Design and Development of a Multiple Concept Educational Renewable Energy Mobile Mini-Lab for Experimental Studies

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Abstract

When students are introduced to the concept of science and engineering projects, one of the instructor's first tasks is to help students understand the difference between non-experimental and experimental projects. In general, non-experimental studies with theory only are not sufficient to prepare a future workforce in engineering and technology fields because this method does not teach the skills of critical thinking, troubleshooting and problem solving. Hands-on experimental projects in addition to the theory of a topic involve the students in critical thinking and engineering processes, developing models of engineering concepts, collecting and recording data, analyzing and presenting data and drawing conclusions. Experimental work of this type focuses on discovery and investigation and aids the students' understanding of concept in details. In the field of alternative energy technologies, there has been a recent demand for a qualified workforce that understands the engineering concept and practical applications.

For renewable energy technologies, students should have a background in energy, electricity and mechanically related topics in order to properly understand renewable energy concepts so that they can enter the field of management and building systems. For students to have a grasp of both theory and experimental knowledge of renewable energy technologies, a laboratory environment is mandatory to conduct related labs. There are many ways to involve students with lab experiments. However, to offer a renewable energy related program, there are additional costs to purchase lab equipment for these classes. Those schools that cannot afford to buy equipment to conduct lab sections may consider building the training equipment themselves. This will reduce the overall costs and give students an excellent opportunity to apply the concepts they learn in the classroom. This current project describes the implementation of a stand-alone and cost-efficient hybrid educational training mobile lab to teach lab sections of renewable energy classes.

Introduction

Dependence on limited energy resources such as fossil fuels results in issues that present generations must address in order to ensure that future generations are able sustain their energy needs. The subject of renewable and clean energy is the main force driving nations to become more environmentally conscious. As a result, there is increased awareness of the delicate balance between the consumption and maintenance of world's energy resources. The new trend in this century is all about "going green" and promoting clean energy, which refers to increasing awareness of the environment. Community attention is focused on current lifestyles which use resources inefficiently and destroy or pollute the environment. According to the Energy Information Administration (EIA), the share of residential electricity used by appliances and electronics in U.S. homes nearly doubled over the past three decades [1-3]. The use of renewable energy sources will help decrease the dependence on energy produced by fossil fuels. Recent attempts from government, academia and organizations have increased energy awareness and promoted use of alternative energy sources. Renewable energy today provides about 9% of the world's energy and 8 - 10% of the U.S. needs [4].

According to a 2011 projection, only 8.2% of the energy supply comes from renewable energy. However, in many parts of the world, these percentages are increasing significantly. Based on current data on global warming, as well as on the current U.S. dependence on overseas oil, there is increasing interest and urgency in the use of alternative energy sources [5-7].

As Sam Houston State University moves toward an environmentally friendly green campus, energy harvesting projects are getting more attention from students and college administration. Recent projects supported by various departments on campus include the use of new LED security lights powered by solar panels with a tracking system, a 2kW hybrid wind and solar system powering LED parking lights and development of an electric boat, among others. The number of renewable energy (RE) projects has been increasing in order to promote RE technologies at school campuses [8-12]. This trend is not limited to on-campus projects, there are also classes developed online to offer energy awareness for the students. In order to offer hands-on experiments to students along with theory, technology program faculty have attempted to purchase laboratory equipment to improve the courses and offer hands-on training. Due to the high cost of laboratory equipment on the market, students and faculty built ten renewable energy training stations with departmental, college administration and local utility company support.

The majority of alternative energy educational training units are built and sold by companies that offer custom-made systems according to their customers' needs; this increases the cost of the training units [13-17]. Alternative energy teaching tools help students to fully comprehend complex concepts with interactive educational training equipment and are very important for the hands-on laboratory sections of energy education. Due to the high costs of educational training units, it becomes a budget concern when equipment is purchased for the laboratory sections of energy related courses. The costs of such equipment range from \$10,000 to \$50,000 per unit [18-21]. If there is a budget concern for a department, the only option to the instructor is to teach only the associated theory of the course, but not the actual application. Even if energy courses are taught in business and education programs, it is imperative to conduct laboratory experiments using equipment and materials, especially in engineering, science, and technology courses.

