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Web-Based Scalable Intelligent Multimedia Virtual Laboratory for Power Engineering

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WEB BASED SCALABLE INTELLIGENT MULTIMEDIA VIRTUAL LABORATORY FOR POWER ENGINEERING

Abstract

A laboratory practicum is considered a key component of engineering education. However a hands-on approach is often ignored for courses involving electrical machines because of safety issues, expenses, and lack of qualified teaching assistants. This paper presents the planning and development of a web-based application that can simulate a virtual laboratory for electric machines. This Virtual Power Laboratory [1] (VPL) is developed on a universal web-based platform that can be accessed anywhere by most mobile devices and modern computers. As a proof of concept, nine virtual experiments have been developed for DC motors and generators. Machine concepts are summarized using text, 2D and 3D graphics as well as multimedia animation. The animated graphical user interface (GUI) plays an important role as it enables students to review and retain basic concepts by building a bridge from the virtual environment to the real laboratory. Multimedia is employed in order to provide visual guidance to the students for better understanding of machines. Once completed, students will be guided and supervised by an intelligent tutor as they learn basic concepts, answer pre-laboratory questions, practice in virtual experiments and compose laboratory reports.

Key Words: Virtual Power Laboratory, Generator/Motor, Animation, Web Application, Intelligent Tutor, Information Management

1. Introduction

Laboratory experience is an essential element of a student's learning process. As the ancient Chinese philosopher Confucius said, "I hear and I forget. I see and I remember. I do and I understand." Unfortunately for topics involving electrical machines, it is often difficult to give students a hands-on learning opportunity due to safety issues, expense, and lack of qualified teaching assistants. The IEEE Power Engineering Education Committee (PEEC) Task Force on Education Resources [2] recently surveyed universities in the United States to determine the state of power education. Of the 118 respondents providing data for the survey, 202 laboratory courses (or less than 2 per program) were offered that were related to power systems or electrical machines. In addition, 22 universities are delivering at least one of their power engineering courses in a distance-education mode, and more than 26 universities are offering power-related courses without any laboratory support.

Over decades of technological evolution of software engineering, symbolically assisted simulation methods and internet technologies [3] have enabled the development of universally accessible virtual laboratories which come close to providing the experience of a physical laboratory. Nevertheless, there is still a debate surrounding the benefits and pedagogical outcomes of virtual laboratories compared to that of physical laboratories. Clearly, a virtual laboratory must be as effective as a hands-on laboratory if that is all the student has with which to learn. But in most instances, especially within engineering, the virtual laboratory can, and

[1] This research has been supported by the National Science Foundation under Grant DUE-1140306.

should, be designed to complement the physical laboratory and, if done correctly, will result in a better educational experience.

Computer-aided design and simulation tools for product development and analysis are now universally accepted in industry [4]. Thus to prepare students for their future profession, it is necessary to provide them with training in simulation and virtual environments. Furthermore, a well-developed multimedia realistic virtual laboratory can be of greater educational value than a physical laboratory [3]. For example, in a physical power laboratory, students' abilities are limited as to what they can observe. The inner-working principles of a DC machine can be better explained through 2D and 3D animations within a virtual laboratory rather than by observation in a physical laboratory. There are several virtual laboratory environments which individually provide learning material about electrical machines and provide e-learning tools using 2D and 3D graphical models [5], but only a few that attempts to integrate both [6].

In the past few years, the authors have undertaken an effort to explore the development of a virtual power laboratory. Its goal is to complement a hands-on laboratory but, to be realistic enough, to provide a satisfactory experience to students who do not have access to a physical laboratory. In this paper, we present a prototype with its elements: the architecture of the virtual laboratory, the knowledge base and a set of experiments for DC motors and generators. This Virtual Power Laboratory (VPL) is developed as a web based application that can be accessed by any modern computer or remotely from a majority of mobile devices. It provides students with an e-learning platform developed using the Adobe software package, Captivate. The mathematical engine is coded in JavaScript to support the simulation of physical machines. For a realistic simulation, we use the nonlinear magnetization characteristic of the machine rather than the linear model commonly found in textbooks. Also, a random number generator has been used in the simulation so that students will see different results every time they perform an 'experiment'. The application is managed by a user management module to guide and supervise students throughout their "laboratory work". An intelligent tutoring system is also being developed to help students learn basic concepts and conduct experiments effectively. This virtual laboratory is an attempt to bring together the best of both worlds in the learning environment: the richness of domain knowledge concepts and the tutoring supported by multimedia 3D interactive simulation that mimics a physical laboratory environment.

The rest of the paper is organized as follows: Section 2 summarizes related initiatives taken by other researchers in the past. The architecture of the virtual machine laboratory, which is implemented using a Frontend Client and a Backend Server, is presented in Section 3. The design and development of Frontend Client and Backend Server are presented in Sections 4 and 5, respectively, which is followed by a brief description of System Evaluation in Section 6. The paper is concluded in Section 7 with discussions on plans for extending the developed prototype to a complete intelligent tutoring system for electrical machines.

