AC 2010-1256: STUDENTS BUILT EDUCATIONAL RENEWABLE ENERGY TRAINING UNITS

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Student-Built Renewable Energy Training Unit

Abstract

Energy is one of the major building blocks of modern society. Understanding energy means understanding energy resources and their limitations, as well as the environmental consequences of their use. When preparing students for their future careers, real world training is a plus during their education. Renewable energy training units are very important for the hands-on laboratory sections of energy education and help the students to understand the concepts and applications of this type of energy. Due to the high costs of the training units, it becomes a budget concern to purchase training units for laboratory sections. Some of the pre-built training units already on the market have a price range from ten thousand to fifty thousand dollars per unit. If there are budget concerns for the program, the only option that remains is to teach theory without the benefit of hands-on training. Taking these issues into consideration, the students in the Industrial Technology program have designed, built, and tested a multi-purpose renewable energy training unit for the alternative energy related classes. This prototype trainer is designed to be used for hands-on activities which provide opportunities for students to engage in experiments that will reinforce the material covered. The safety of the unit was confirmed after several tests in different conditions on campus.

1. Introduction

We live in an age of environmental awareness, and alternative energy education is present in most of our daily conversations in engineering, technology, and science education. Renewable energy today provides about 9% of the world's energy and 8 to 10% of the U.S. needs [1]. However, in many parts of the world these percentages are increasing significantly. Based on current data on global warming, as well as the current U.S. dependence on overseas oil, there is an interest and urgency in utilizing alternative energy sources. In order to prepare students for their future careers, real-world training is imperative for their education. University campuses in the United States are taking important steps to establish alternative energy research and education. For example, undergraduate engineering and engineering technology programs are now including laboratory-based curriculum in alternative energy [2-8]. Hands-on laboratory experiments using educational training units offer enhanced learning experiences. These units provide a real time display of key system properties as well as surrounding conditions through a data acquisition system.

The majority of alternative energy educational training units are built and sold by companies that offer custom-made systems according to the customers' needs; this increases the cost of the training units [9-13]. 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 purchasing training equipment for the laboratory sections of the courses. The costs of such equipment range from ten thousand to fifty thousand dollars per unit [14-17]. 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. Taking these issues into consideration, building an energy training unit becomes a smart idea for exposing students to alternative energy fields. The training units need to be designed for use in hands-on activities, which provide students

opportunities to engage in experiments that will reinforce the material covered. The cost of the training unit should be kept low in order to make the project cost-efficient. In this project, the outcomes enable the participant to understand and work with the developed systems. The aim is to design and implement interactive educational training units that include solar and wind technologies, human power, passive solar air/water heating, and hydrogen fuel cell energy harvesting systems for any level of Alternative Energy Systems courses. This alternative energy educational training unit operates as a portable mini-lab.

The way students became involved in this project began in the Spring'09 semester when several senior students asked the electronics instructor if they could take an directed study course with the instructor in the summer and Fall 2009 that would be challenging and relevant to alternative energy technologies. The course instructor designed a renewable energy course to be offered in the Spring'10 semester and needed to build ten training units as a mini-lab to teach the lab sections of the class. Four students decided to design and build the training units and enrolled in directed study courses in both Summer and Fall'09 semesters.

2. System Design

Usually alternative energy training equipment is manufactured to train people in the use of one energy source. As a consequence, the customer is forced to buy separate units to teach different alternative energy technologies such as wind technology, human power, biomass, and hydrogen fuel cell systems. It is very rare to see combined training units to teach multiple energy sources in one integrated system. These issues make the establishment of the alternative energy program and laboratory more expensive and difficult to implement. In our prototype integrated training system, six energy sources were combined in one training unit to include 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 Green Meter® data acquisition system [18]. The block diagram of the energy harvesting sources connected to the training unit is shown in Figure 1. In this figure, only major connections are shown.

