

16th Int. Conference on Electrical Drives and Power Electronics Slovakia

September 24 - 26, 2007

DISTANCE LABORATORIES IN ELECTRICAL ENGINEERING

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<u>Abstract.</u> The paper deals with the basic philosophy and structure of remote controlled laboratory for experimentation in Electrical Engineering. The laboratory collects experiments from fields of Power Electronics, Electrical Machines, Electro-Mechanical and Motion Control Systems. The workbenches in the real laboratory are used over internet. The real experiments of the remote controlled laboratory are placed at various universities. A special care is devoted to preparation of the learners to experimentation, including examining their knowledge before joining to the experiment. To have a feeling of participation in the experiment, except of the measurement data, also the signal from web camera is transferred to a distance operator.

Keywords: e-learning, remote controlled experiments, engineering education

1. INTRODUCTION

Although modelling and dynamic simulation are basic tools for understanding and verifying theoretical subjects, the experimentation with a real system plays a fundamental role that cannot be replaced. Analysis of these tools from view of modern education is given in [1].

Practical education needs to be based understanding phenomena that occur in real systems. Remote control of the experiments trough Internet comes as a solution to these problems, allowing students to control them, without leaving their normal workplace.

Rapid development of ICT technologies since beginning of 90ties enabled expansion of online distance laboratories. Their utilisation presents the latest trends in education – to get practical experience by experimentation with measurements, verifying properties of complex equipment and well as analysis of the equipment in various operation points. Tacking advantage of the internet and development of related technologies, an increasing number of remote access solutions are being developed. A remote hardware experiment are adapted in such a way that it can also be accessed from the Web that enables distance sharing of the experiment by other individuals and/or institutions.

Currently numerous solutions for remote controlled experiments in various fields of practical education can be found and also there are numerous projects running focused to their developments that are presented at special conferences, e.g. in [2] and special sessions of the scientific conferences.

2. TYPICAL ONLINE DISTANCE EXPERIMENTS SOLUTIONS

A brief overview of several typical examples from field of electrical engineering is presented next, namely of electrical machines, drives, power electronics and their applications that we are interesting in. In this paper the focus is on the used technology and content (educational goal) of the experiments.

Simple remote experimentation with power semiconductor devices (diodes, BJT, J-FET, and phototransistors) is reported in [3]. The student can get output characteristics of each device and to study their behaviour in different conditions.

Development of a remote-access control system allowing users to perform control through Internet is shown in [4]. A DC motor control module is used to illustrate the design there. The system consists of an internal distributed system and an application system linked by a data acquisition (DAQ) interface card. Web server, video server and LabVIEW controller server are designed based on a client– server structure.

Importance of teaching PID control techniques at undergraduate level is pointed out in the paper [5] that introduces a remote experiment where the DC motor is controlled by PID controller. The remote user can test PID digital algorithms and parameters, change reference velocity values and register the motor output velocity profile. Again the LabView environment is used there.

An example of design and construction of virtual laboratory of electrical machines (both AC and DC motors) is presented in [6]. The remote experiment consists of a three – axis positioning system, measurement technique with GPIB bus, server and measured circuits. Position system is used to switching the circuit among different inputs and outputs on measured boards and measurement technique. The subsystems are interconnected by GPIB bus and measured values for current, voltage, frequency and revolution are transferred into the server. Server applications are programmed in software LabView, providing measurement, calculations, control and web publishing for complete virtual laboratory system.

The paper [7] presents an education kit based on real system consisting of an automatic controlled AC drive. The power system consists of a cage induction motor supplied from power electronic converter. The control is provided by two ways: locally on a computer directly connected to the inverter and simultaneously serving as a network server. The second one is held remotely by computer connected to the network fulfilling part of network client.