2. Related Initiatives

Prior research on simulation environments for electrical machines can be broadly classified into three categories:

a) A Matlab/Simulink based simulation environment [6,7,8]. The advantage of this approach is students' prior experience with Matllab/Simulink and the availability of the mathematical tools and graphical interface offered by these programs. It is relatively easy to motivate students to practice in a Matlab/Simulink based virtual environment than any other software environment. However, as a standalone virtual laboratory, either pre-installations are required for the laboratory simulation environment or a software download mirror must be made available before the laboratory session starts.

b) A traditional machinery laboratory with a computer data acquisition interface [9, 10]. Simulation environments of these types of laboratories are realized by the machine-to-machine interfaces from computer to actual power instruments. It can be developed [11] using high level programming software, such as C++, Pascal, and the .NET framework. The advantages here are that real time control can be performed on these types of virtual experiments because the physical connection to the actual machines reduces the delays. However, as in the previous approach, remotely accessible interfaces cannot be offered.

c) A web based virtual machine laboratory. In [12] and [6] the authors have represented their works to extend their Matlab based simulation designs to web based approaches. Some other ideas were proposed by [13] to build an Adobe Flash based virtual environment and were hosted through internet. While these simulation environments are excellent tools for self-learning of machine concepts, students do not receive any 'tutoring' support. Also none of the above approaches can be fully supported on popular mobile devices, such as smart phones and tablets, due to software authorizing issues.

This project is aimed at developing a universally accessible and sufficiently realistic virtual laboratory environment using the MangoDB/ExpressJS/AngularJS/NodeJS (MEAN) web server as the primary information management system. Also a Django/Python based web server was hosted in parallel to provide intelligent tutoring services. Javascript was chosen as the mathematical tool for machine simulations. Details of the architecture are described below.

3. Virtual Power Laboratory (VPL) Architecture

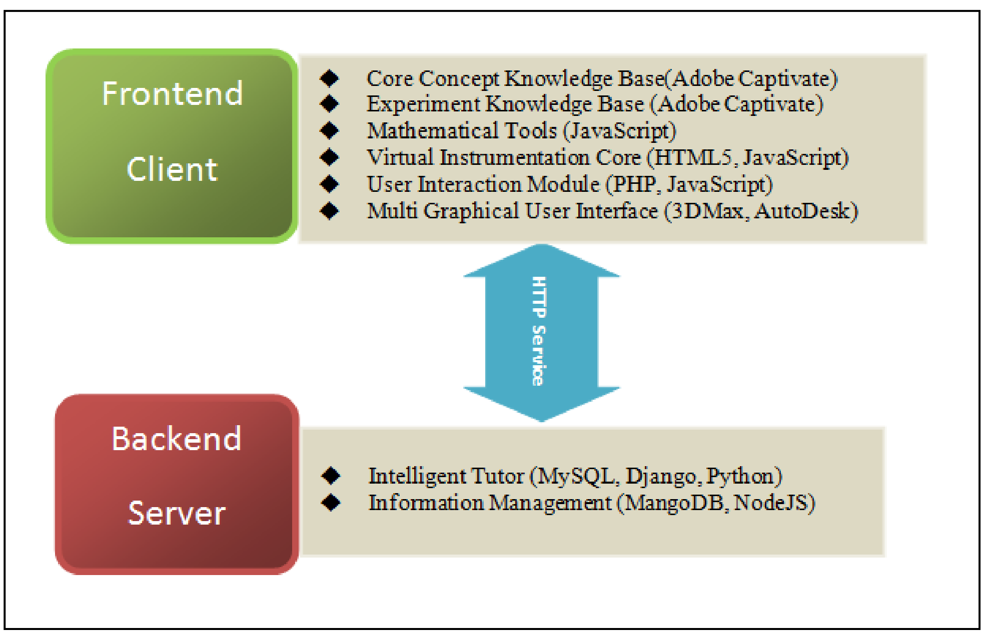


Figure 1. Architecture and Technology for Virtual Power Laboratory

The design of the Virtual Power Laboratory (VPL) focuses on three main objectives: 1) to extract learning materials from traditional machine courses and to compile them in a knowledgebase for the virtual laboratory, 2) to virtualize laboratory experiments and physical laboratory equipment and 3) to design and manage web based application that can offer services remotely accessed by students. The following paragraphs provide an in-depth description of the development of the software environment comprising the virtual machine laboratory.

As shown in Figure 1, the virtual machine laboratory is implemented in two parts: a Frontend Client and a Backend Server. The Frontend Client is an e-learning platform consisting of 1) a **Core Concept Knowledgebase**, 2) an **Experiment Knowledgebase**, 3) **Mathematical Tools**, and 4) a **Virtual Instrumentation Core** that are interfaced with 5) the **User Interaction Module** through 6) a **Multimedia Graphical User Interface Module**. All these modules are managed and supported by the Backend Server that has the ability to offer secured http service as well as dynamic database management. The Backend Server shown in Figure 1 has 7) a **Scalable Information Management Module** and 8) an **Intelligent Tutoring Module** (planned) to supervise and guide the students by providing both visual guidance. Both the Frontend Client and the Backend Server are designed to be secure, stable and scalable. This laboratory application will also be accessed through the Internet on popular mobile devices.

4. Frontend Client: eLearning Platform

Figure 2 shows the architecture of the front-end eLearning platform, which is organized as several interconnected modules:

a) Multimedia Graphical User Interface
b) Core Concept Knowledgebase
c) Experiment Knowledgebase
d) Virtual Instrumentation Core
e) User Interaction Module

