User-defined Electrical Experiments in a Remote Laboratory

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Abstract

Laboratory exercises in electrical engineering courses can be performed remotely using real equipment. A number of user-defined experiments on electrical circuits have been conducted over the Internet at Blekinge Institute of Technology (BTH), Sweden; the experiments have been carried out in different locations simultaneously using the same experimental hardware located in a small closed laboratory at BTH.

The laboratory provides a remotely controlled switch matrix, two function generators, a digital multi-meter, and an oscilloscope. The matrix replaces the traditional breadboard and students and other users around the globe use it to form circuits from components mounted in component holders in the matrix. It has five nodes; a jumper lead or up to four components can be connected between each pair of nodes. The laboratory supervisor or a teacher can easily swap components. Users control the instruments using virtual front panels in the same way as they had done earlier in the local laboratory; the only difference is that they no longer form the circuits and connect the test probes manually.

Circuits are defined using PSpice compatible net lists. The sources and components available in the laboratory are listed in a library. This library can be added to the libraries in, for example, the evaluation version of PSpice. Students can, within certain limits, modify the circuits shown in the laboratory instruction manuals or even design circuits of their own. A virtual laboratory instructor checks the circuits formed automatically before the voltage is applied to avoid possible damage.

Is it possible to establish a reasonable balance between the teachers' needs and the complexity of the hardware? Can the virtual instructor check the circuits formed without making advanced calculations or simulations? This paper addresses these questions and discusses implementation issues.

Introduction

It is well-known that real experiments are indispensable in engineering education as a means of developing skills for dealing with physical processes and instrumentation. The traditional way of conducting experiments is to go to a university laboratory where students work in teams and receive tutorial help from teachers. Models for using information technology to enhance the learning experience for students who are asynchronous in time or/and space and which are also suitable for on-campus students have been presented earlier[1,2]. A number of so-called remote laboratories have been set up by some universities around the world. These offer remote access to laboratory equipment and experimental setups[3].

Laboratory exercises are run in the remote laboratory for undergraduate education in electrical engineering at Blekinge Institute of Technology (BTH)[4]. A number of people located in different places around the globe can perform experiments simultaneously using client PCs connected to a laboratory server via the Internet. They download the client software from the laboratory web site. This is one way to use the equipment and premises efficiently. The cost of the equipment and its maintenance can be cut down if the number of lab stations is reduced and/or the laboratory is used outside ordinary working hours.

Another purpose of the remote laboratory at BTH is to provide exercises which are almost identical to conventional ones. In fact, the exercises in the remote laboratory could also be performed in the traditional manner. The same laboratory instruction manuals will serve the purpose. Conventional laboratory exercises have been used with success to teach science and engineering for many decades. To try to copy these exercises might be a good starting point from which new teaching methods could emerge.

In a traditional laboratory the students can perform experiments of their own using the equipment and components available. In the remote laboratory at BTH it is only possible to form predefined circuits using the laboratory servers described earlier. This paper focuses on user-defined experiments made possible by a new laboratory server. First the traditional method of doing laboratory exercises will be examined and then the remote version will be described.

Traditional laboratory exercises are a successful teaching method

In a traditional undergraduate electronics laboratory at BTH eight identical lab stations are available. At each station there is a lab box with a white plastic breadboard which is detachable and some desk top instruments as shown in Figure 1. An instructor provides the components necessary for each laboratory session. Every exercise is described in an instruction manual. The normal procedure for performing a single experiment is as follows:

1. The student forms the circuit specified in the laboratory instruction manual using the breadboard and some of the components provided. The instruments are connected to test points.
2. The instructor checks the circuit formed to avoid possible damage. If the circuit is harmless the student is allowed to go on and activate the voltage source.
3. The student reads the instruments and evaluates the results. If they are acceptable s/he