More complex experiment is presented in [8] showing a web based interactive teaching of PWM methods on example of a most widely used three-phase bridge converter. In the first part the basic methods of PWM: carrier based sinusoidal (CB-SPWM), carrier based PWM with zero sequence signal (CB-ZSS-PWM), and space vector modulation (SVM) are described. Special emphasis is given to relations between CB-ZSS-PWM and SVM. In the second part selected developed applets for individual training of PWM methods are briefly described

An example of advanced and more complex control and teleoperation is presented in [9] where experimental equipment is explained on background of a course that is included as a part of mechatronics education. Employed HW is in-house developed embedded DSP-2 control system, which applies MATLAB/Simulink for the control algorithm design. for simulations and also for practical implementation. DSP-2 is supported by specially developed library for Simulink where basic programming blocks are included. For more advanced algorithms, the possibility to include user's C programming language code in the executable Simulink model is utilized. The control course is upgraded with remote control course, where the students learn how to control trough internet their previously developed advanced control experiment.

The above brief overview of some typical solutions presents only a fragment of published references of remote laboratories, of course. In our case we are developing a more complex system of virtual laboratory containing not only single experiments but the whole set of the experiments [20] that are distributed across Europe and the experiments allocated there cover basic fields of electrical engineering. They are placed in different laboratories at universities. The system to be developed presents an open system enabling later expansion. The virtual (distance) laboratories are not any web-based simulation. They present real electrotechnical experiments conducted in the laboratory, but they are remotely controlled and monitored by web-based tools with visualization of measuring apparatus, electronic components and many more factors.

Design of such a system except of technical solutions dealing with access and sharing of remote experiments requires solving number of other tasks that is pointed out in the following.

3. REMOTE PEMCWEBLAB, ITS FUNCTIONALITY AND SUBSYSTEMS

To support distance learning in electrical engineering we developed a set of remotely controlled real experiments from fields of electrical engineering mainly from Power Electronics and Electrical Drives, so that they create the *PEMCWebLab* (Fig. 1).



Fig. 1 Principal structure of the distance laboratory

3.1 Integrated Learning System

The *PEMCWebLab* creates an integrated learning platform. Several learning issues are addressed such as:

- Learning objectives
- Education
- Animation
- Simulation
- Experiment

In the first part the learning objectives of each experiment are addressed. In the part education a theoretical background of the each individual experiment is given. Interactive animations developed in the previous project are addressed further. The last educational method before experiment is the simulation.

The main function of *PEMCWebLab* is to provide a webbased remote control for designed experiments. The learning process includes several, specially designed, experimental tasks. However, for safety reasons no one will be allowed to perform any experiment until he, or she, has shown adequate knowledge of the experiment. Entering wrong input parameters, due to insufficient knowledge of the experiment, may also lead to improper operation of the experiment. Therefore, a learning routine is designed for learners to gain the prerequisite knowledge which is required before attempting the experiment.

After completion of the online experiment, the learners are given an opportunity to take a simple questionnaire or alternatively to submit their report through the available feedback subsystem for its final evaluation (depending on the requirement enforced by the instructor). All learning procedures are recorded for future reference and analysis.

3.3 Evaluation Subsystem

To use PEMCWebLab in order to achieve desired learning effect, the system first has to assess the learners' prerequisite knowledge of experiments. This is done throughout an evaluation subsystem before it permits the learners to access online experiments. Several types of evaluations are used in this system. The simplest method is to use a questionnaire that only contains true or false type questions, single questions, and multiple-choice questions. Instructors may also ask learners to submit simulation results or reports of the simulation tasks via e-mail, and then evaluate the results manually. Another possible method of online evaluation that is currently being considered is a peer review method. An experienced learner who has been trained can be assigned as a Teaching Assistant (TA) for that experiment. The TA can talks then to, or correspond with, anyone who requests permission to do that experiment. Once this TA believes that the new learner has adequate knowledge of the experiment, he or she can grant this learner access to that experiment. In this way the instructor's workload can be reduced. In the future an automatic evaluation will be employed.

