# A Conceptual Approach to Developing a Universal Remote Laboratory for Education and Research in Electrical Power Engineering

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## Abstract

One crucial element of education in electrical power engineering is the laboratory component. The laboratory instruction may be delivered in physical laboratories using real equipment or through simulation software tools, and in many cases utilizing both simulation and real equipment. Remote laboratories, where experiments are performed on real equipment remotely via simulation interfaces, have recently gained keen attraction. In this paper, a novel approach to delivering remote laboratory education is presented. The major components forming the new laboratory system include a real power system, an online monitoring and control station and a web client-server system. Sample activities that may be performed remotely through this laboratory are described. These activities range from a simple experiment for evaluation of transformer performance to more involved studies such as voltage stability and generator startup. Renewable energy activities may also be added. In addition to laboratory instruction and applied research, this remote laboratory is expected to be an ideal setting for distance learning.

## Introduction

Laboratory instruction is a critical part of a solid Electrical Power Engineering curriculum. It is well presumed that hands-on experimentation is a vital practice necessary for all graduating electrical engineers. Traditionally, the laboratory requirement in power area for most Electrical Engineering curricula involves a course in energy conversion principles covering dc and ac machines, transformers and introductory power electronics. In recent years, the use of computer simulation tools for laboratory education has been noticeably widened. However, studies normally performed on utility power systems have always been simulation-based. These include power flow analysis, short-circuit studies and power system stability among other studies. With rapid developments in computer visualization tools, virtual depiction of most engineering concepts and design methods is now possible and fairly affordable. Advances in communications and in digital signal processing and the wide use of the Internet have led to the feasibility of remote laboratories. In this case, real equipment and instrumentation may be housed in a remote location while the control of this equipment can be performed locally. Furthermore, the instrumentation and equipment can be animated locally in conjunction with real audio and video received form the remote equipment location. This virtual local animation of a laboratory is the front-end of a real laboratory which is located remotely.

## Laboratory Types

Laboratory education may be delivered via three types of laboratory settings; real, simulation and remote, each with distinctive merits. In a real lab, there is a face-to-face experimentation with real equipment. The simulation lab, however, allows working only with simulated models of the devices. Working remotely with real devices through virtual depiction of these devices via software user interfaces is termed as remote lab.

A comparison among these types has been presented[1]. The debate continues over the effectiveness of each laboratory type; real, virtual or remote on meeting the objectives of laboratory education[2]. Based on a local energy plant, an energy system laboratory was developed such that real-time data could be collected for simulation studies[3]. A previous work[4] presents a comparison between face-to-face students carrying out experiments in a real laboratory and distance students performing the same experiments in a virtual lab. It was shown that distance students were not disadvantaged compared with students working face-to-face. An internet-based approach was followed for remotely using real equipment located in multiple universities[5]. The role of laboratory component in power engineering education was discussed by an IEEE panel[6]. Further literature review indicates the tendency and favorability toward virtual laboratory mode particularly when the virtual laboratory site is linked to a remote real laboratory.

## Laboratory Description

The envisioned remote power laboratory is a small power system independent of the power grid and is composed of a set of generating buses (mostly renewable energy sources such as solar PV panels and wind power units), and a transmission system including transformers, overhead lines and underground cables. Fig. 1 shows a schematic diagram of the proposed laboratory system. Various types of loads such as induction motors with variable frequency drives can be connected at different buses. A fully coordinated protection scheme may be installed. As an essential part of this laboratory, a real-time monitoring and control system must be developed with the capability of controlling all protection and switching devices. Users of this remote lab will simply be web clients with a variable-permission protocol for monitoring and/or control of different parts of the system. Continuously updated experiments can be designed, tested and made available for use by clients.

## Sample Laboratory Activities

The following activities may be performed remotely via virtual user interfaces:

1. Transformer Performance

    a. Record one set of instantaneous values for the input and output voltages and current in addition to their phase relationships.
    b. Knowing predetermined values of the transformer equivalent circuit evaluate and verify the values of the input voltage and current in terms of the recorded output voltage and current.

c. Evaluate the input power, output power, losses and transformer efficiency under the given loading conditions.
d. Calculate the percentage voltage regulation under the same loading conditions.

