica University of Bucharest and the power engineering program at Arizona State University.**

***Index Terms*—Education, e-learning, relays and breakers closure, remote experimentation, web-based laboratories.**

I. Introduction

THE higher engineering learning environment has to be at least contemporary, if not ahead of the leading technologies of a society. Until now, we can report a significant effort expended into organizing off-campus delivery of lessons using multimedia tools [1]. Laboratories based on simulation techniques have also been set up for remote access [2]. The first goal of implementing such facilities into engineering curriculum is to attract students to computer-mediated learning [3], [4].

Recently, scheduling flexibility for laboratory classes has become an important issue, since many students have extended commitments, especially part-time students enrolled in master-level programs. One solution addressing these needs is to develop web-based laboratories, on an Internet platform from which real (versus simulation) experiments can be conducted at anytime, without instructor surveillance or guidance.

Engineering education has also a costly component that is not directly time-related: sophisticated (and implicitly expensive) equipment, whose use might be difficult because of insufficient availability. Issues of equipment availability are often addressed practically by the time multiplexing of laboratory schedules and through the use of laboratory teams of students who work together rather than individually. But each of these solutions has their drawbacks—mainly relating to providing each student with hands-on experiences in a way that can practically fit into their education schedule. Existing equipment can be shared among researchers and students enrolled in different programs and with different schedules and knowledge levels. Offline data processing, often required after completing a laboratory experiment, can be accomplished either in the classroom—which supposes a longer student presence in the laboratory and an appropriate computer setup—or in other locations, which means that experimental data have to be somehow transferred to the offline processing unit, the strongly preferred solution being in this case the use of the Internet layer. When simultaneous users are dispersed and remotely located, they are not sharing the same real location, but a virtual one: the laboratory platform.

Institutional collaboration can be achieved through the virtual exchange of equipment, which can be accomplished in a "webring." In this concept, each institution provides specific experiment(s), for which laboratory equipment is shared together with experimental data and protocols. The bandwidth and number of users from each institution is "paid" in proportion to their contribution in terms of equipment and accessibility time. This is an impetus for overseas cooperation since the time differential favors extended use during periods when the home institution students are otherwise asleep. The diversity of power engineering topics taught and practically performed can be extended in this way.

Most educators have utilized Java platforms for greater portability and easier access via web browsers [5]. There are also projects [6] developed in the LabVIEW environment that can be executed on a LabVIEW player freely distributed by National Instruments.

II. Virtual Laboratories in Power Engineering

The dominance of the Internet is acknowledged in the development of information and communication technology that has made Web-based distributed solutions increasingly attractive. Apart from providing other services, the World Wide Web is being looked upon as an environment for hosting modeling and simulation applications [2], [7]. One of the major advantages such models provide is their ability to help students develop

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technical skills. The users manipulate virtual hardware (a simulator) to develop proficiency for operating the corresponding real world system. To preserve the advantage of the Internet, web-based laboratories require a tradeoff between simulation and actual operation of the laboratory equipment. A laboratory is commonly defined [8] as: 1) a place equipped for experimental study in a science or for testing and analysis; a place providing opportunity for experimentation, observation, or practice in a field of study, or 2) an academic period set aside for laboratory work [9]. A virtual laboratory is defined [9] as an interactive environment for creating and conducting simulated experiments: a playground for experimentation. It consists of domain-dependent simulation programs, experimental units called objects that encompass data files, tools that operate on these objects, and a reference book.

Consider the scientific meaning of simulation as "goal-directed experimentation with dynamic models" [10]. Also, denote a virtual laboratory as being based on the first definition of laboratory presented above, that is, a place providing opportunity for experimentation. In the work described below, a virtual laboratory becomes a virtual location inside the web, having a distributed nature and a dynamic configuration. Laboratory equipment available in the web-ring can be shared together with experimental data and protocols. In the field of remote experiments used for distance learning purposes, one identifies two major solutions. The first approach uses one or more data acquisition cards as a versatile interface between the physical phenomenon and the digital realm. The experiments are accessed either synchronously or asynchronously by at least one user via different software.