enters them in a laboratory report. Where this is not the case, some troubleshooting must be carried out, if necessary, with the support of the instructor.
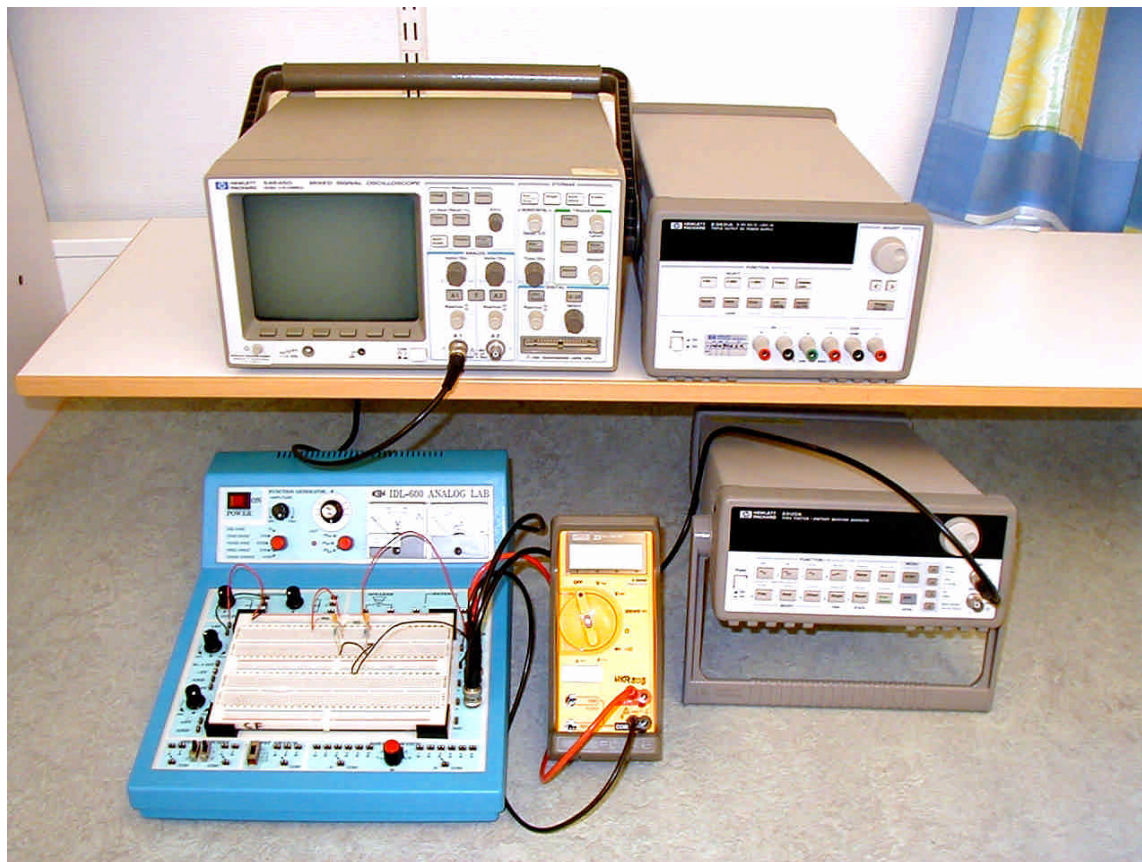

Figure 1: A traditional lab station in a laboratory for undergraduate education in electrical engineering at BTH.