Students and faculty in the Industrial Technology program designed, developed, built and tested ten multipurpose RE mobile training units for alternative energy related education. The units were designed to be used in hands-on activities to provide opportunities for students to engage in experiments that would reinforce the material covered. More importantly, students experienced a real-life design and production process ranging from purchasing, requests for donations, writing proposals, generating reports, metal working, wood working, electronics, computer-aided design, painting, market and literature search, team work, and working with industry to complete the project. This paper reports all of the details for building a mobile system for educational purposes along with the curricular materials. The materials in this study were to be used for educational purposes only; the authors can be contacted for further information and collaboration.

Design

Usually, educational training equipment is manufactured to educate students on a specific topic such as rotating machines, power electronics systems, refrigeration, plants, controls, HVAC, instrumentation, hydraulics, etc. This is also true in the field of renewable energy education; usually an educational training unit presents a single energy source topic such as solar, wind or biomass energy system. As a consequence, the educator is forced to buy separate units to teach each alternative energy technology such as wind technology, human power, biomass, solar energy or hydrogen fuel cell systems. It is very rare to see combined training units to teach multiple energy sources in one integrated system. One of the main reasons for this is that energy systems typically are taught separately for topics such as photovoltaic systems, wind energy systems, geothermal energy, fuel-cell systems, etc. General energy courses cover most of the renewable energy topics but usually only theory is taught with a minimum of lab experiments. For example, business- and economy-based energy courses only cover the theory of energy systems. Engineering technology programs are more application-based to offer more hands-on experiments as compared to engineering programs.

Another reason for a lack of hybrid trainers is the space and cost issues present—except in cases where the system is custom made. If the training equipment is hybrid, this increases the size of the unit, which may cause problems if lab space is limited. The design concept in this study covered a custom design for the schools and teaches both general renewable energy systems and specific energy systems such as photovoltaic and wind energy. However, these topics cause the establishment of an alternative energy program and laboratory to be more expensive and difficult to implement. In the implemented prototype for an integrated educational training system, six energy sources were combined in one training unit that included wind, solar, human power, passive water heating, passive air heating and hydrogen fuel cell technologies. The unit serves to compare the efficiency and reliability of each source using a data-acquisition system. The block diagram of the energy harvesting central module is shown in Figure 1.

Besides the modules in the block diagram, there are energy-related modules available to mount on the central unit for study. These modules include data acquisition, thermoelectric, piezoelectric, friction, flywheel and rotary units; human-power kits; and, temperature, light, sound, mass, rotary, force, VI, rainfall, anemometer, wind vane, humidity, irradiation, barometric pressure, heat-index, wind-chill and dew-point sensors.

A 3D CAD (Computer Aided Design) model of the mobile metal stand was created using Autodesk Inventor [22] to estimate the number of metal parts (tubing and brackets), bolts and nuts, wheels and paint of the training unit. The design of the mobile frame and wind turbine stand are shown in Figure 2. The upper portion of the stand has a rectangular frame to mount the solar modules. This frame can be manually adjusted to study seasonal sun energy as it reaches the earth's surface. It allows users to tilt the frame with the solar panels attached in order to study -15 to +15 degrees, depending on the location and season. The frame can be tilted 180 degrees to study tilt angles and the efficiency of the solar module relationships [23]. The total price of materials to build ten metal stands was $654.40 (based on a discounted quote from a local business). This amount can change dramatically depending on building materials of the training unit housing.

