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Design and Implementation of a 1kW Photovoltaic System as a Training Infrastructure

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Abstract

The Solar Instructor Training Network (SITN) program of the South-Central Region is one of eight nationwide regions that are funded by the U.S. Department of Energy to train instructors how to teach implementation of solar photovoltaic systems. One of the eight regions is the South-Central Region led by the Energy Institute at Houston Community College-North East, collaborating with Ontility the first 3 ½ years and now Janet Hughes Solar Consulting (solar energy training providers) and the Interstate Renewable Energy Council (IREC). The primary goal of the project is to help facilitate and support the creation of a well-trained and highly qualified solar energy workforce of sufficient size and diversity to meet the projected needs of the U.S. Another goal of the project is to integrate solar technology within existing college and university courses and programs. The regional training providers (RTPs) of the SITN offer programs that meet the project goals and work closely with the National Administrator to foster the growth of a well-trained energy workforce.

Sam Houston State University (SHSU) became part of the South-Central Provider for the SITN program in January, 2013. As a continuing recipient of the U.S. Department of Energy's SITN project for the South-Central region, SHSU works closely with Houston Community College-North East to establish and develop a training program which includes solar photovoltaic courses and laboratory resources. As part of the recipient agreement, SHSU's qualified faculty developed solar PV classes and created classroom and laboratory instructions and spaces. The goals of this paper are to share experiences gained as a recipient of the SITN program and to demonstrate how to establish a complete 1kW Solar Photovoltaic system to conduct laboratory instructions. Student learning outcomes are also summarized in the paper. Industrial Technology students and faculty (electronics, electronics and computer engineering technology, construction management, design and development, safety management) are involved in the project for both design and implementation phases. A small storage shed (power house) was built, and concrete blocks were prepared by the students to use in the installation of five aluminum poles for the solar panels. The system is complete and is being used as part of laboratory demonstrations and instructions.

Background

The U.S. Department of Energy established the SITN composed of nine Regional RTPs to help fulfill a critical need for high-quality, local, and accessible training in solar system design, installation, sales, and inspection through a robust network of *train-the-trainer* programs. The network has nine providers and partnerships in eight regions of the United States. Providers represent one organization while partnerships represent multiple entities at different locations. A detailed map is shown in Figure 1. The SITN is a five-year effort which started in 2009 to establish a geographic blanket of training opportunities in solar installation across the United States. The SITN promotes high-quality training in the installation of solar technologies. Nine regional resource and training providers support the professional development of trainers and instructors of solar photovoltaic (SPV) technologies across the country. The goals of Solar Instructor Training are to accelerate market adoption of solar technologies by ensuring that high-quality installations are standard and to create sustainable jobs within the solar installation industry. The training has an emphasis on basic topics associated with SPV operations (safety, utility interactive systems, grid tied with battery back-up systems, off-grid systems, troubleshooting and maintenance, solar energy generation, structural mounting, electrical wiring, and NEC code requirements). The Interstate Renewable Energy Council (IREC) is the National Administrator for the SITN. IREC manages SITN's collaboration and coordinates joint activities and works with a broad set of stakeholders to prioritize and address solar-related training and operations. The role of IREC is to serve as the national point of contact–to assist with project's goals, to conduct outreach for best practices, manage collaboration, coordinate joint activities, and address issues related to solar trainings, etc. [1-3].

The central objective of the SITN/South-Central Region is to enable a rapid increase in the amount of solar installation workforce in Arkansas, Oklahoma, Louisiana, New Mexico, Missouri, and Texas. SITN establishes and maintains a network of educational, industry, and state partners to ensure the availability, effectiveness, and standardization of solar installation training throughout the South-Central region at secondary and post-secondary training programs (vocational technical high schools and programs as well as community college programs). Standardized solar training of instructors will, in turn, provide a seamless career pathway for solar installation technicians.