Remote experiments add a new flexibility

The new laboratory server at BTH is shown in Figure 2. To the left there is a PXI (PCI Extensions for Instrumentation) chassis (PXI-1000B) containing a controller (PXI-8176) and four plug-in boards from National Instruments. The controller comprises a PC connected to the Internet which hosts the plug-in boards in the form of two function generators (PXI-5411 and PXI-5401), an oscilloscope (PXI-5112) and a digital I/O board (PXI-6508). The instrument settings are controlled from the host computer and there are no buttons or control knobs on the generators or the oscilloscope, only connectors. Next to the PXI chassis is a Data Acquisition/Switch Unit (Agilent 34970A, 34901A, 34903A, and 34904A) which functions as a multi-meter; this is connected to the controller via the GPIB (General Purpose Instrument Bus). To the right is a power supply (HP E3631A). The server software is written in LabVIEW 6.1 (Laboratory Virtual Instrument Engineering Workbench)[5].
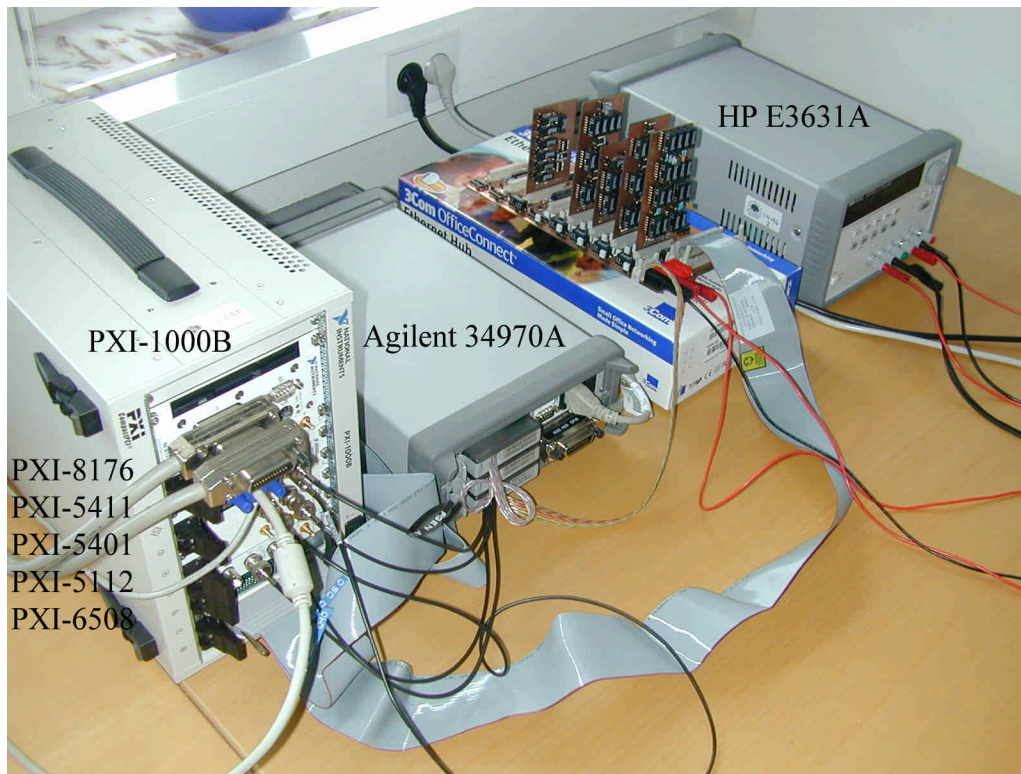
Figure 2: A laboratory server for experiments in circuit theory and basic electronics.

A small remote laboratory which provides a "virtual breadboard" with four nodes using a relay switching matrix has been presented earlier[6]. It provides two sources and three resistors. Would it be possible to replace the traditional breadboard by a remotely controlled switch matrix large enough to accommodate most of the circuits used in electrical and basic electronic experiments in undergraduate education? The matrix used in the remote laboratory at BTH has five main nodes and ten main branches, Figure 3. The main nodes are denoted A, B, C, D and GND. The ground terminals of the function generators and the oscilloscope are connected to GND. Each main branch can be composed of a jumper lead or up to four components with two leads mounted in parallel in holders on the printed circuit boards shown in Figure 2. In this way a total of 40 different components can be connected. All connections to node A are shown in Figure 4. To support components with more than two leads such as transistors or operational amplifiers an additional printed circuit board and some software modifications are required. The laboratory supervisor or the teacher can easily swap components. The switches used to connect the components are mounted near the component holders on the printed circuit boards. The server controls these switches using the digital I/O board in the PXI chassis. The switches in the Data Acquisition/Switch Unit are used to connect the instruments to the nodes. This configuration meets the requirements for circuit theory experiments at BTH.
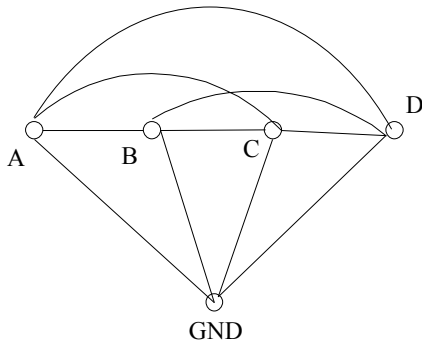
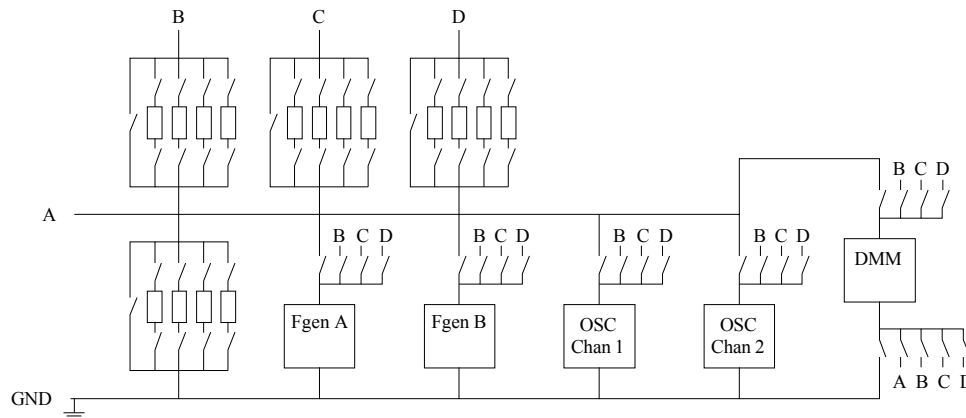Figure 3: The switch matrix has five nodes and ten branches.