3.3 Feedback Subsystem

A feedback subsystem plays an important role in improving the performance of the learners and the use of the *PEMCWebLab*. Feedback to learners often includes the evaluation results and suggestions on learning, while feedback to instructors and supervisors often includes problem reports on the *PEMCWebLab* and questions during the learning process. Peer or learner–instructor interactions are both significant in this feedback subsystem. In framework of the *PEMCWebLab* the authors have developed several feedback mechanisms. Feedback to learners may be provided instantly from predefined functions or from an instructor or administrator with a certain time delay. E-mail is one of the easiest ways for learners to communicate with instructors. Discussion forums or online chat rooms also provide different environments for the feedback.

4. EXPERIMENT ADMINISTRATION

Every experiment has its own server, because it is located at the different location. Remote users first log onto a main booking server, after which they will be directed to the specific server for actually performing the experiment.

4.1 Experiment Administration

A central booking system is available at the project page PEMCWebLab.com Booking system is provided through Moodle software. Layout of the Moodle pages for all experiments is uniform. This page will contain menu with the following submenus:

Submenu:

- 1. Learning objectives
- 2. Education
- 3. Animation
- 4. Simulation
- 5. Experiment

All the submenus at the booking system are to be accessed without restriction of number of students. The actual booking is provided in the *submenu Experiment*. The experiments can be booked one week ahead, the length of the offered time window for the experiment varies from 5 to 30 min. Before the experiment becomes available online, it should be tested to verify the correctness of the experiment results as well as the stability of the experimental set-up. The power to some experiment is available 24 hours a day; some experiments are available for safety reasons in the working hours only. An administrator of each experiment can restrict the use if the experiment for his purposes during some days or hours only. Supervisors have to routinely check the status of each experiment to make sure that each of them is functionally correct and is available for use.

Several clients can connect to PEMCWebLab.com simultaneously. However, Internet bandwidth becomes extremely limited when too many remote users request to use this system. Several concurrent, remote users are allowed via an Internet connection for each experiment. However, each experiment in the *PEMCWebLab* can be operated only by a single remote user at a time. The system thus considers each experiment as a "resource", and remote users who wish to operate a specific experiment should first get permission to operate the experiment. Once the resource

is in use, other remote users cannot access that resource, because it is then marked as "locked." All the remote users without access permission can see only the online, real-time video of that experiment.

4.2 Server Site Administration

As already said every experiment has its own server and it is located at the different location. Remote users first logged onto a main booking server, after which they will be directed to the specific server for actually performing the experiment get into the page of the experiment itself. Fig.1. is showing a typical procedure if the booking and server site administration. After the user requests a time window from the experiment located at measuring server 1 (action 1) the booking system (Moodle) creates a mirror web page of an experiment at the public part of the measuring server (action 2). Next the user obtains an access to the page of the experiment (action 3). This access is limited to the user who booked the experiment. After the experiment is finished the the mirror page is erased from the public part of the server. This way nobody can log in without first booking the experiment via the booking system.

5. SET OF REMOTE EXPERIMENTS

A Leonardo da Vinci EU project titled "*E-learning Distance Interactive Practical Education - EDIPE*" [2] is suggested and approved to create a full set of distance laboratories. Twelve universities with the span across the EU (from the countries: NL, F, D, PL, CZ, SK, HU, RO, GR) are participating in the project.

The expected specific results are:

- Learning objectives for the distance experimental education,
- The guidelines for project oriented measurements with the learning objectives for distance and /or virtual practical education,
- Synthesis oriented experimental measurements,
- Technology and technical documentation for distance practical education and measurements via the Internet,
- Different designed measurements each with its own philosophy.

The outputs from the project will present:

- teaching material (in electronic form; guidelines, manuals, documentation in English and other languages),
- distance and virtual laboratories approached via web,
- visualisation and the layout of the measured system, and
- measurement results obtained via Internet.

The modules listed in Table 1 are proposed (grouped into sets of modules) in such a way that they cover fundamentals and basic applications of the EE and advance topics including the application as well:

6. EXAMPLE OF THE WEB AND MEASURING PEMCWEBLAB SERVER

The main part of the system is the web server, which is responsible for all the web services, web pages and the correct functionality of the user interface. The web server also communicates with other applications which can access the other parts such as the measured data.