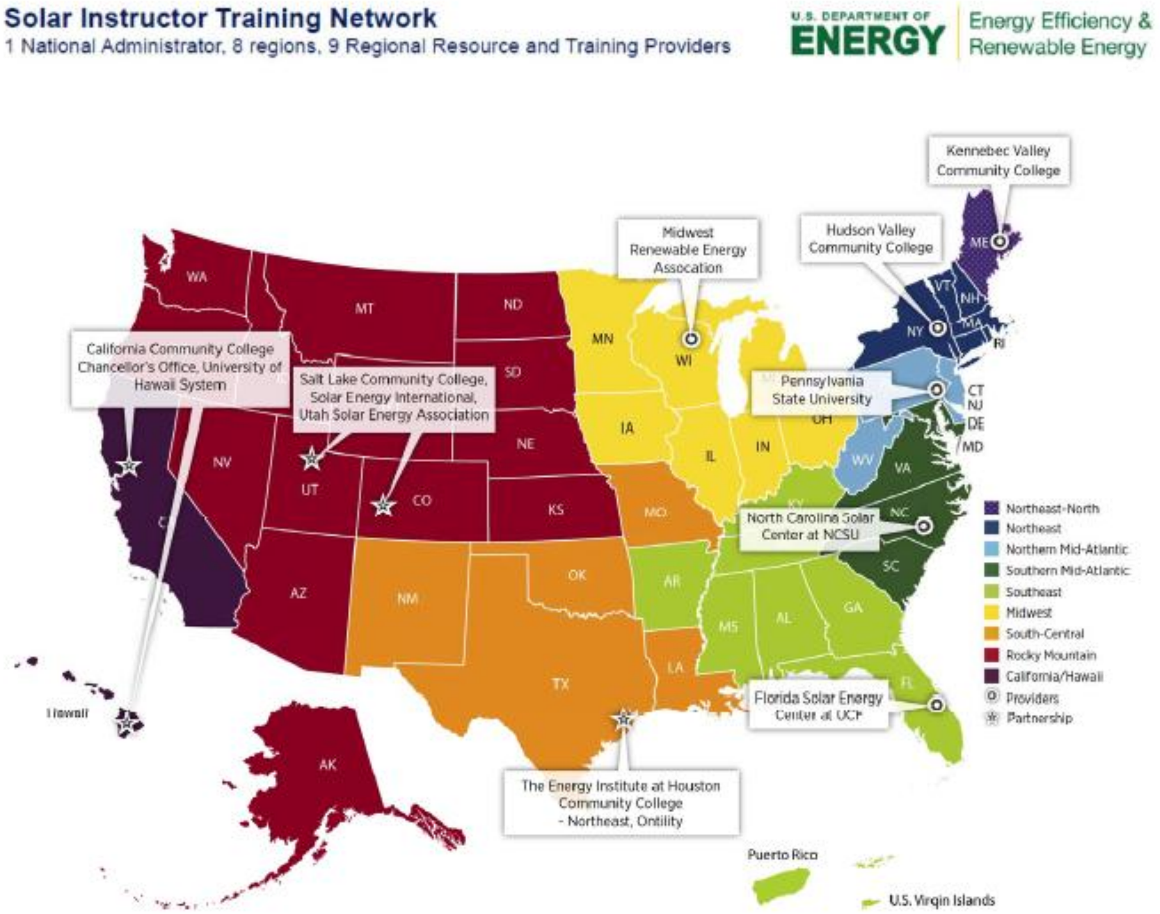


Figure 1. Solar Instructor Training Network Map [1]

Program Focus

The instructional and collaborative activities of the SITN South-Central Region are focused to meet our milestones, objectives and goals. While these activities are numerous, it is possible to distill our efforts into a coherent list that represents the key aspects of our work:

- Guiding instructors to train the next generation of solar installers.
- Provide solar photovoltaic (SPV) training based on our curricula which is IREC accredited and taught by our North American Board of Certified Energy Practitioners (NABCEP)-approved providers and IREC certified instructors.
- Hands-on solar laboratory training kit (SPV) with multiple system configurations to be used by instructors:

    - Grid, backup, and off-grid
    - Micro AC inverters
    - Multiple racking techniques
    - Other components