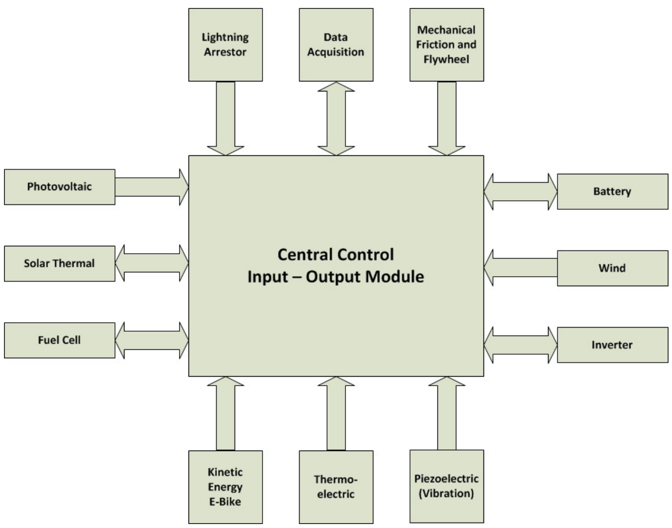

Figure 1. General Block Diagram of the Central Module

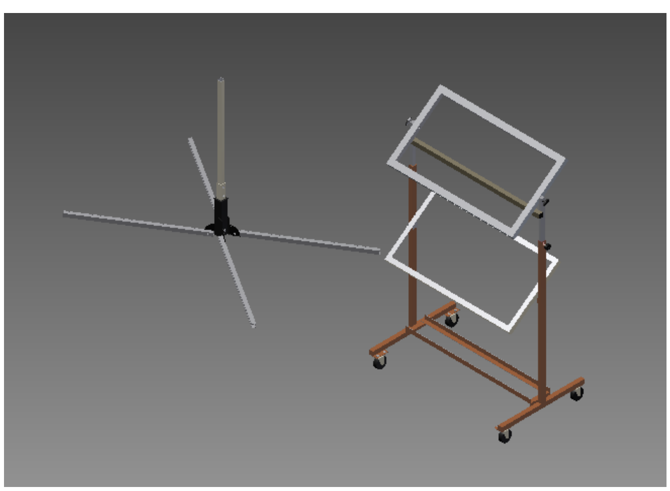

Figure 2. CAD Model of Stand Frame and Wind Turbine Stand

The training unit components were identified after extensive market research. The compatibility of the parts was confirmed, and specification sheets were stored in a database to draw components using the Autodesk-AutoCAD software tool. The design layout helps to locate drill holes and to make cutouts to place and align the components on the module board. After getting dimensions of all the parts from either specification sheets or by measuring the parts, they were put into digital form so that they could be used for the CAD design. The following CAD file is just one of the concepts that were developed using this method. There are many components that make up this training board; all of these components were drawn on a 1:1 annotation scale, which allowed us to properly place the components onto the board as if it were in a real application. This made for optimum assembly of these parts allowing for maximum space utilization of the training board. The AutoCAD design layout is shown in Figure 3.

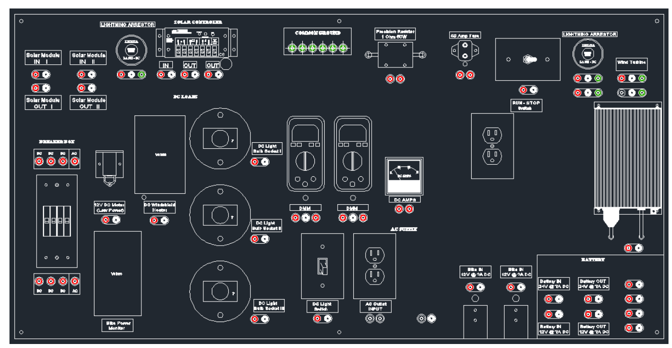

Figure 3. The AutoCAD Design of the Training Control Unit Layout

In order to reduce safety concerns, Pomona electronics panel-mount jacks for sheathed plugs were used so that there would be no contacts readily available to users of the module. The wire connections between the contacts of the jacks are located behind the panel where users have no access [24-26]. Banana Plugs with patch cords and panel-mount jacks are all sheathed types and contacts and are not exposed to users. This reduces the safety concerns of the unit, which was tested under various conditions. For this design, the AutoCAD layout was used, including all of the drilling and component specifications. The CAD layout was shared with a local small business that does woodworking so that a prototype of the module could be made for test purposes. After revisions and updates on the prototype module, ten identical units of modules were built using CNC (computer numerical control) operated machines. The overall work was done including machining from the design layout and furnishing the melamine of 5/8" thickness. Also, a PVC edge banding of 3mm slightly radiused edges were applied for durability purposes of the units. Ten units cost $425.00 (discounted price) including all of the materials, design work and prototype module.

Each unit can accommodate two to three students at a time. This mobile mini-lab is capable of using wind and solar technology, active/passive human power, passive water heating systems, passive air heating systems, and hydrogen fuel cell technology. The unit includes two solar panels, a wind turbine connection, a charge controller, measuring devices, circuit breakers and fuses, lightning arrestors, a battery, an inverter, switches, a DC generator, a temperature sensor, irritation sensor, an anemometer, two power sensors, and data acquisition peripherals. The system has the capability to accept several different RE sources at a time and convert those intermittent voltage sources to constant voltage to charge a battery. The charge controllers handle the charging process of the battery at different input voltages that vary by intensity of light energy, wind speed and human kinetic energy.