A second pedagogical method uses standard digital instruments that can perform either standalone or connected to an external processing unit, usually a local personal computer (PC). The communication layer allows either serial or parallel data streaming and drastically determines the overall performance of the experiment. The first approach is more suitable for complex experimental setups and imposes special requirements in terms of security access [11]. The second method is mostly oriented toward realizing a more realistic software replica of the equipment itself. In this latter technique, a special concern is the equipment safety. Topics from distributed measurement systems field of study are very suitable for this second type of remote experiment. Fig. 1 shows the front panel of a client application as used in a Internet-based calibration of a digital voltmeter [e.g., the device under test (DUT), physically connected—at the remote location—to a calibrator unit (CLD)] and a hardware platform connected to the Internet [12].

III. Remote Experiments Over the Internet

In this section, an experiment designed for students enrolled in electrical engineering is presented. The particular hardware employed here is organized around a data-acquisition (DAQ) board. Ultimately, this online laboratory seeks to present fundamental topics in commutation such as synchronous contact closure in three-phase systems, closing time dispersion of a switches lot, relay command, and electromagnetic noise

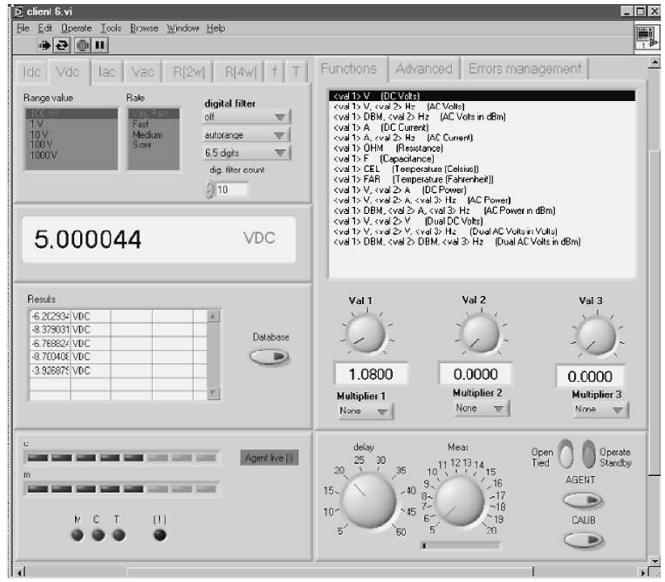

Fig. 1. Example of the front panel (client application) of the remote calibration process, using a step-by-step calibration procedure. The equipment is located in a measurement laboratory at Politecnico di Milano, Italy. The actual calibration process is fully controlled from a web location (this example is hosted on a computing platform at the Politehnica University of Bucharest, Romania).

measurements. The application is also intended to serve as online course support for the in-class lectures on measurements systems and other power engineering topics.

This virtual laboratory (VLab) utilizes equipment and software distributed between two universities from which remotely located students can perform experiments. The software solution is a multiuser, client-server architecture developed in the LabVIEW environment. The server application is unique to the communication interface and protocol (e.g., parallel, Centronics-based) between the computer and the specific laboratory hardware. Fig. 2 shows the particular architecture of VLab. One of its nodes, VLab PUB, hosts a total of eight PC stations, and a network server, interconnected via a fiber-optic link with the main node of the Romanian Academic RoEduNet wide-area network. Each remotely accessed device is connected to a PC running a specific server application. Then, the user is operating the equipment via a client application that can be formed by multiple client modules. All servers, including the one responsible for user authentication are running on PCs located in VLab PUB. It is not necessary for all server applications to be housed on the same machine; in fact, the bandwidth availability can be improved if the video server, for example, is running on a separate computer.

Fig. 3 shows the schematic of the experimental setup in the case of three-phase contactors. The three voltages and three currents are acquired on six differential inputs of the data acquisition card (PCI-AT-E4 from National Instruments), while its maximum sampling rate (200 kHz) assures a maximum delay between the input channels of 30 μs. This value is acceptable when considering the closing time of typical contactors. Students are required to save data and then process it in a specialized environment (e.g., Matlab) to find the dependence of contacts nonsynchronicity from the load type. The control signal, sent from a DAQ digital output, is the time reference.