Figure 4: Connections to node A. The connections to B − D are identical.
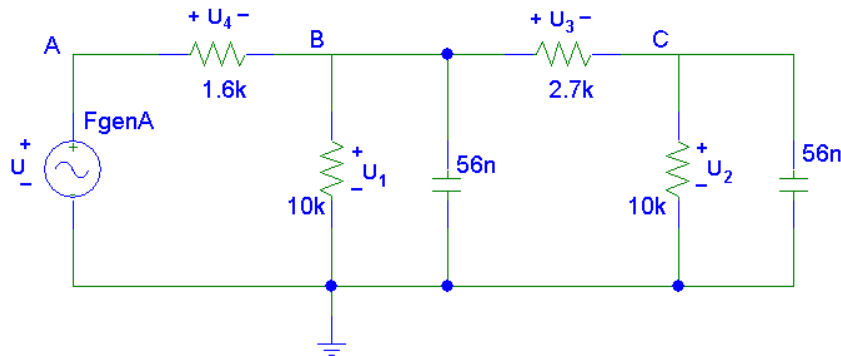

Figure 5: Circuit for testing Kirchhoff's voltage law.

In the client user interface there is no virtual breadboard. The circuits to be formed are defined using PSpice-compatible net lists. These are sent to the server to set the switches in the matrix. In an assignment in the third laboratory exercise in a circuit theory course at BTH, for example, the task is to test Kirchhoff's voltage law using the circuit in Figure 5. There are four nodes in this circuit.