- Provide and circulate the Solar Mobile Training Unit for educational outreach
- Provide ongoing support, continuing education, and communication with training partners through a variety of forums including:

    - Webinars
    - Website
    - Site Visits
    - Conference Calls

- Conduct Pilot Solar Institutes for secondary teachers and students

Literature

Technology and engineering programs in many higher education institutions are developing alternative energy related curricula such as classes, projects, training, and certification programs. Renewable energy (RE) teaching systems and projects help students to better comprehend complex concepts by including a renewable energy project or series of laboratory experiments. The importance of experiential activities such as laboratory sessions is highlighted by many authors [4-8].

Energy knowledge and renewable energy based projects are important in order to prepare students to be competitive for careers in the growing fields of energy related engineering, science, and technology for the future. Preliminary projections from the Bureau of Labor Statistics state that the number of expected energy related green jobs is expected to increase by 11% by 2016, and most of that growth is expected to be in the environmental or energy related sectors [9-10].

Edgar Dale's cone of learning shows that participating in discussions or other active experiences may increase retention of material by up to 90% [11]. Richard Felder and Linda Silverman recommend several teaching techniques to address all learning styles, one of which is to provide demonstrations for students with sensing and visual learning styles and hands-on experiments for students with active learning styles [12]. According to Moore [13], there is a direct correlation between in-class performance, laboratory attendance, and performance. In renewable energy courses, active learning can be achieved through a variety of activities which include lab and project experiments with hands-on projects and hands-on laboratory experiments [14-17].

There are recent renewable energy related projects that have been created to focus on student learning and promotion of clean energy sources. According to a recent project report, an integrated electric power system was designed and installed in the Taylor Wilderness Research Station in central Idaho by a team of undergraduate and graduate students under the supervision of faculty. Projects included establishment of a hydroelectric generator, a photovoltaic array, a fossil fuel generator, and control units. The results of this project and previous attempts were shared with academia in an engineering education conference in 2010 [18-20].

The Training Infrastructure at SHSU

The SHSU faculty made a commitment to join with Houston Community College to work on the Department of Energy's Solar Instructor Training Network Grant in January 2013. The design of this Consortium is particularly useful for the integration of train-the-trainer sessions for faculty and graduate students at the SHSU campus and to create clear articulation among levels of training. SHSU is prepared to participate as an active partner in the building of the South-Central Solar Training Consortium to meet and upgrade training facilities through grant budget support. As part of the project, SHSU faculty works closely with Houston Community College-North East to establish and develop a training program which includes solar photovoltaic courses and laboratory resources. As part of the recipient agreement, SHSU's qualified faculty developed solar PV classes and created classroom and laboratory instructions and spaces.

Project Design

Student Majors in Design and Development (3 students), Construction and Safety Management (6 students), Industrial Technology Electronics (4 students), and Electronics and Computer Engineering Technology (1 student) enrolled in directed/independent study courses is part of this project. Initially, 5 students majoring in Industrial Design and Construction Management were tasked to create a 3D model of the project infrastructure. Students worked with project faculty, physical plant administration, and a licensed master electrician (including IREC Master Trainer certification) to design the lab infrastructure. The design work is shown in Figure 2. The infrastructure was located nearby the 10,000 square-foot production laboratory. All of the production, assembly, and testing processes were accomplished in the production lab before the implementation. Autodesk Inventor was used to design the complete renewable energy training infrastructure. After the design process and all the approvals, construction management students and faculty built a power house (12ft X 8ft X 10ft) for all of the equipment. Due to safety and size regulations, this power house allows only 8 people to work at a time. ***Note***: *There are wind turbines installed on the light poles shown in Figure 2. The project using the wind turbines is* *not referred to in this paper. There is another project to establish wind energy training and lab environment in the planning stages. The SHSU wind energy training infrastructure is also presented in another paper. Both wind and solar PV training systems can be used as hybrid or individual lab environment for teaching and lab purposes.*