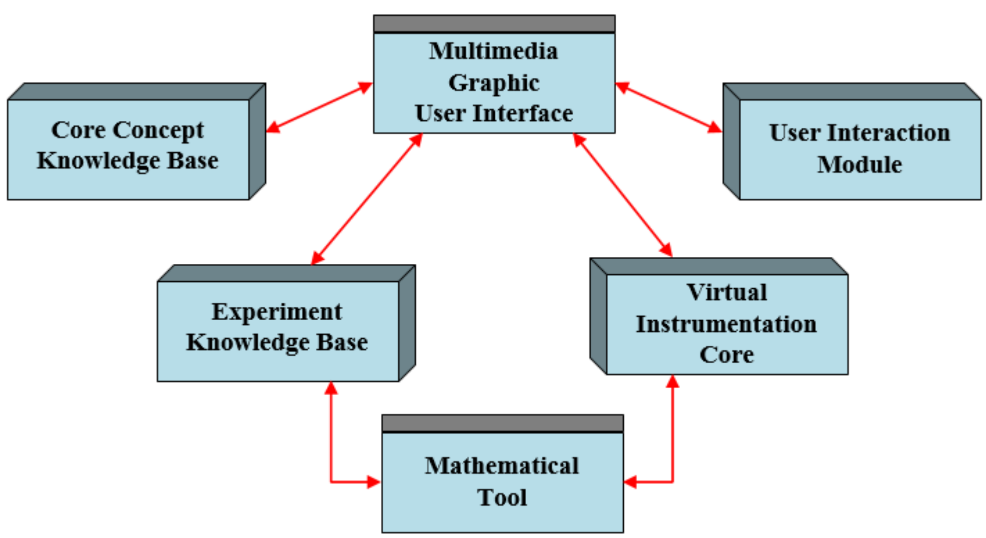


Figure 2 Architecture of the Virtual Machine Laboratory

4.1 Multimedia Graphic User Interface

As the student 'enters' the virtual laboratory, the initial screen instructs the students to choose one of the options, such as a) Review basic operating principles of machines, b) Review how the machine is constructed, c) Review experimental concepts, or d) Perform an experiment. The student interacts with the software environment through the User Interface using a mouse, keyboard or any human/computer interface device. The multimedia interface [14] is a set of interactive modules, developed using Adobe Captivate, a commercial multimedia authoring system. If the student chooses to do an experiment, an experiment template is presented with machines and instruments similar to those found in a typical physical power laboratory.

The GUI interface is implemented using HTML and JavaScript programming languages, which make the interface adaptable to popular mobile devices. Since the platform technology for web based laboratories could take different forms [15], the common feature among all platforms is a powerful Internet hosting module. This external interface has two purposes: the first is to perform data acquisition, signal conditioning and control in the virtual experiment setup; the second is to perform the necessary Internet computation and protocol procedures.

4.2 Core Concept Knowledgebase

This virtual laboratory is expected to acquaint students with the fundamental concepts of electrical machines, in particular the DC generator and DC motor. The core concepts must be conveyed in succinct paragraphs yet with sufficient details and mathematical rigor. Thus, it is necessary to create a multimedia model that can graphically illustrate the properties of the physical machine as well as describe its properties using appropriate mathematical equations. In our system, the multimedia core consists of video clips and three dimensional (3D) animations. This multimedia core plays an important role in the virtual laboratory system as it illustrates the basic concepts using graphics and texts.

The GUI shown in Figure 3a and 3b implement a fully operational multimedia core together with the description texts. This allows the student to visually experience and understand the physical machines. The interactive 3D animation embedded in Figure 3a performs a complete set of sequential operations of a DC generator in order to illustrate the generation of voltage as a coil rotates in a magnetic field.

The multimedia knowledgebase core is not only a collection of critical concepts of the machine, but also is an interactive media that takes the students through a step-by-step learning process. The aim of this multimedia module is to offer a simple and straightforward learning tool that can simplify the complex fundamental knowledge into intuitive expressions.

The core concept knowledgebase module is a collection of the fundamental information extracted from traditional teaching materials. It is categorized into three different types:

a) Descriptive knowledge
b) Interpretive knowledge
c) Mathematical knowledge

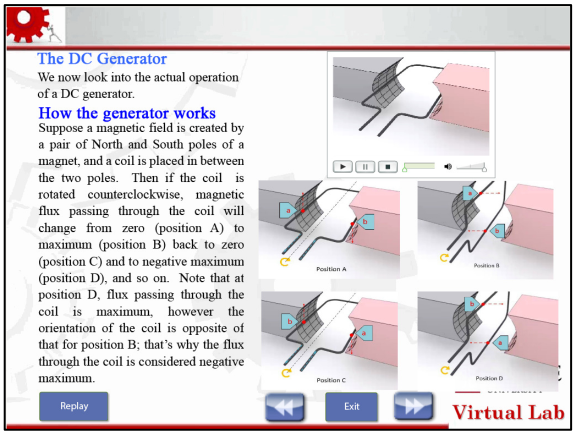


Figure 3a. Multimedia Core Animation

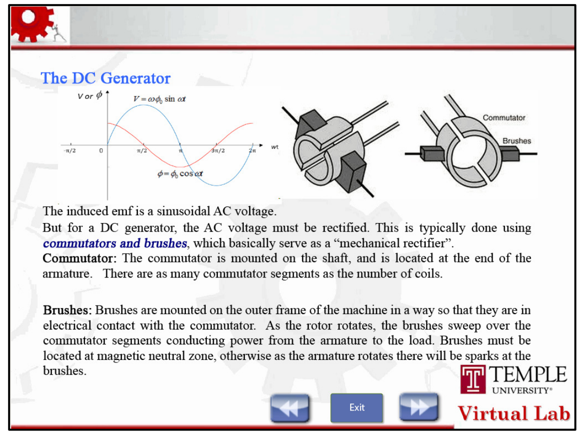


Figure 3b. Multimedia Core

The **descriptive knowledge** is extracted from standard textbooks on electrical machines used at universities. It is naturally expressed in declarative sentences or indicative propositions to elaborate the complex conception in a simple way. For example, Figure 3a shows change of flux through a coil rotating in a magnetic field. Figure 3b shows the description of brushes and commutators in a realistic DC generator. The knowledge is transcribed in the multimedia core using animations and images. In this way, "tedious" concepts are expressed by an interactive process, which can help students to graphically associate the knowledge with the realistic mechanism behind the concepts. For example, animations illustrated in Figures 4a and 4b help explain the descriptive knowledge behind the Generator/Motor mechanisms and Right/Left handed rules. (Actual animation can be observed by visiting the project website http://vpl.temple.edu)