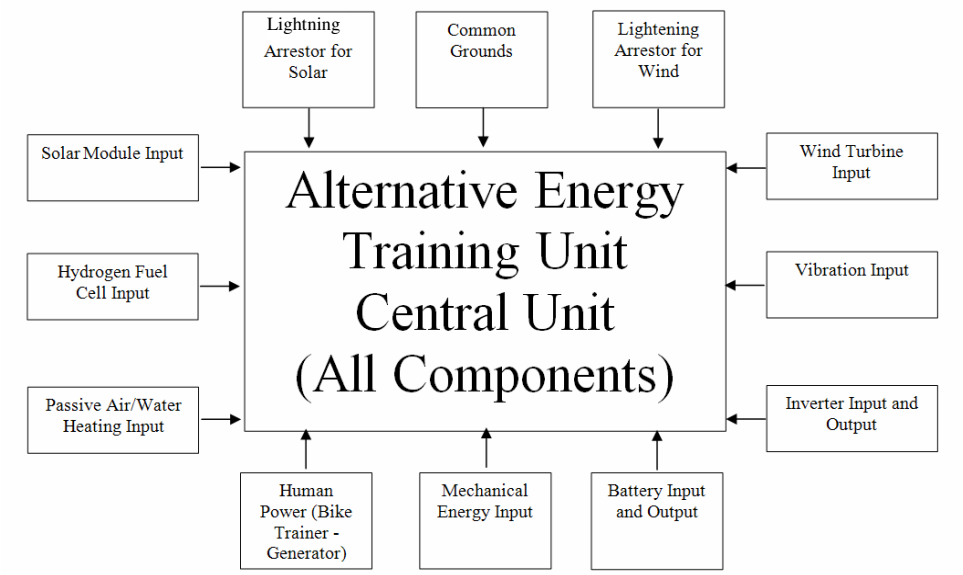

Figure 1. The general block diagram of the energy harvesting system

Figure 2 shows some of the major components and their connections through the training unit.

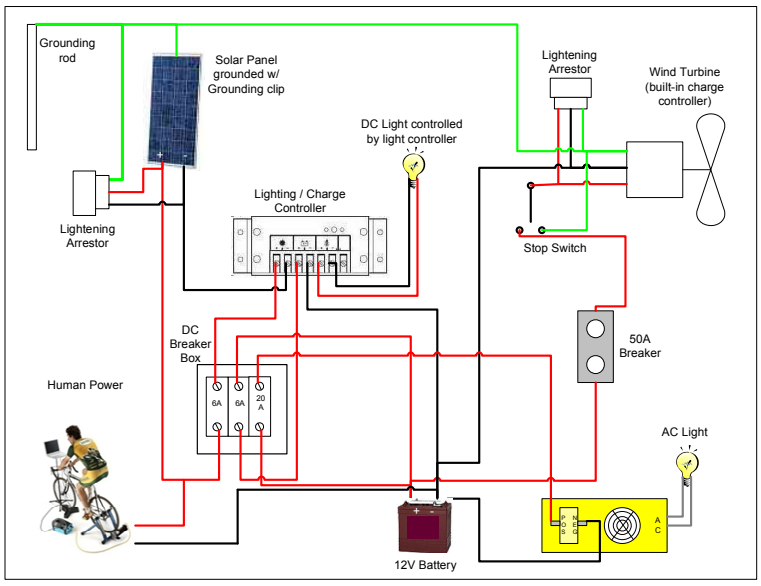

Figure 2. Major components and their connections of the training unit

2.1. Metal Stand (Frame)

To begin planning the units, the current commercial training units were studied to get a general concept of different training station metal housings, the nature of parts used and stands (frames). After investigation of the existing training unit designs, a 3D CAD (Computer Aided Design) of a metal stand was designed with real dimensions before ordering the metal parts of the training unit. The 3D design of the system was accomplished with PTC Pro Engineer Wildfire 4.0 [19]. In the 3D design, the location of each component was determined to identify distance of parts to make patch-cords. The prototype design of the metal frame is shown in Figure 3.