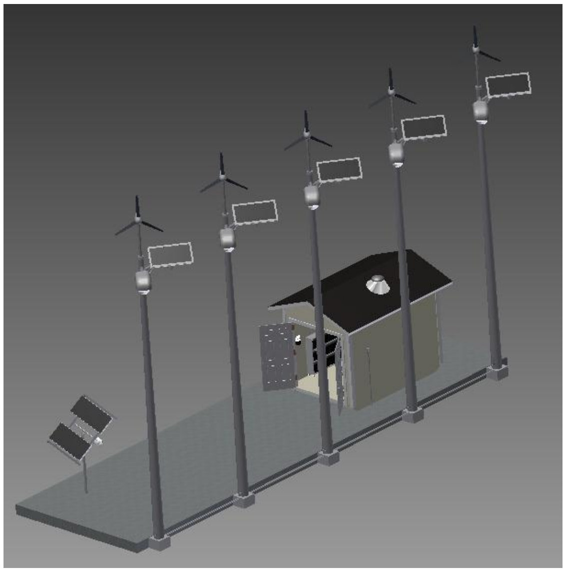


Figure 2. Complete design work for the RE lab

Project Implementation

Salvaged outdoor lighting towers were converted to hold wind turbines and solar modules to serve lab sections of the renewable energy courses and demonstration purposes. Five light poles were installed near the industrial technology lab facility by construction and electronics major students. Shading analysis of the lab facility was completed using solar path finder shading analysis tools. For the shading analysis, 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 was provided to students. A sun path calculator was 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 pictures of the solar path finder are shown in Figure 3.

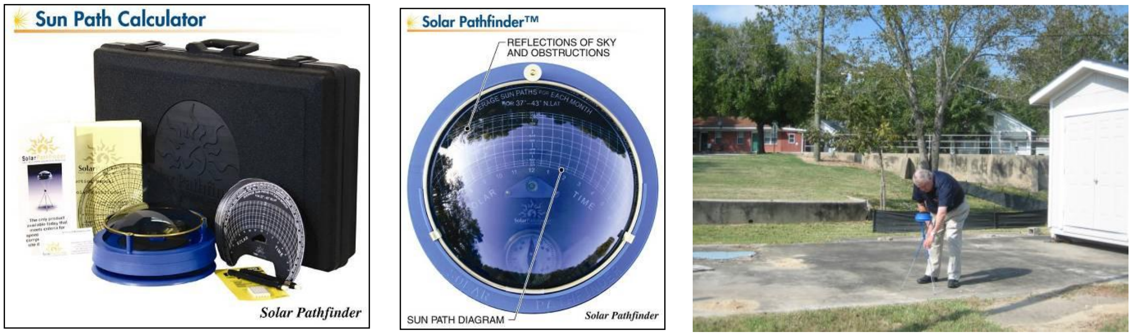


Figure 3. Solar path calculator system

The Solar Pathfinder™ is located at the proposed array site, 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 with suggestions for the given experiment.

After shading analysis, five poles were installed and solar modules and wind turbines were attached. The design work of brackets and metal frames to attach wind turbines and solar modules to properly and securely attach the power generation components was completed by design and development students. All the brackets and frames were built and tested in the lab facility. Figure 4 shows pictures of the light poles with the wind turbines, solar modules, and power house. Additionally, old light fixtures were retrofitted and rebuilt to house new LED lights to be attached to light poles. Students were able to fit two or three efficient LED lights into a single light fixture for future studies. A comparison study between various LED lights and traditional street/parking lights was conducted and reported to the University Physical Plant. Figure 5 shows design of light poles with wind turbines, solar modules, and LED light fixtures. The design of a new frame for solar module installation is also shown in Figure 5.