Production and Testing

The prototype training unit project had four phases and was finished in a year. The first phase of the project used a 3D CAD design system with 3D parametric modeling software tools. After the design of the system, all of the necessary parts for one unit (prototype unit) were determined and ordered from various manufacturers or vendors. Then, the wheeled metal frame, which is the housing of the training unit, was built in the production lab. The balance of the housing (frame) was important because of the heavy components placed on it, such as a battery, solar modules, inverter and computer case. All of the components were mounted on the board (5/8" MDF) which is the actual training unit. The board was then fastened to the wheeled frame and all necessary wiring was done to test the system in different locations on campus and for use in renewable energy education. The prototype unit was extensively tested to eliminate or reduce any safety issues, and improvements were applied before the production of the remaining ten units. The remaining units were built quickly since the completed prototype model could be referenced, with the remaining parts acquired with support from internal/external funds.

Building a reliable system to eliminate safety concerns is of importance because of the variable voltage outputs from different alternative energy sources. Special attention was given to the location of battery and circuit breakers/fuses to eliminate any hazard caused from short circuits in the system. The training unit and all of the peripheral equipment around it are shown in Figures 4 and 5.

The wind turbine is mounted separately from the training unit; it was placed on a separate stand in order to avoid any accidents due to spinning wind turbine blades. The wind turbine output was connected to the training unit module through a long cable for power reading and data acquisition purposes. A hydrogen fuel cell unit and hydrogen gas canister was placed near the training unit frame and a connection was established via cables with connectors. The fuel cell unit was kept in a separate metal box instead of on the metal stand housing for safety purposes. Both solar thermal air and water heating units were also placed near the training unit and wired to the training unit module with connectors. Two of the electric bikes—for studying energy generation through human kinetic energy—were connected to the training module through wires with connectors. Detailed information about hydrogen fuel cell unit, solar thermal air and water heaters, and electric bikes are not shared in this paper because it is not within the scope of this project.

Figure 4. Renewable energy training unit

Figure 5. Renewable energy training unit with peripherals

A single 12V@75A deep-cycle battery was used as a storage unit. The voltage level of the wind turbine, electric bike, fuel cell unit and solar panels was 12V and can be easily connected to the battery without any buck (step-down) converters. The project investigators avoided using multiple batteries for safety reasons. Due to the knowledge level of potential users (high school students, teachers and college students), using multiple batteries may cause an unexpected short and create a potential hazard. Instead, a single battery protected with a fuse, insulated connecter switch, and circuit breaker was used as a storage device. In the future, multiple batteries and super capacitors will be added and will be used to teach senior-level engineering and technology students.

Experiments for Workbook

Several basic laboratory experiments were written in order to conduct the lab experiments. All of the experiments were prepared to be conducted in the potential RE-related education classrooms and workshops using the mobile mini-lab. There are already fifteen basic laboratory experiments written but they are not combined in a booklet to be used as lab workbook yet. The number of experiments can be extended using additional modules available on the market. For example, a small hydrogen fuel cell kit can be added to the training unit for demonstration purposes to teach science concerning fuel cell technology to K-12 students. Complexity and level of experiments can be extended according the knowledge level of the students by adding more modules to the training unit.

- Training Unit Guide
- Overview to Photovoltaic Technology
- Basic Electricity & Measurements (Voltage, Current, Resistance, and Power)
- Solar Panel Output Measurements (Voltage, Current, Power, Temperature)
- Series-Parallel Connections of Solar Modules
- Effects of Temperature, Irradiation, Humidity, Wind to Solar Module Output
- Solar Panel Efficiency – Shading Effects
- Solar Path Finder - Side Shading Analysis and Solar Tracking
- Overview to Wind Power Technology
- Wind Turbine Output Measurements (Voltage, Current, Resistance, and Power)
- Series-Parallel Connections of Wind Turbines
- Wind Power Efficiency – Wind Speed vs. Turbine Efficiency
- Wind Speed and Direction Measurements
- Battery Charging & Protection
- AC/DC Load Characteristics and AC/DC Conversions
- Hybrid Systems - Wind and Photovoltaic
- Energy Generation from Human Power – Electric Bike and Hand Crank Generators
- LED (Light Emitting Diode) Technology and Comparison to Traditional Lighting
- Energy Harvesting from Piezoelectric Materials
- Flywheel Energy Harvesting and Storage
- Energy Harvesting from Friction Technology
- Thermoelectric Energy Harvesting Technology
- Energy Harvesting from Hydrogen Fuel Cell
- Measurements I – Light, Temperature, Sound, Mass, Rotary, Force, VI, Rainfall
- Measurements II – Humidity, Barometric Pressure, Heat Index, Wind Chill

The experiments contain pictorial connections of the modules instead of standard schematics in order to provide visual connections between components. This simplifies the level of understanding of the experiment connections; otherwise, all of the participants of the workshops would have to be taught the meaning of the each symbol on the circuit schematics. Although it may be easy for college students majoring in engineering and technology programs to learn the symbols, this can create frustration for students and teachers at the K-12 level or for community members to learn the meaning of the symbols. However, experiments are being revised to include schematics with standard symbols along pictorial drawings. Based on feedback from past workshops, it is very helpful to use pictorial connections when conducting experiments.