Interpretive knowledge is defined as the knowledge of how, and especially how best, to perform certain tasks. In this laboratory, this type of knowledge includes all instructional guides for experiments extracted from typical machine laboratory manuals. Due to the content of this type of knowledge, it is difficult to provide a straightforward discussion to help the students interpret the knowledge behind the lab instructions, for example, some of the "how-to" or "why" questions may not have a direct answer. In this project, the authors are compiling all possible interpretive knowledge together in the database, which will be eventually coupled with the *intelligent tutor* module.

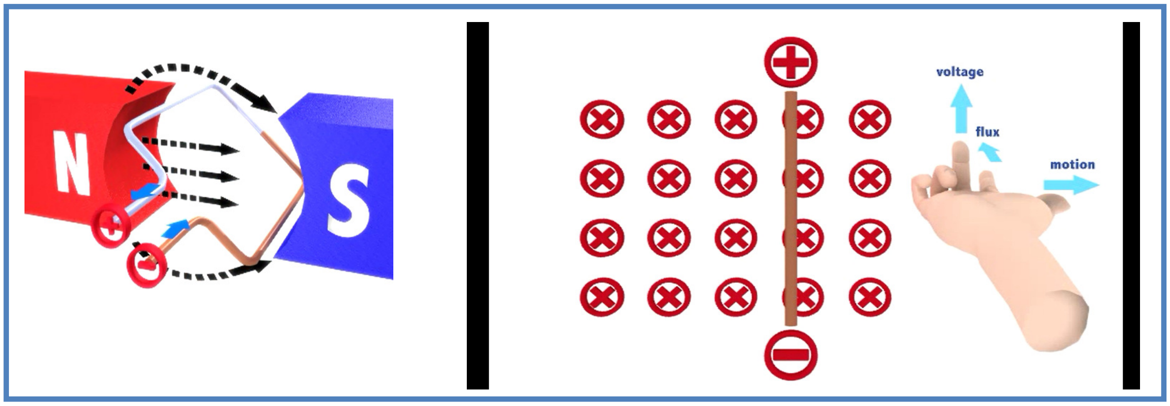


Figure 4a. **3D animation for generator concept.**

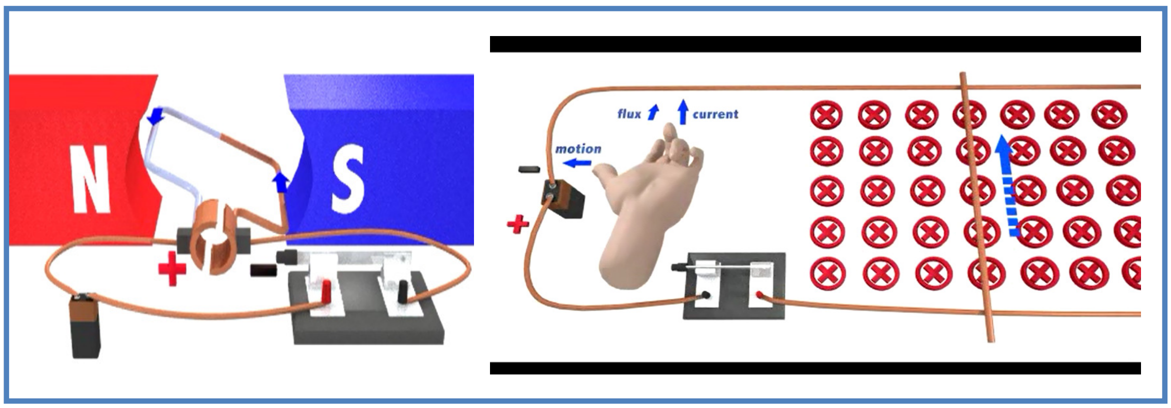


Figure 4b. **3D animation for motor concept.**

The **mathematical knowledge** provides the mathematical descriptions of the operation of a DC machine in both transient and steady state modes. For example, the speed of a shunt motor can be described using circuit equations based Kirchhoff's current and voltage laws. These equations are presented and are embedded using text and graphics as necessary.

All of these knowledge sub-bases are constituents of the main knowledgebase of this project. They are queried by other modules of the software. The knowledgebase may be updated during the evaluation process for correctness and usability.

4.3 Experiment Knowledge Base

A set of laboratory experiments on DC Machines, similar to those commonly used in real laboratory courses, has been developed in the virtual laboratory [20]:

TABLE I. VIRTUAL POWER EXPERIMENTS LIST

Experiment ID	Virtual Experiment Titles	Number of Activities
1	Magnetization characteristics of a separately excited machine	3
2	Voltage buildup of a shunt generator	4
3	Loading of a shunt generator	1
4	Series generator load characteristics	1
5	Compound generator load characteristics	3
6	Starting of a shunt motor	1
7	Speed control of a shunt motor	1
8	Torque speed characteristics of a shunt motor	1
9	Torque speed characteristics of a series motor	1

The prototype experiments help students to understand the principle of machine's operation and its unique connection to an electrical circuit. Experiments also allow students to measure various quantities, such as current, power, voltage etc. The virtual machines have a default rating in terms of operating voltage, current, and power, which can be changed by the user if necessary.