Groups of specialised subjects		Modules
1. Fundamentals	1.1	Single Phase and Three Phase Rectifier Circuits
of Electrical Engineering	1.2	DC Circuit Measurements and Resonant AC Circuits
2. Power Electronics	2.3	Power Converters
	2.4	Power Factor Correction
	2.5	PWM Modulation
	2.6	DC-DC Converter for Renewable Energy Sources and Microgrid
	2.7	Power Quality and Active Filters
	2.8	Power Quality and/or Electromagnetic Compatibility
3. Electrical Machines	3.1	Basic Electrical Machinery – Synchronous Generator
	3.2	DC Machines
	3.3	Basic Electrical Machinery – DC Motor
	3.4	Basic Electrical Machinery – Asynchronous Motor
4. Electro-Mechanical and Motion Control Systems	3.1	Basic Elements of Internet based Tele-manipulation
	3.2	Mechatronics, HIL (Hardware in the Loop) Simulation
	3.3	High Dynamic Drives - Motion Control
	3.4	Automotive Electrical Drive
	3.5	Complex Control of a Servodrive by a Small Logic Controller
	3.6	Intelligent Gate Control by a Small Logic Controller (SLC)

Tab. 1 List of modules with remote controlled experiments in the EDIPE project

6.1 Measurement Application

Most of the similar applications use LabView [7]. In the case described here the measurement application communicates with measurement instruments via a GPIB interface. This application was written in a Matlab environment and finally compiled / built as an executable application. Matlab has to be installed together with its "Instrument Control Toolbox" to provide communication via the GPIB interface. This toolbox is a general programming interface, controlling all instruments equipped with a GPIB interface.

6.2 Control of Power Part

There is an application, programmed in C++ language, which controls the on and off switching of the power supply of the measuring instruments and the measuring board. The data bits of a parallel port are used as a control signal. A built-in remote controller controls the power switches by means of radio waves (see Fig. 2).



Fig. 2. Principle of power controlling

6.3 Software

The main functional part is the connection between the web server and the measuring applications which in turn communicate with the measuring devices themselves. In Fig. 3 (left) a simple state diagram of the web page is shown. The "*DelftWebLab page*" bubble represents the web page with measured data. From this page the user can run the measuring application (dash line). The two arrows pointing away from the "*DelftWebLab page*" bubble represent some events which might occur:

- The first event, namely the 'On change settings of the measurement instruments', occurs when some parameters are changed e.g. the vertical scale of the scope, etc.
- The second event occurs periodically, refreshing the web page to show the latest measured data.

On the right side of this figure, there is a block diagram of a measurement cycle. The dashed line represents cooperation between the functionality of the web page and the measuring application. When the measuring application is launched, the program periodically controls the measuring instrument, reads the measured data and stores the measured data to a file.



Fig. 3. Cooperation of the web server and a measuring application

7. CONCLUSIONS

In this paper basic philosophy and structure of remote controlled laboratory - called the PEMCWebLab is introduced. It will collect real remote experiments from various application fields of Electrical Engineering. Especially the field of electrical drives and power electronics (ED&PE) is represented by excellent and unique solutions.

Altogether 18 different experiments are under development currently. The course materials and case studies giving a guide to particular experiments will complement them in a short future. Together with the interactive animations and theoretical studies the developed PEMCWebLab will create a complete educational solution. The unique and centralized booking system described in the paper will help to facilitate the remote laboratories placed in institutions round Europe.

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AKCNOWLEDGEMENT

This work has been performed within the project "Elearning Distance Interactive Practical Education (EDIPE)". The project was supported by the European Community within framework of Leonardo da Vinci II programme (project No CZ/06/B/F/PP-168022). The opinions expressed by the authors do not necessarily reflect the position of the European Community, nor does it involve any responsibility on its part.

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