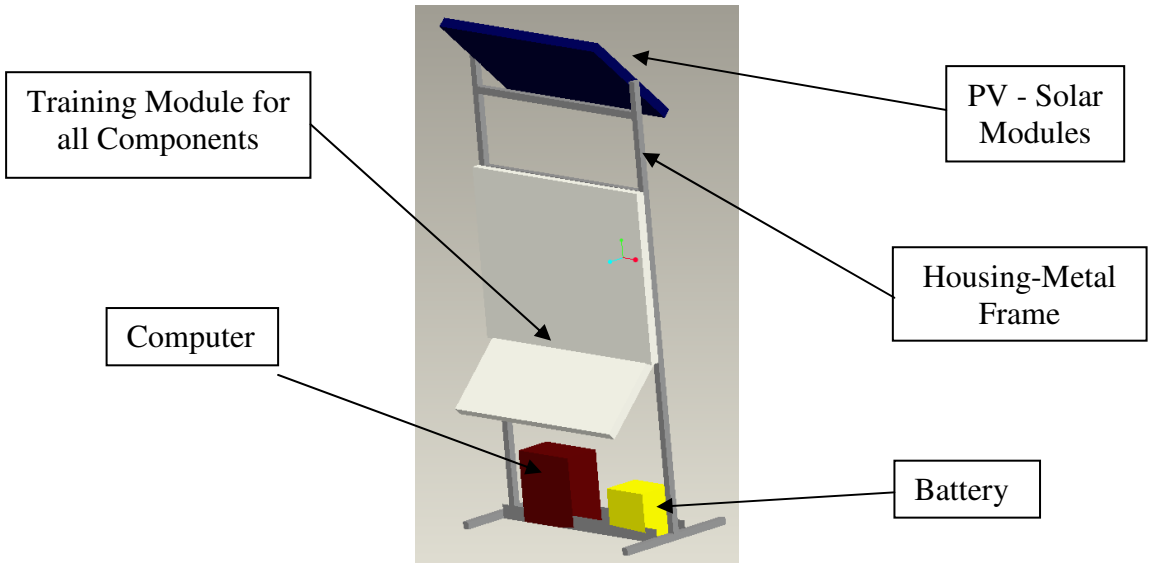

Figure 3. The Draft 3D Pro Engineer Wildfire Design of Training Unit

After 3D CAD design of the training unit stand, the necessary components were purchased to construct a metal frame in the production lab. The specifications and the cost of the parts for the metal frame are summarized in the Table 1.

Table 1. The Specifications of the metal parts for training unit stand

	Test Stand Material Takeoff						
		1 1/2×16 ga	1 1/4×16 ga	1 1/2×1/8	1×1/8	3/16×1 1/4	3/16×4
2	Piece (All lenghts are in inche	Tube	Tube	Angle	Angle	Flat	Flat
3	1	53	17	48.25	24	4	3.5
4	2	53	17	48.25	24	4	3.5
5	3	32	51.5	7.25	48	4	3.5
6	4	32		7.25	48	4	3.5
7	5	48.25					
8							
9	piece count	5	3	4	4	4	4
10	cuts widths	1.25	0.75	1	1	1	1
11	lenghts	218.25	85.5	111	144	16	14
12	**Total Length (in)**	**219.5**	**86.25**	**112**	**145**	**17**	**15**
13	(ft)	18.29	7.19	9.33	12.08	1.42	1.25
14	**# joints (20')**	**0.91**	**0.36**	**0.47**	**0.6**	**0.07**	**0.06**
15							
16	**Number of stands (N)=**	**10**					
17	×N (in)	2195	862.5	1120	1450	170	150
18	×N (ft)	182.92	71.88	93.33	120.83	14.17	12.5
19	**×N (joints)**	**10**	**4**	**5**	**7**	**1**	**1**
20							
21		×1	×N				
22	1 1/2 Tube Plag	**4**	**40**				
23	1 1/4 Tube Plug	**2**	**20**				
24	1/2 Heavy Hex Nut	**2**	**20**				
25	1/2×1 Heavy Bolt	**2**	**20**				
26	3" Casters Swivel- Lock	**4**	**40**				

The total price of materials to build ten metal stands is $554.40 dollars. This amount can change dramatically depending on building materials of the training unit stand. In our prototype, some metal tubing (35%) was donated by local steel companies.

2.2. Training Unit Module

The actual 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 actual components using AutoDesk AutoCAD software. The design layout helps to locate drilled holes and to make cuts to place and align the components on the board. The first drawing concept was done by a design and development student in which many of the components and other parts were put into digital form so that they could be utilized for the CAD design. After measuring the board and placing all of the components into this CAD file, the project progressed quickly. Many of the concepts that came after were an easy fix due to the CAD file, which allowed us to change design without incurring cutting and mounting parts. The following CAD file is just one of the concepts that have been developed using this method. There are many components that comprise this training board; all of these components were drawn on a 1:1 annotation scale which allowed us to properly place the components on to the board as if it was in a real time situation. This made for optimum assembly of these parts allowing for maximum space utilization of the training board. The AutoCAD design layout with all the parts is shown in Figure 4.