The window appearing on the client PC screen when the user starts this test is shown in Figure 6. The experiment option panel shows the default net list corresponding to the circuit in Figure 5. In the circuit there are seven items: one source, four resistors, and two capacitors; in the net list there is one row per item. In PSpice the ground terminal is denoted '0', replacing GND. The user can edit the net list and thus modify the circuit, but s/he can only select components that are available in the matrix. A PSpice-compatible library lists the sources and components defined in the system. This library can be added to, e.g. the evaluation version of PSpice. Net lists generated in PSpice can be opened in the experiment option panel.
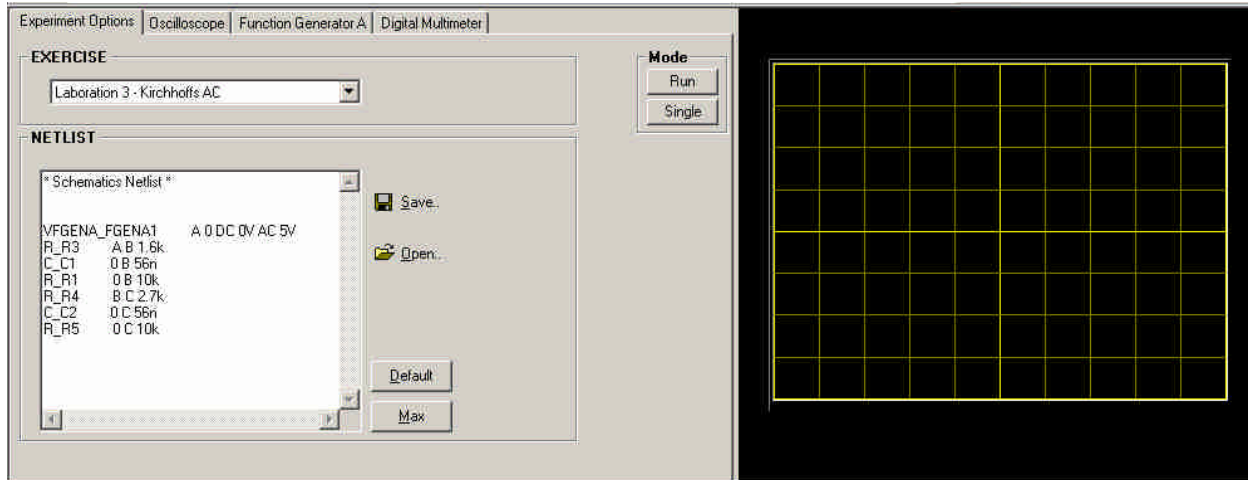

Figure 6: Experiment options panel for exercise 3 in circuit theory.