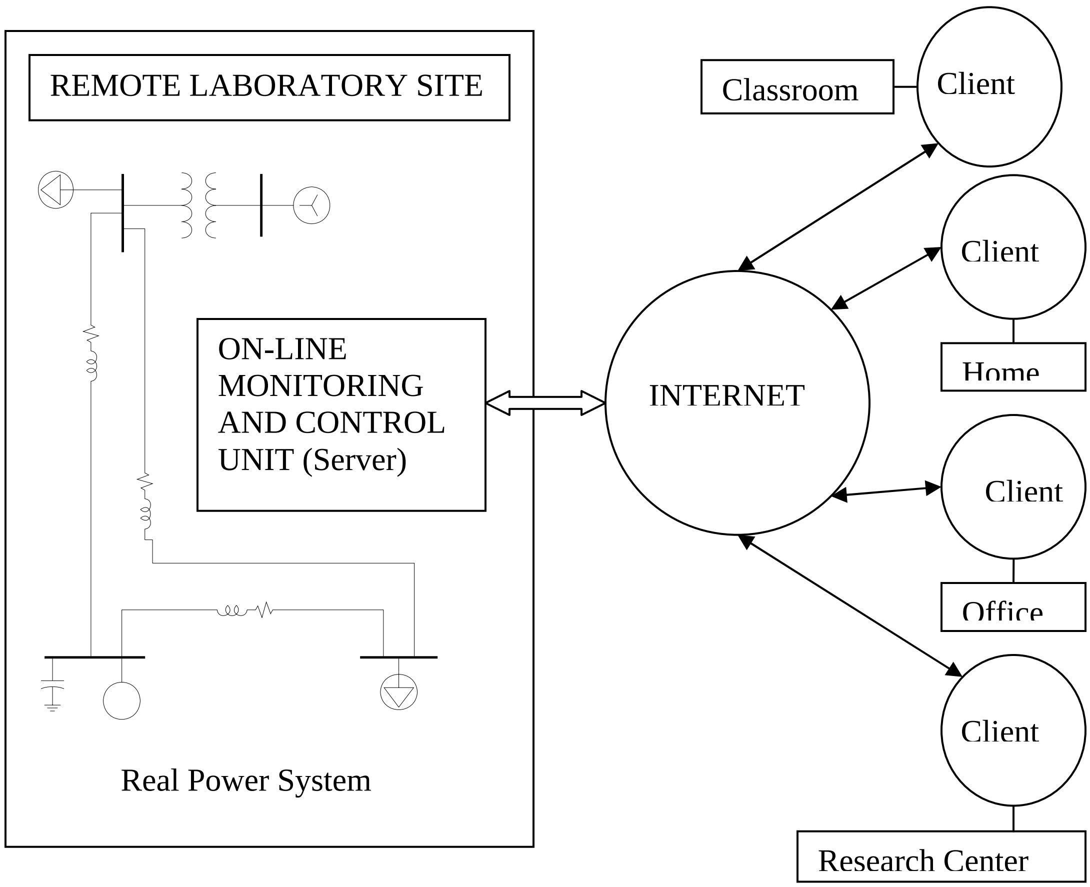


Fig. 1. Schematic view of the proposed remote laboratory system

2. Motor Acceleration and Variable-Frequency Control

a. Start an induction motor under known loading conditions and record the motor parameters from start to full-speed following a certain starting method.
b. Repeat step "a" using additional starting methods.
c. Study the performance of the motor during starting under these different methods
d. Vary the motor speed using a variable-frequency drive and record motor current waveforms.
e. Analyze the harmonic contents of the motor current.

3. Power Flow Analyses

   a. Record the voltage magnitude at each bus at a given time.
   b. Using the values found in step "a" as initial values, perform the load flow study.
   c. Compare the simulated output results with the real-time data shown on the virtual interface.
   d. Study the significance of line losses and voltage drops on various branches under different loading conditions.

4. Short-Circuit Analyses

   a. Perform a pre-tested short-circuit scenario and observe the operation of various protection devices.
   b. For the conditions of "a", perform a simulated short-circuit study.
   c. Repeat steps "a" and "b" for other pre-tested short-circuit studies.
   d. Compare the simulated output results with the real-time data recorded.

5. Device Coordination Study

   Using a radial primary distribution feeder, coordination of various protection devices may be presented. Real time performance of the relays both as primary operations and as backup operations may be tested.

6. Voltage Stability

   Voltage instability occurs due to primarily the lack of sufficient reactive power support. Susceptibility of any bus to voltage collapse can be studied by evaluating the sensitivities of the voltage at these buses to changes in the injected reactive power. Other dynamic factors may be investigated as well.

   (a) Select a load bus to undergo a voltage stability test.
   (b) Monitor and record bus voltages in addition to active and reactive power flow
   (c) Vary incrementally the load at this bus until the voltage collapse occurs.
   (d) Evaluate the voltage stability sensitivity indices.
   (e) Study other factors that may influence voltage stability.

7. Emergency Generator Start-up

   Another importance experiment for power engineering students is bringing up a backup generator online. Whether triggered by a loss of power signal or a manual startup case, there are certain conditions need to be met before actual connection occurs. This experiment may be designed such that the conditions for a successful startup be monitored and analyzed, then, a command for execution is sent. One condition to verify is that the loading condition (both real and reactive power) during startup allows a valid generator operating point.

## Renewable Energy Activities

Other activities may also be added to include renewable energy links. For example, a photovoltaic panel system can be a part of an experiment covering the maximum power point tracking process. An experiment aiming at power conditioning from a wind generator as well as its overall performance is another example.

## Concluding Remarks

A universal remote laboratory has been suggested for education and research in the area of electrical power engineering. The conceptual laboratory offers unlimited expandability to cover a wide range of topics and educational experiments. Working with a real system in addition to advanced visual animation technologes, users are expected to gain immense doses of practical experience. A cost analysis for a start-up practical system is yet to be performed.

## References

[1] H. Mohamed-Nour, "Simulation and Virtual Laboratory Education in Electrical Power Engineering," AEAS Conference Presentation, Cairo, Egypt, December 2008.

[2] J. Ma and J. Nickerson, "Hands-On, Simulated, and Remote Laboratories- A Comparative Literature Review," ACM Computing Surveys, Vol. 38, No. 3, Article 7, September 2006.

[3] C. Gooding, J. Hinson and D. Stubblefield, "Clemson University's Energy Systems Laboratory: A Hands-on Learning Experience for Students and Faculty," Energy Engineering, Vol. 103, No. 2, 2006

[4] R. Blanchard, S. Moron-Garcia and M. Bates, "Converting the physical to the virtual: providing a laboratory experience for distance learners in engineering," Current Developments in Technology-Assisted Education, FORMATEX 2006.

[5] M. Albu, K. Holbert, G. Heydt, S. Grigorescu and V. Trusca, "Embedding Remote Experimentation in Power Engineering Education," IEEE Transactions on Power Systems, Vol. 19, No. 1, February 2004.

[6] L. Sevg, "Modeling and Simulation Concepts in Engineering Education: Virtual Tools," Turkish Journal of Electrical Engineering, VOL.14, NO.1 2006,