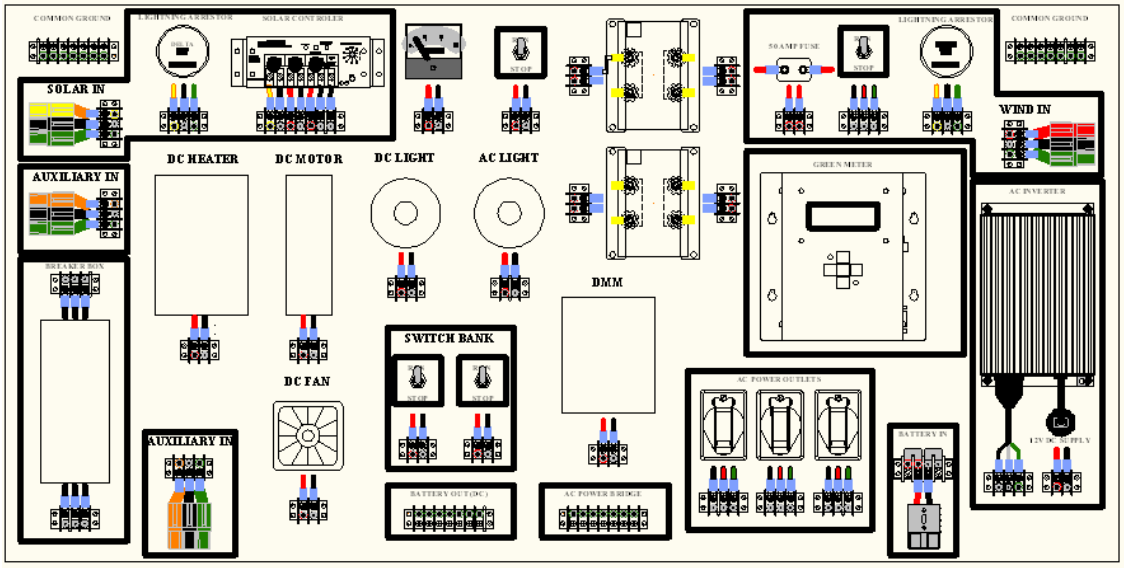

Figure 4. The AutoCAD design of training control unit layout

Each unit has the capability to train two to three students at a time. This mini-lab is capable of teaching wind and solar technology, active/passive human power, passive water heating systems, passive air heating systems, and hydrogen fuel cell technology. The unit includes: a solar module, a wind turbine, a charge controller, measuring tools, circuit breakers and fuses, lightning arrestors, a battery, an inverter, switches, a DC generator, a Green Meter® (a temperature sensor, irritation sensor, an anemometer, two power sensors), and data acquisition peripherals. The mini-lab training unit contains basic equipment generally required for a residential installation. The system was wired with proper grounding, disconnects, breakers, and GFI load receptacles. The training unit also houses a data acquisition panel where solar irradiation, PV voltage, PV current, PV module temperature, and ambient temperature are displayed and available for computer data logging. The safety of the unit was confirmed after several tests in different conditions on campus. This unit is aimed to be used in general renewable energy classes offered in the technology program. It may also be offered for workshops to high school/community college science/engineering instructors and students during weekends and summer breaks.

The system has the capability to accept several different renewable energy 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, human kinetic energy, and hydrogen fuel cell etc. The modules and sub modules of power generation from ambient energy sources using Alternative Energy training unit are detailed for each energy source.