Virtual front panels are used to set and connect the instruments. The oscilloscope panel is shown in Figure 7. In this example channel one is connected to node B and channel two to C in Figure 5. The function generator is set to 5 V amplitude and 1000 Hz. The multi-meter can be used to measure voltage, current and resistance. If, for example, the user wishes to check the resistance of the 1.6 kohm resistor in Figure 5, s/he must delete all the entries in the net list in Figure 6 except this particular resistor; it is permitted to connect the ohm-meter to the resistor leads when the source is removed. Finally, the user must press the 'Single' button to send the connections and the instrument settings to the server. The result which is returned from the server is shown in Figure 8.
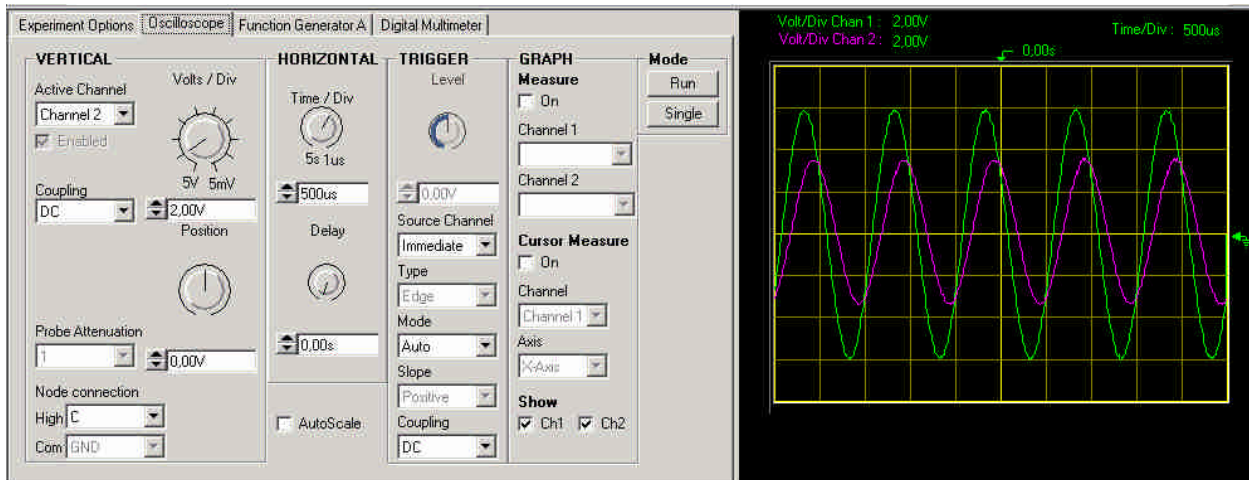
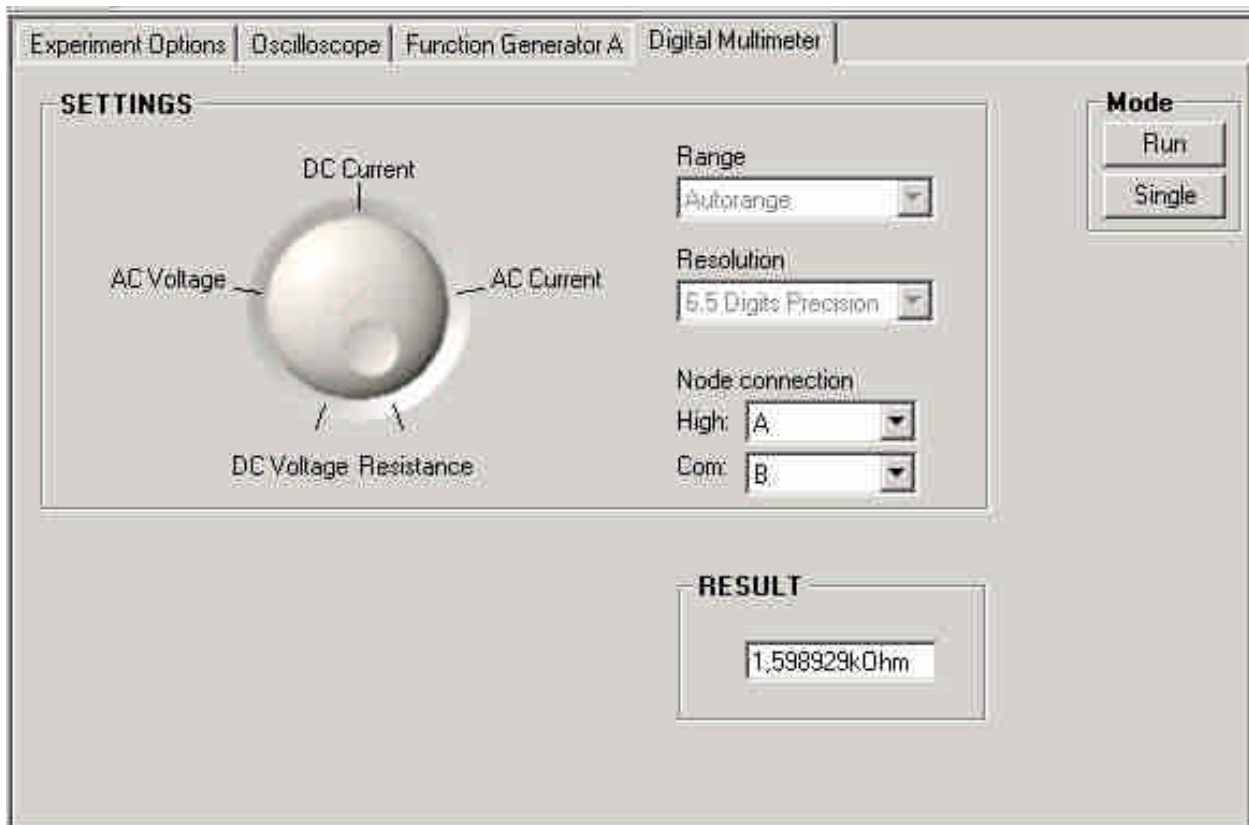Figure 7: The virtual front panel of the oscilloscope.

Figure 8: The virtual front panel of the multi-meter.

To make current measurements in a branch in a circuit the branch must contain a jumper lead only. An assignment in the first exercise includes an experiment for testing Kirchhoff's current