For each experiment, the machine circuit model is expressed using standard equations (omitted here for brevity) based on Kirchhoff's voltage and current laws. For armature induced emf, we use the Langevin function (1), which is more a realistic representation of magnetic saturation than the linear approximation commonly found in textbooks. In addition, Newton's laws have been used to describe the speed profile of the machine state as a function of time.

$$L(x) = A(\coth(x) - \frac{1}{x}) , \qquad (1)$$

where *coth* is the hyperbolic cotangent function. Using the Langevin function, the induced emf in the armature is expressed as

$$E = L(I_F) + r \qquad (2)$$

where r is a small random number, and I_F is the field current. Thus every time a student performs an *experiment* using the virtual laboratory, the random number r will take a different value so that the corresponding induced emf will be slightly different even if the field current is the same. This makes the *experimental* results of the virtual laboratory not exactly repeatable as is commonly observed in a real laboratory.

The experiment knowledgebase is designed similarly as the core concept knowledgebase. The main difference is that the experiment knowledgebase requires an interface between the Frontend Client and Backend Server to facilitate access of the contents from various mobile devices. Since the virtual laboratory must run as a scalable web application that can be accessed by a majority of the current mobile devices, mathematical contents of the experiment simulations are coded in JavaScript.

4.4 Virtual Instrumentation

In the virtual experiments module, the student is presented with a circuit template (Figure 6 and 7) containing the basic circuit components required for a typical experiment, e. g., the machine armature, field windings, open jumper positions for ammeters and voltmeters, rheostats as well as a load or power supply. The student then connects the various components as a shunt machine or a compound machine as appropriate. If needed, the student can go back and review the circuit configuration or basic concepts using the knowledgebase of various machines. The student initiates the experiment by activating the power button after the software environment determines that the student has completed the circuit configuration correctly.

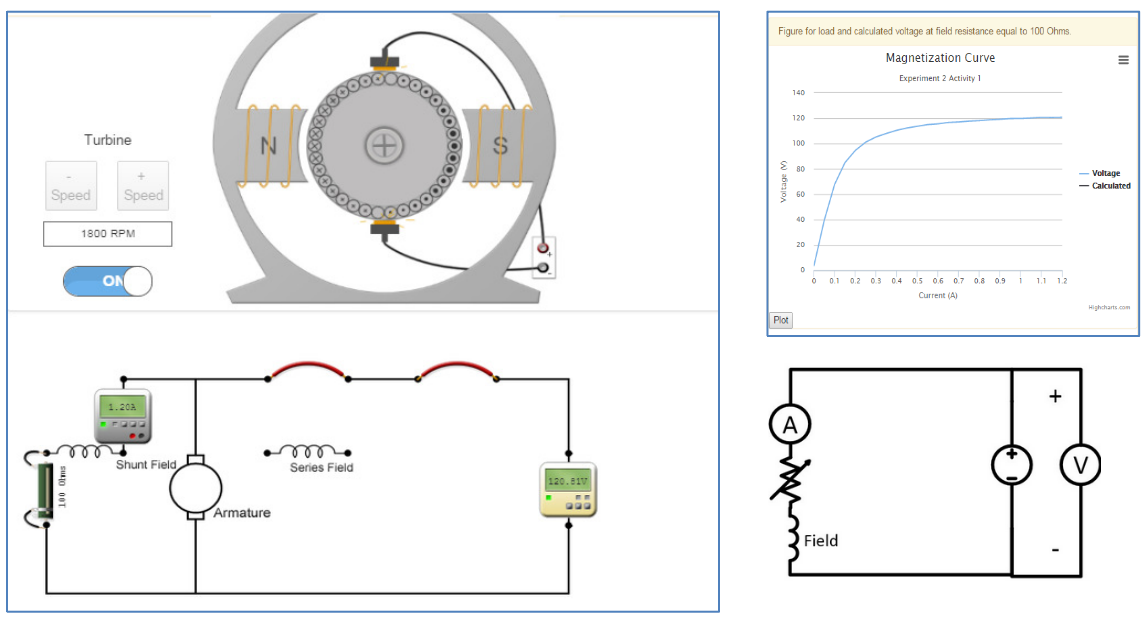


Figure 6. Experiment 2 DC Generator Circuit Diagram Template

Once a machine is started, the *Experiment Knowledgebase* module runs the mathematical model of the machine in the background and sends a data stream of various circuit quantities to be displayed on virtual instruments. This data stream arrives in real time and creates a feeling that the actual machine is running in real time. In order to better virtualize the equipment, the animated machine simulates sparks at the brushes as the turbine rotates. Students can clearly picture the realistic machine mechanism through this virtual experiment.

One of the important aspects of this virtual experiment is to play *'what if'* scenarios on the operation of a machine. For example, one may ask what happens to a DC shunt motor if the applied voltage reduces by 50%, or if the load increases by 50%. These types of experiments may not be safely performed in a real machinery laboratory. The virtual laboratory will provide a unique opportunity to the students to conduct these experiments without incurring any real physical damage to the machine or measuring equipment.

Figure 7 gives the screenshot of the measurement data from a typical experiment. Although it is possible to automatically populate the table with experimental data, the authors have decided to allow the user to manually record the experimental data as is done in a real physical laboratory. Once the experiment is concluded, results can be plotted on the computer screen.