- Solar Input
  - PV modules
  - lightening and charge controller
  - lightning arrestor
  - circuit breakers
  - solar pathfinder

    - battery
    - amp-meter

- Wind Turbine Input
    - wind turbine
    - charge controller
    - lightning arrestor
    - start/stop switches
    - circuit breaker/fuse
    - amp-meter

- Passive/Active Human Power Input
    - bicycle
    - bike power generator
    - portable power pack and power monitor
    - bridge rectifiers

- Green Meter®
    - temperature sensors
    - irritation sensors
    - anemometer
    - DC and AC power sensors

- General Components
    - DC loads (DC motor, LED light bulbs, heater)
    - AC loads (receptacles, LED light bulbs, heater, AC motor)
    - power inverter
    - battery (with protection fuse)
    - input/output jacks
    - different size terminal blocks
    - different color banana jacks and plugs with patch cords
    - passive air and water heating system (common source)
    - measuring tools and testing equipments

3. Overall System

The prototype training unit project had four phases and was finished in six month. The first phase of the project was 3D design and simulation of the system using 3D parametric modeling software tools. After the design of the system, all 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 due to heavy components such as battery, solar module, and inverter, computer case. All the components were mounted on board (plywood) 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 related classes.

The remaining units will be built quickly because of the completed prototype model. Remaining parts for ten training units were acquired with support of internal/external funds. 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. These units will be completed with a grant in Spring 2010. 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 photograph of the prototype training unit is shown in Figure 5. The wind turbine is remote mounted from the training unit; it was placed on the roof of a storage shed built to store training unit components. However, the wheeled wind turbine with short tower will be placed next to training unit when connections and wiring are being done by students.

Figure 5. The photograph of the renewable energy training unit

4. Laboratory Experiments Workbook Design

A laboratory experiments workbook is being written to explain the training unit capability, operation, and parts used to conduct lab experiments. All the experiments are being prepared are to be conducted in the renewable energy related classes and potential workshops to be offered in the Spring'10 semester. A folder with the specifications data for each component on the training unit was prepared to check the operations of each component and as a reference for students. During the laboratory experiments, students can refer to this folder to find the specifications of each component to conduct the lab experiments eliminating connection difficulty. There are

already fifteen laboratory experiments written; general titles in the workbook are listed in Table 2.

Table 2. Experiments using training units

Table of Contents	
Preface	
Introduction to the Student	
Introduction to the Training Unit Training Unit Guide	
Parts List	
Assignments Overview	
Experiment 1	Basic Electricity & Measurements (Voltage, Current, Resistance, and Power)
Experiment 2	Learning Solar System Components and Connections
Experiment 3	Solar Pathfinder and Solar Tracking[20]
Experiment 4	Solar Cell Output Voltage Measurement
Experiment 5	Energy Generation from Solar Modules
Experiment 6	Solar Power Efficiency
Experiment 7	Learning Wind Power System Components and Connections
Experiment 8	Wind Turbine Voltage Measurements
Experiment 9	Energy Generation from Wind Turbines
Experiment 10	Wind Power Efficiency
Experiment 11	Battery Charging & Protection
Experiment 12	AC & DC Load Experiments
Experiment 13	Measurement of Temperature, Irritation, Anemometer, AC/DC Power
Experiment 14	Wind and Solar Combination System
Experiment 15	Energy Generation from Human Power
Appendix: Parts Specifications	

As an example, the description of experiment 3 (Solar Pathfinder and Solar Tracking) was detailed here. In the experiment, students were divided in three groups and were provided three Solar Pathfinders, assistive software, and laptops to use software. A short description of the equipment, summary of the experiment, and questions were provided in the experiment paper work. A sun path calculator is used to view the solar window for a particular location for assessing shading. Other means can be used to evaluate shading, but sun path calculators are usually the quickest and easiest to use. The Solar Pathfinder™ is a popular type of sun path calculator that consists of a latitude-specific sun path diagram covered by a transparent dome. The dome reflects the entire sky and horizon on its surface, indicating the position and extent of shading obstructions. The sun path diagram can be seen through the dome, illustrating the solar window. The solar window is compared to the obstruction reflections to determine the dates and times when shading will occur at the site. When a sun position is overlapped by an obstruction,

then from that location the sun would appear behind the obstruction and the location would be shaded. The pictures of the solar path calculator are shown in Figure 6.