law using the circuit in Figure 9. IPROBE is a special diagram symbol available in the library. It represents normally a jumper lead but if a user connects the multi-meter set for current measurement in a branch with an IPROBE symbol, a client software routine replaces the jumper lead by the instrument to make it possible to measure the current. When the user removes the instrument the routine restores the jumper lead. In the assignment students are expect to measure the current in three different branches and there is only one multi-meter in the laboratory. They have to measure in one branch and then move the instrument to another. The client software is written in Visual Basic 6 using Component Works.
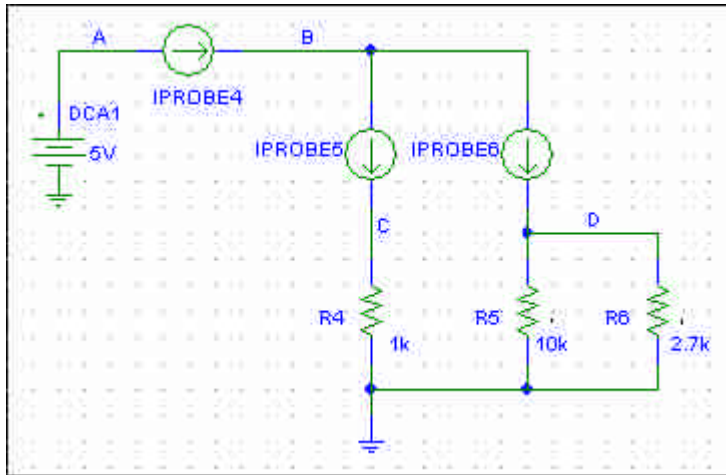

Figure 9: Circuit for testing Kirchhoff's current law.

What happens if the user forms a circuit which could be destructive, e.g. could overload a resistor? In a remote laboratory with simultaneous access it would be fatal if a resistor were to be burnt. Thus it is vital to check the circuits before the voltage is applied just as an instructor does in a traditional laboratory. A virtual instructor must be introduced into the laboratory software. For a general case where no restrictions are imposed on the components, sources, and instruments, the virtual instructor must check:

- *The voltage appearing across each component.* For some components transients are important.
- *The load impedance of the function generators.* These are short-circuit protected; the load impedance should, however, be 50 Ω or greater.
- *That the output voltage of one function generator does not damage the other generator.*
- *That no source is connected when the user tries to connect the multi-meter when set as an ohm-meter.*

Thus far, only the last rule has been implemented. Instead, a number of safe circuits have been defined. The corresponding net lists are denoted 'max lists' to indicate that subsets of the already defined circuits are also safe. The laboratory supervisor or a teacher makes the lists and thus decides what is safe. S/he must mount the corresponding components in the component holders when such a list is introduced into the system.

The normal procedure for performing a single experiment in the remote laboratory is as follows:

1. The student starts the client and selects the exercise wanted. The experiment options panel will be displayed on the screen. S/he can choose an experiment and use the default net list or the max list defined for the experiment. The student can also delete components or sources in the list. The instruments are connected to desired test points. Finally, s/he presses the 'Single' button to send the list, the instrument settings and the instrument connections to the server.

2. When the user request is dequeued on the server side, the virtual instructor compares the list received with the max list belonging to the experiment selected in order to ascertain that the desired circuit is safe. Where this is the case, the circuit will be formed, the instruments set, the test probes connected and the voltage applied. The outcome will then be returned to the client computer. In other cases an error message will be returned.

3. If there is no error message, the student reads the result on the virtual front panels of the instruments and evaluates it. If the result is acceptable, the student will enter it in the laboratory report. Where the result is not acceptable, troubleshooting must be carried out - if necessary, with the support of a real human instructor if on duty.

Conclusions

A new laboratory server supporting user-defined experiments was implemented during the summer 2002 and was used for the first time in a circuit theory course for campus students at BTH some months later. The students performed the first exercise in the traditional manner in order to become familiar with the equipment. This exercise is, however, available over the Internet as well. The students performed the three remaining exercises from a computer room on campus supervised by a human instructor. A few students to performed them from home without instructor. To attract distant learning students, BTH must provide a full circuit theory course and not only remote laboratory exercises.

A switch matrix with five nodes, ten branches and 40 components in component holders is enough to form circuits to support all the experiments included in courses in circuit theory at BTH. In the next version of the laboratory components with more than two leads will be supported. The complexity level of the hardware is acceptable. A virtual laboratory instructor checks the circuits formed by a user before the voltage is applied in order to avoid possible damage. A number of safe circuit configurations are defined by the laboratory supervisor or a teacher.

The laboratory can be used whenever it is not being used in ordinary education. The address of the home page of the exercises is:
http://www.its.bth.se/distancelab/english/Kretsteorilabbar/intro.html.

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