Its mobile structure extends the use of the system in various locations for training, troubleshooting and testing purposes. The system contains all equipment usually required for a remote residential installation of complete wind and photovoltaic energy systems. The main equipment in the system are two 60W photovoltaic modules (to study series and parallel connections), a charge controller, batteries, AC and DC disconnects and breakers (fuses), an inverter, a 400W wind turbine (mounted on a separate stand), switches, receptacles, digital and analog meters, a battery analyzer, lightning arrestors, a step-down transformer as well as AC and DC loads. The system also contains equipment for laboratory purposes to study energy systems including a data acquisition unit, a computer, kinetic and potential energy systems kits (thermoelectric, friction, flywheel, rotary, human power), various sensors (temperature, light, sound, mass, rotary, force, VI, rainfall, anemometer, wind wane, humidity, irradiation, barometric pressure, heat index, wind chill and dew point).

There is also external equipment available to study hydrogen fuel cell technology, solar thermal energy (water and air heating), kinetic energy (electric bike) and thermoelectric and piezoelectric technologies. Due to the size and weight of this equipment, for each system, a mobile metal structure was built to move these units between training equipment to offer students more flexibility using all of the equipment. This mobile system can be used to teach renewable energy systems for sixth through twelfth grade levels in K-12, or for teachers, college-level educational systems and workforce development. For specific knowledge levels, the mobile unit comes with a variety of experiments developed by senior students and faculty. These experiments are being revised in order to publish all of the experiments in a workbook as a future goal.

Discussion and Conclusions

This project idea came to light due to budget limitations to purchase commercially available training equipment. Project coordinators still prefer to have commercially available products because of the prepared lab manuals and technical support by the companies. However, especially for undergraduate research institutions, this type of project offers excellent hands-on training opportunities for the students. Students involved in this project learn stripping/ crimping of wires, reading specifications of the components, contacting companies for technical support where equipment is purchased, drilling holes with a variety of drill bits, cutting square/circular holes with routers, creating 2D/3D layouts and drawings for drilling and component orientation purposes, welding and metal and wood working to build the module frame. Students also experience troubleshooting and connections between various RE components such as charge controllers, batteries, lightning arrestors, circuit breakers and fuses, rectifiers, inverters, wind turbines, switches, AC and DC loads, grounding rods, thermoelectric generators, piezoelectric materials, measuring and data acquisition tools. Since the spring 2009 semester, approximately 35 students (mostly undergraduate and three graduate students) have been involved in this experience.

Students involved in this project conducted structured independent research, used creative thinking, and shared hands-on experiences, which was beneficial to them. The training units were used to develop an understanding of the way that energy is collected and stored. Establishing alternative energy teaching and research interactive training units involved our undergraduate and graduate students, faculty and community for future alternative energy projects and training. A fully functional training unit provides for applied energy education workshops for local community colleges, secondary/high school science/technology teachers and students, as well as for interested citizens who have not been exposed to state-of-the-art renewable energy. Students can obtain valuable knowledge by doing research related to their major/minor.

The outcome of this project was an efficient, easy approach to building and operating a cost-efficient and mobile alternative energy training unit that works as a stand-alone mini-lab. It is an interdisciplinary project because this study gathered students from a variety of disciplines and merged their knowledge in this experimental project. The project engaged student participation from disciplines such as construction management, design and development, safety management, agricultural engineering technology, industrial technology and electronics. The results of the reliability of these types of projects will lead other institutions to develop their own systems. Students involved in this project were able to participate in hands-on experiments that will benefit their future careers. Building a renewable energy teaching and research training unit as a mini-lab will help to establish a laboratory and involve our undergraduate/graduate students, faculty and community as they learn about alternative energy. A fully functional laboratory training unit will augment applied energy education workshops for local community colleges, secondary/high school science/technology teachers, students, and especially interested others not already exposed to state-of-the-art renewable energy.

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