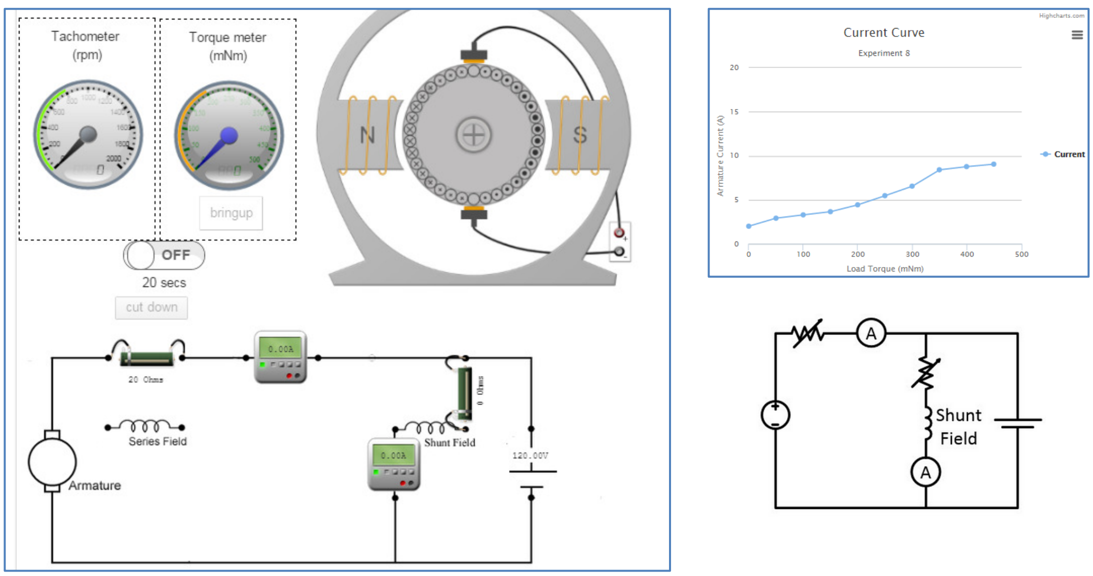
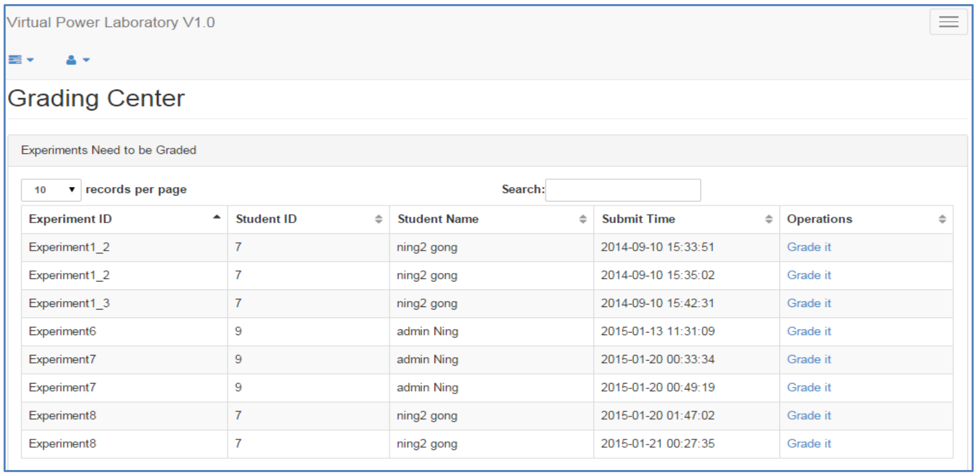


Figure 7. Experiment 2 DC Motor Circuit Diagram Template

4.5 User Interaction Module

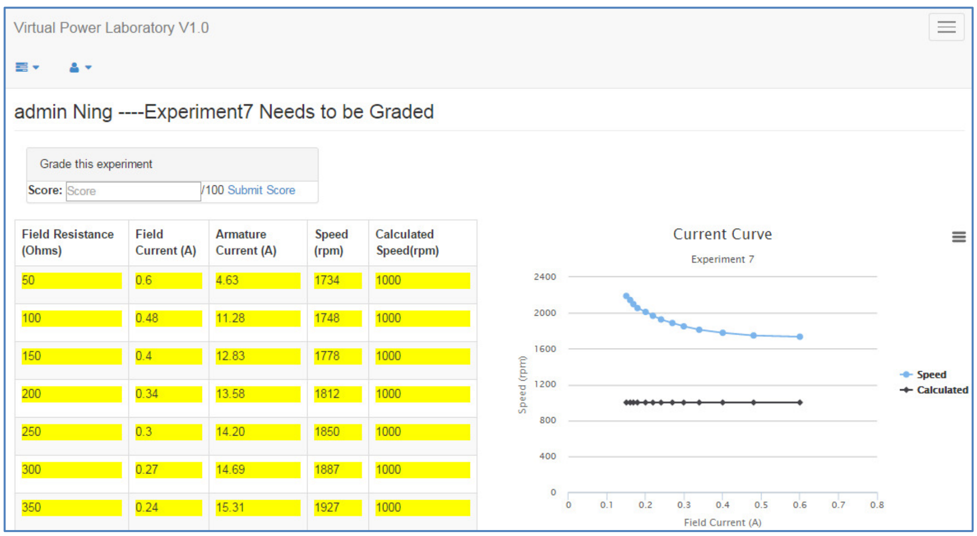
The User Interaction Module is implemented between the Frontend Client and Backend Server. It is a bridge to navigate the users' operations to the Backend interpreting and storing engines. In order to provide the students with better guidance as they progress, students' operations are stored and tracked by the User Interaction Module.