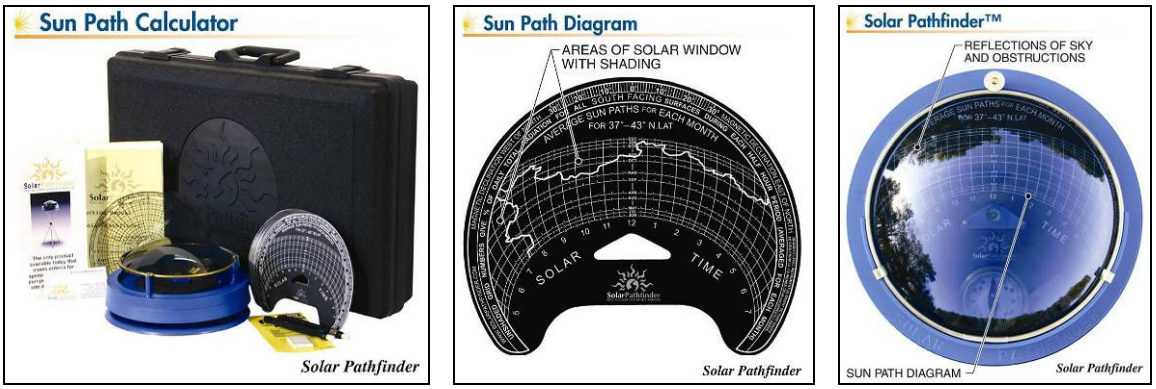

Figure 6. Solar path calculator system

To use the Solar Pathfinder™, the unit is located at the proposed array site. It is leveled and oriented to true south with the built-in compass and bubble level. (The compass reading may require adjustment for magnetic declination.) Looking straight down from above, the user observes reflections from the sky superimposed on the sun path diagram, and traces the outlines of any obstructions onto the diagram. Students draw shading areas in different locations and identify obstructions around the solar modules. Students are required to submit a detailed report and suggestions for the given experiment.

Necessary improvements on this manual will be made in the Spring'10 semester by obtaining a class survey from students. Also, any errors identified during the laboratory experiments will be noted by an instructor and necessary actions will be taken for updates to the manual. This lab manual will be updated to include more experiments such as hydrogen fuel cell systems, mechanical to electrical energy conversion, biofuel etc. and the training unit is upgraded with necessary components. Adding more components to the training unit may lead to a design change of the system to enlarge the board space.

5. Significance of Results

Students involved in this project conducted structured independent research, used creative thinking, and shared hands-on experiences that also were beneficial to their gained knowledge. The training units were used to develop an understanding of the way that the energy is collected and stored. Establishing alternative energy teaching and research interactive training units involve 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 and interested population who are not exposed to state-of-the-art renewable energy. Students can obtain valuable knowledge by doing research related to their major/minor. The units will:

- Increase scholarly productivity of faculty
- Provide leverage to target larger state and federal external funding sources, i.e. NSF, Department of Energy Grants.
- Highlight unique expertise of new faculty
- Provide new opportunities for undergraduate/graduate research projects
- Offer educational workshops specifically for High School students/teachers
- Provide enhanced teaching laboratory experiences for classes
    - IT 469 Energy Harvesting, Conversion, and Storage Technology
    - AGR 493 Alternative Energy
    - AGR 330 Electricity
    - IT 134, IT 232 Electronics Technology
    - X59X Alternative Energy
    - X500 Energy Harvesting

Conclusion

The outcome of this project was an efficient, easy to build and operate, cost-efficient alternative energy training unit which works as a stand-alone mini-lab. This study gathered students from a variety of disciplines together, merging their knowledge in this experimental project. The results of the reliability of these types of projects will lead other institutions to develop their own systems. The project engaged student participation from different disciplines (construction management, design and development, and electronics.). The team leader (faculty advisor) set up meetings to organize working schedules, progress reports, and the construction was conducted as part of the initial project. All necessary construction and production tools are located at the IT Building; therefore this location was used to construct the training unit. The Computer models of the system were designed using Computer Aided Design and Drafting software tools by the Design and Development Majors in the Design and Drafting Lab. The Electronics Majors used equipment in the electronics laboratory for the electrical part of the structure and for testing the system. The determination of the system reliability and safety was tested with detailed calculations and measurements by Industrial Safety Management Majors and Minors. 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 learning about alternative energy. This lab and the hands-on renewable energy related classes will promote Alternative Energy Education at Sam Houston State University. 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 population who are not exposed to state-of-the-art renewable energy.