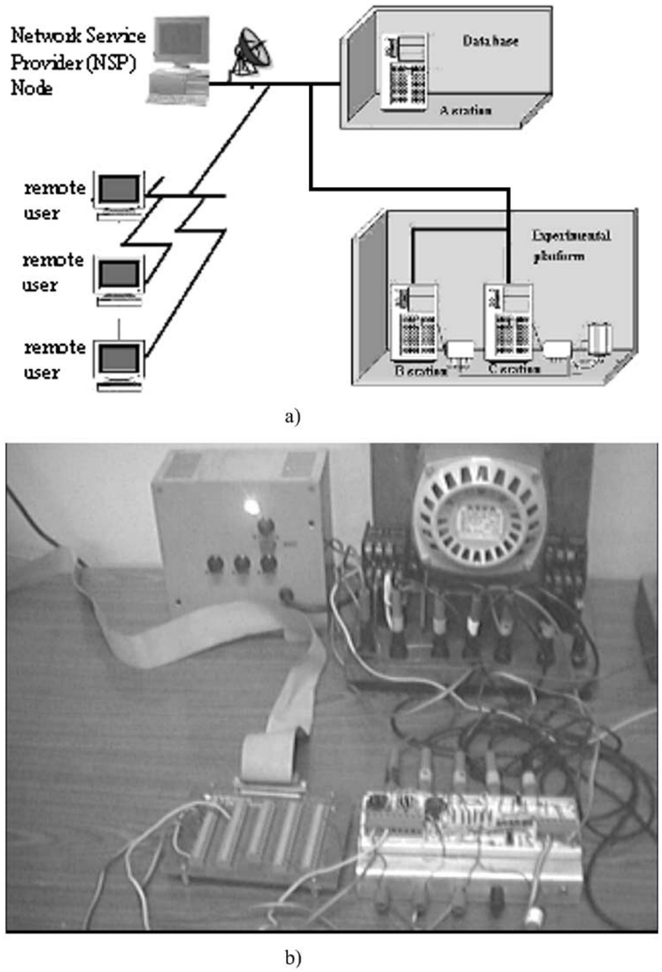

Fig. 2. Virtual laboratory (Vlab). a) General diagram of the VLab architecture; b) an experimental setup.

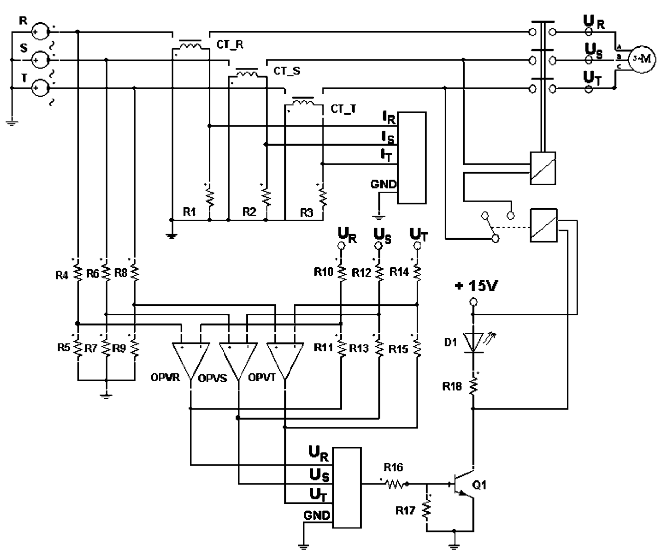

Fig. 3. Simple schematic for studying the three-phase contactor for motor-type load using a DAQ card.

Figs. 4 and 5 show typical waveforms as seen on the front panel of the client application. In this example, there are two on-line users, one of them becoming the master user after selecting the control switch. All of the actual selections (i.e., number of acquired points, acquisition rate, etc.) made by the master user are visible on each user's front panel.

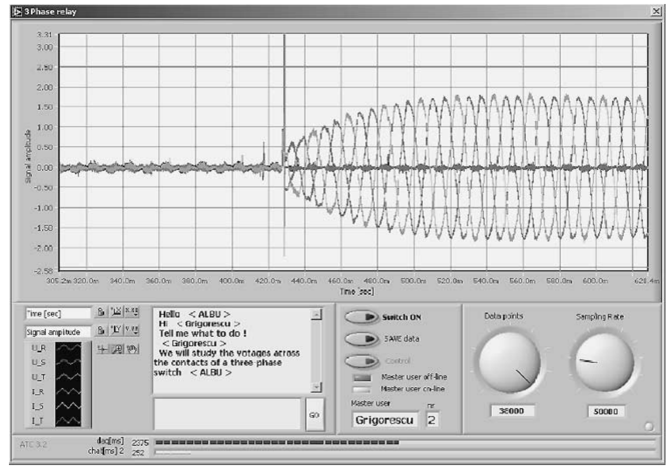

Fig. 4. Voltage and current waveforms at low-voltage contactor terminals (located in Europe) as visualized at the remote-user location (U.S.).