Administrative users, such as instructors and teaching assistants, have access to management tools offered by User Interaction Module. Following an authorization process, administrative users have the ability to: 1) Enroll a student to the laboratory, 2) Import students using a batch file, 3) View the students' reports in grading center, illustrated by Figure 8a and 8b below, 4) Grade the laboratory reports, and 5) View and edit the students' scores. These actions are invisible to student users and visitors.



Experiment ID	Student ID	Student Name	Submit Time	Operations
Experiment1_2	7	ning2 gong	2014-09-10 15:33:51	Grade it
Experiment1_2	7	ning2 gong	2014-09-10 15:35:02	Grade it
Experiment1_3	7	ning2 gong	2014-09-10 15:42:31	Grade it
Experiment6	9	admin Ning	2015-01-13 11:31:09	Grade it
Experiment7	9	admin Ning	2015-01-20 00:33:34	Grade it
Experiment7	9	admin Ning	2015-01-20 00:49:19	Grade it
Experiment8	7	ning2 gong	2015-01-20 01:47:02	Grade it
Experiment8	7	ning2 gong	2015-01-21 00:27:35	Grade it

Figure 8a. Experiment Grading Center



Field Resistance (Ohms)	Field Current (A)	Armature Current (A)	Speed (rpm)	Calculated Speed(rpm)
50	0.6	4.63	1734	1000
100	0.48	11.28	1748	1000
150	0.4	12.83	1778	1000
200	0.34	13.58	1812	1000
250	0.3	14.20	1850	1000
300	0.27	14.69	1887	1000
350	0.24	15.31	1927	1000

Figure 8b. Experiment Report to be Graded

5. Backend Server

The Backend Server is implemented as a secured HTTP service for wired or wireless networks. The whole architecture enables reliable real time data exchange channels among the servers, web browsers and various databases. The servers collect and transfer real-time data from dynamic databases, and distribute this data to the end users' web browsers. The Backend Server system has a set of two sub-servers offering various web based services:

a) Intelligent Tutoring Server
b) Information Management Server

5.1 Intelligent Tutoring Server

The intelligent tutor, which is currently being planned acts as a virtual laboratory assistant that "*watches*" what the student is doing and learns from the student's actions, what he or she knows, does not know or knows incorrectly. The tutor software is an AI module [16] based on rules and procedures that relate the student's knowledge to that needed to perform the experiment successfully.

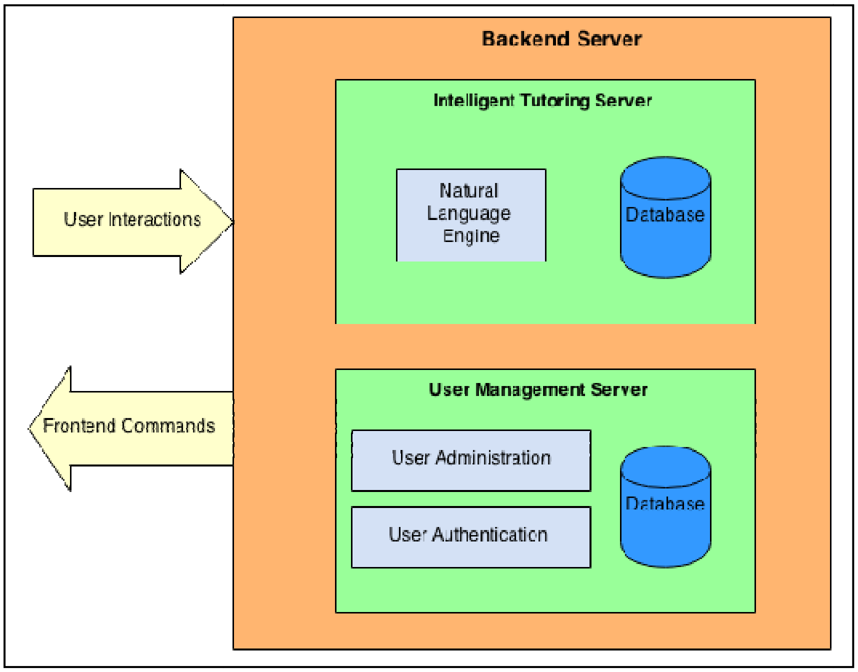


Figure 9. Backend Server Structure

As is shown in Figure 9, it is planned that the tutoring server has User Interactions as its input. These interactions will be generated by the Students Interaction Module in the Frontend Client including the user inputs, progress, records and so on. These data will be processed by a Natural Language Engine implemented in Python and Django. The interpreted commands will then be generated by the engine and passed to the Frontend Server. The commands will vary depending on the inputs. The Natural Language Engine, for example, will process the inputs to see whether the students' operations are correct or what kind of result could be predicted if the users are performing a certain action. The commands that will be passed to the Frontend Server can be oral or visual instructions to guide the students properly.