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Appendix: Major Part & Equipment List and Prices

Photovoltaic Unit

Component	Manufacturer	Model	Cost
Photovoltaic Panel with J-Box	Kyocera	KC65T 65W 12V	$335.40
Ground/Roof Fixed Tilt Legs	Unirac	990006	$118.15
Sunlight Light Controller	Morningstar	10-12 10A, 12V	$94.43
Breaker Panel Breakers	Midnite Solar	BabyBox 4 Slot AC or DC	$30.24
6A Din Rail Mount Breaker	Midnite	OBB-6-150VDC-DIN	$13
20 Amp Din Rail Mount Breaker	Midnite	OBB-20-125VDC-DIN	$13
73 AH Sealed Gel Cell Dual Terminal Battery	MK Battery	8G24DT-DEKA	$208.08
Inverter	Exeltec	XP 125-12	$216.32
AC LED	C. Crane	Vivid PAR 20 LED Floodlight 120VAC	$17.62
Solar Pathfinder	Solar Pathfinder	With Case & Tripod	$289
Analog Amp Meter Kit	Southwest Wind Power	2-ARAC-102	$26
DC Lightning Arrestor	Delta Lightning Arrestors	LA302	$35
110A Fuse & Holder for Battery	Xantrex	TFB110C	$40.66
Solar Pathfinder Assistant Software	Solar Pathfinder	Assistant Software PV	$149

(PV Only)			
DC LED	C. Crane	12P Vivid+ LED Light Bulb, DC	$24.95

Wind Turbine Unit

Component	Manufacturer	Model	Cost
Wind Turbine	Soutwest Wind Power	1-ARBL-10-12	$699
2-Position Stop Switch	Air-X	2-ARAC-101	$33
Circuit Breaker	Soutwest Wind Power	3-ELOT-1147-05	$27
Circuit Breaker Box	Soutwest Wind Power	CBBOOT-30/50	$2.24
DC Lightning Arrestor	Delta Lightning Arrestors	LA302	$35
Analog Amp Meter Kit	Southwest Wind Power	2-ARAC-102	$26
12V 135Ah (20Hr) Sealed AGM Battery	Universal Battery	UB121350	$304.22
110A Fuse & Holder for Battery	Xantrex	TFB110C	$40.66
Inverter	Morningstar	Suresine 300W 12V	$256

Data Acquisition Monitoring Unit

Component	Manufacturer	Model	Cost
GreenMeter Hybrid Energy Monitor	ICP Solar		$340.06
AC-DC Adapter (120V)	ICP Solar		$24.72
DC Sensor Dual	ICP Solar		$98.01
Irradiation Sensor	ICP Solar		$99
Temperature Sensor	ICP Solar		$69
Wind Speed Sensor	ICP Solar		$99

Additional Parts

- Barrier Terminal Blocks (Variety of terminals depends on part input/output)
- Screw type Banana Plug Receptacles (Red, Green, White, Black)
- Banana Plugs for Patching (Red, Green, Black, White)
- Screws (Metal Machine Screws #6 - 3/4')
- Ring Terminals (for 10AWG, 12AWG, and 14 AWG)
- Wiremold wall-mount pvc receptacles
- Wiremold wall-mount pvc light switches
- Toggle Switches (Standard)
- 8" Cable Ties

- Connector Housings for solar, wind, and human power inputs (Red, black, Green)
- Contacts LP-LD 30A 12/14 AWG
- Roll Pins for 15,30 & 45 Amp Housing
- Powerpole Mounting Wings
- PP75 Loose Piece Colored Housing 75A (Green, Black, Red)
- PP75/SB50 Loose Piece Contact - 75A (10/12 AWG)
- Roll Pins for 75 Amp Housings - 5 pins
- SB50 Loose Piece Colored Housing 50A – Gray
- PP75/SB50 Loose Piece Contact - 50A (10 AWG)
- Digital Multi Meters
- Stranded Hookup Wire (12 and 14AWG - Red, Green, White, Black)
- Red/Black Zip Cord 10AWG
- Newmar Battery/Charger Monitor - PT Series Charger Accessory
- 12V DC Heater
- 12V DC Motor
- 12V DC Brushless Motor - 15,000 rpm
- AC/DC Standard Light Bulb Sockets
- High Quality Surface Mount Socket - Copper Components
- Metal Tubing for Training Stand
- 10,12,14,16AWG Stranded Wires