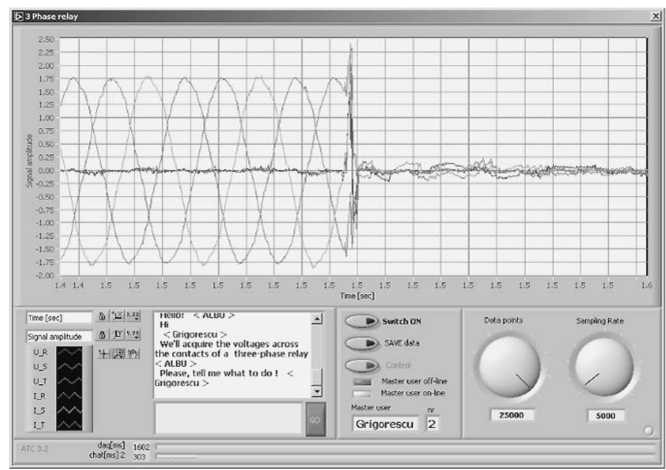

Fig. 5. Voltage and current waveforms at low-voltage contactor terminals (located in Europe) as visualized at the remote-user location (U.S.).

Fig. 6 presents the schematic used for a synchronous controlled eight-relay bank using a parallel port with the corresponding voltages given in Fig. 7. The application is realized in the LabVIEW environment. A client of the LabVIEW application is embedded into another application, dedicated to the time dispersion study of the relay switches.

IV. Concluding Remarks

Designing a multiple-access experimentation platform is especially effective for power systems educational purposes. Students can practice utilizing the power devices in a tutorial mode, before they actually perform experiments. The equipment—usually sensitive to voltages and currents outside the rated range—is better protected from accidental misuse by implementing various levels of (inexpensive) software protection. Such an implementation allows real-time operation of distributed research teams. Similarly, the specific master (and client) software can be installed on the computing station of an industrial testing unit, which could then be exploited for research purposes. Overall, the educational exposure versus

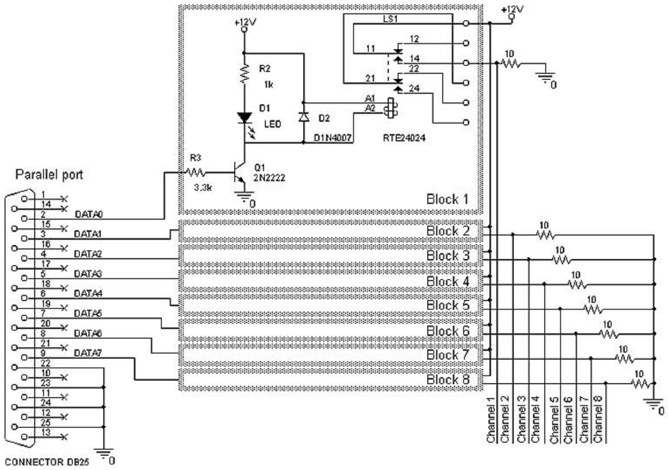

Fig. 6. Simple schematic for controlling a bank of eight relays from the computer parallel port.

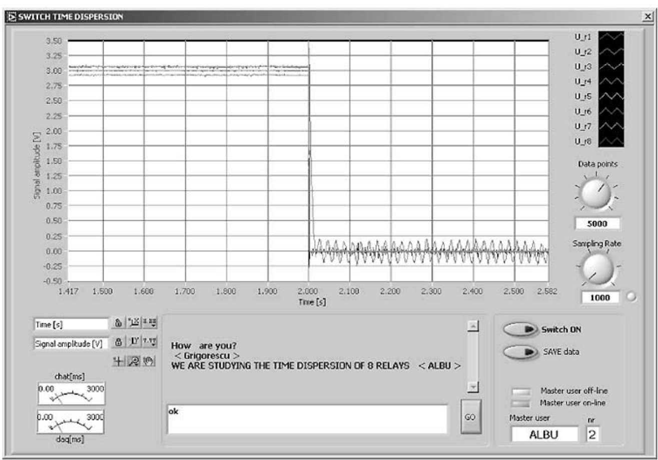

Fig. 7. Voltage across contacts of eight synchronously controlled relays.

cost favors the use of remote electronic laboratory experiments in many circumstances.