5.2 Information Management Server

The authors elected to host all of the information management functionality remotely. The nature of the virtual laboratory demands maximum accessibility to user interaction with the system. A web-based interface will also make it easy to integrate with other virtual laboratory systems in the future. The information management server is implemented on Dreamhost Cloud Service. To minimize costs, we utilize Micro Instance [17] which provides small but consistent computing resources; capacity can also be dynamically increased in bursts as needed. The Micro Instance is well suited for our system due to its low throughput and periodic administration cycle by a small number of users. On the Micro Instance, the system is built using the MEAN framework which is a high level web framework that stands for MangoDB, ExpressJS, AngularJS and NodeJS. It is a combination of Backend technologies that can provide a seamless architecture that includes all layers identified as follows [18, 19]:

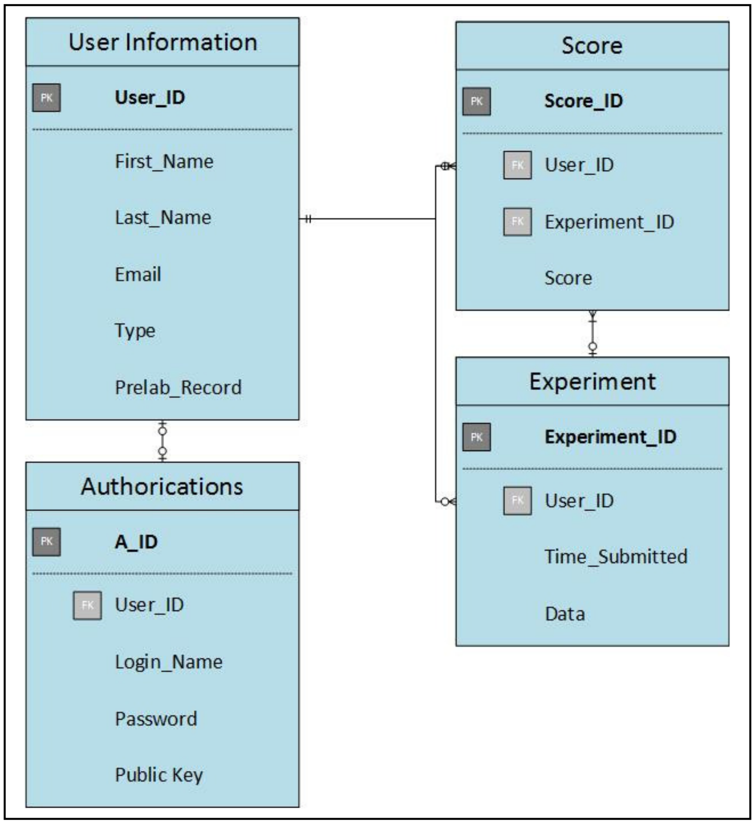


Figure 10. Entity-Relation Graph for the database models. The Primary and Foreign Keys are all illustrated in the figure

a) The *Model Layer* is the database API that can support any kind of database specified in the settings file. In the system we applied four MangoDB tables to represent the models, please see Figure 10 for the details of the database Entity-Relation graph. Particularly, we represent the *pre-laboratory records* as a part of the student registration information instead of storing them into message template. That's because the *pre-laboratory record* varies for different users. It will save space when sharing the user ID as a primary key within the User Information table. Specially, in the User Information table as illustrated in Figure 10, the types of the users are defined as Students, Teachers and Administrators. Different types of users are assigned with different authorization privileges which are elaborated previously in Section 4.5.

b) The *View Layer* is the server code that includes interfaces with the Frontend Client to handle custom experiment data and user requests. The data input lists and predefined mathematical equations are implemented here. This layer also offers a bridge connecting the model layer.

c) The *Template Layer* has the interface that uses NodeJS and the latest web technology. This layer is a light-weighted loosely coupled interface connecting the Frontend browser and background databases, especially, MangoDB as used in our system. The template language offers a layered sequential database access through the View and Model layers. This design results in a flexible and quick query execution speed, which ensure a fast reactive decision making service in the proposed virtual laboratory.

All these layers linked together compose a seamlessly coupled data server model. This means that changes in a certain layer won't have any significant influence to elements in other layers. Thus the integration of a system management server with the MEAN model adds extra scalability to the Virtual Power Laboratory.

6. System Evaluation

The first version of proposed virtual laboratory system has been tested and maintained at Temple University since June 2014. All of the functions itemized in this paper have been tested for their fully functionality. Meanwhile, a computer based adaptive assessment tool is being developed which will be integrated into the current system. Once the tool is developed, it will be a great enhancement for the virtual laboratory by automatically gathering feedback from the students. This assessment tool will be focused on the evaluation of this application. Thus, once it is integrated with the system, we will be able to answer: 1) How much difference there is between the traditional hands-on laboratory and the virtual laboratory, 2) Whether or not the virtual instrumentation and experimentation have provided great educational values to Power Engineering, and 3) How is the educational goal reached by the Intelligent Tutoring module. System evaluation will be analyzed based on the data output from this assessment tool.

7. Conclusions

This paper presents the development and implementation of a Virtual Power Laboratory (VPL) based on web based approaches. The VPL architecture is implemented in two parts: a Frontend Client and a Backend Server. The Frontend Client is an e-learning platform consisting of a vast knowledgebase on electrical machine concepts and experiments. The Backend Server offers secured http service as well as dynamic database management. Both the Frontend Client and the Backend Server are designed to be secure, stable and scalable. This laboratory application is accessible through the Internet on computers and popular mobile devices.

For universal accessibility, we use the MangoDB/ExpressJS/AngularJS/NodeJS (MEAN) web server as the primary information management system. Also a Django/Python based web server was hosted in parallel to provide intelligent tutoring services. Javascript was chosen as the mathematical tool for machine simulations. The VPL server is hosted and maintained at Temple University.

As a proof of concept, a set of nine experiments have been developed for DC machines. The DC machine has been simulated using standard circuit equations, a nonlinear magnetization characteristic, and Newton's law for dynamics. Multimedia is incorporated in order to provide visual guidance to the students for better understanding of the concepts. Further research is in progress to embed the intelligent tutoring system so that the '*virtual tutor*' can assess the student's progress and guide the student with prerequisite material on the subject matter.

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