Some educators feel that virtual laboratories may not be as effective as manipulating real equipment. For example, it can be argued that students do not attain respect for power measurements, and actual manipulation of test equipment afforded by hands-on experience; however, remotely located hardware may be superior to simulation. Further, students appear to be attracted to computer use in this education application, thus taking advantage of the students' expertise in computer software applications. Often overlooked is the fact that psychologically speaking, the remote student is shielded against the adverse consequences of the misconnection of equipment. Software protection interlocks prohibiting the student from making such mistakes increases the longevity of the equipment. For this reason, some institutions might consider initially utilizing the remote method to "train" the student before his/her use of the equipment for in-laboratory experiments. Another drawback to simulation is the fact that the student does not enter the actual laboratory, so there is less hardware troubleshooting (e.g., loose wiring or connections) whereas the (nonsimulation) approach taken here retains these possibilities but in a restricted form.

One of the main advantages offered by VLab is that students from all over the world can use the equipment located in a particular laboratory. Each university that is part of the ring of virtual laboratory users can provide a different subset of experiments. The diversity of power engineering topics taught and practically performed can be extended in this way.

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REFERENCES

[1] L. Harasim, "A framework for online learning: the virtual-U," *Computer*, vol. 32, no. 9, pp. 44–49, Sept. 1999.

[2] A. Guru, P. Savory, and R. Williams, "A web-based interface for storing and executing simulation models," in *Proc. Winter Simulation Conf.*, J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, Eds. Lincoln, NE: Dept. Ind. Manage. Syst. Eng., Univ. Nebraska, 2000, pp. 1810–1814.

[3] G. Karady, G. Heydt, M. Michel, P. Crossley, H. Rudnick, and S. Iwamoto, "Review of power engineering education worldwide," in *Proc. IEEE Summer Power Meeting*, vol. 2, Edmonton, AB, Canada, July 1999, pp. 906–915.

[4] J. Kyyra, "Challenges in the teaching of electrical power engineering—motivation of students and change of paradigma," in *Proc. Int. Conf. Eng. Educ.*, Oslo, Norway, Aug. 2001, pp. 8D6-26–8D6-30.

[5] M. Bertocco, F. Ferraris, C. Offelli, and M. Parvis, "A client-server architecture for distributed measurement systems," *IEEE Trans. Instrum. Meas.*, vol. 47, pp. 1143–1148, Oct. 1998.

[6] K. Holbert and M. Albu, "A signal processing laboratory employing on-line teaming for remote experiments," in Proc. Amer. Soc. Eng. Educ. Annu. Conf. Expo., Nashville, TN, June 2003.

[7] M. Joler and C. G. Cristodoulou, "Virtual laboratory instruments and simulations remotely controlled via the Internet," in *Proc. IEEE Antennas Propagat. Soc. Int. Symp.*, vol. 1, Boston, MA, July 2001, pp. 388–391.

[8] Webster's Ninth New Collegiate Dictionary, 1983.

[9] The Virtual Laboratory Environment, L. Mercer, P. Prusinkiewicz, and J. Hanan. (1990–91). *http://www.cpsc.ucalgary.ca/Research/bmv/vlab.orig/vlab.html.* [Online]

[10] T. Oeren, "Impact of data on simulation: from early practices to federated and agent-directed simulation," in *Proc. Europe. Simulation Soc. Conf.*, Shaping Future with Simulation, T. L.Th. L. van Stijn, I. Smit, H. de Swaan Arons, L. Dekker, and A. W. Heemink, Eds., Delft, The Netherlands, June 2001.

[11] X. Vilalta, D. Gillet, and C. Salzmann, "Contribution to the definition of best practices for the implementation of remote experimentation solutions," in *Proc. IFAC Workshop Internet-Based Contr. Educ.*, Madrid, Spain, Dec. 2001, pp. 37–42.

[12] M. Albu, A. Ferrero, F. Mihai, and S. Salicone, "Remote calibration using mobile, multi-agent technology," in *Proc. IEEE Instrum. Measure. Technol. Conf.*, Vail, CO, May 2003, pp. 21–23.

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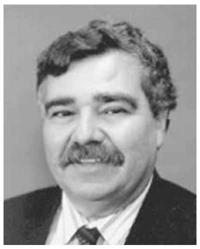

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