Figure 4. Solar Photovoltaic Lab and project environment

Figure 5. Retrofitted light pole housing solar module, wind turbine, and LED light fixture

Power House Skylight Installation

Tubular Skylights are energy efficient high performance lighting systems that are cylindrical in shape and are designed to light rooms with natural sunlight. A small clear collector dome on the roof allows sunlight to enter into a highly reflective *light pipe* that extends from the roof level to the ceiling level. The light pipe is coated with a silver mirror quality finish that allows the full spectrum of sunlight to be channeled and dispersed evenly into a room by a diffuser located in the ceiling. This project involved the installation of four units (13” tubular prismatic diffuser type skylights) on the roof of the power house. Students learned to identify a best location on the roof to install skylights for efficient use and increase illumination in the dark areas of a house or building. They determined the length of light pipe for installation. The power house serves as a unit for the current 1kW solar photovoltaic energy system. In Figure 6, a skylight installed on the power house is shown using both indoor and outdoor photos.

Figure 6. Skylight installed on a power house

Integration of the Photovoltaic System Components and System Wiring

Seven students, four faculty members, and an outside consultant (SITN-funded consultant) worked on the integration of the system components and wiring to complete the project. A bucket truck was provided by the SHSU Physical Plant to install the solar panels, LED light fixtures, wireless weather station, and to pull the wires from light poles to power house. Students were provided experience in various types of job duties such as determining right conduit sizes, installing conduits, pouring concrete slabs for the light poles, learning wire types and codes, calculation wire gauges, balance of the components of the solar PV system, dealing with AC vs. DC electricity and conversion, deep cycle batteries, various power tools, preparing and reading electrical and construction drawings, finding correct location and tilt angles of the solar panels, etc. Figure 7 shows the layout of the outdoor wiring and conduits from light poles to power house.

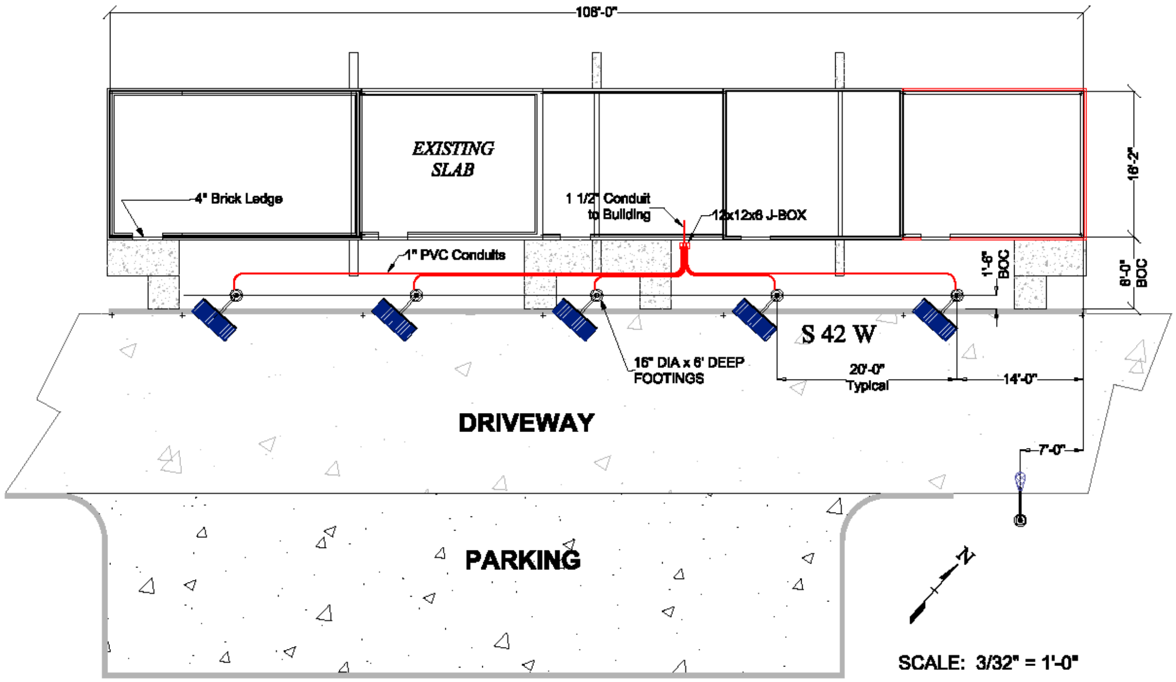
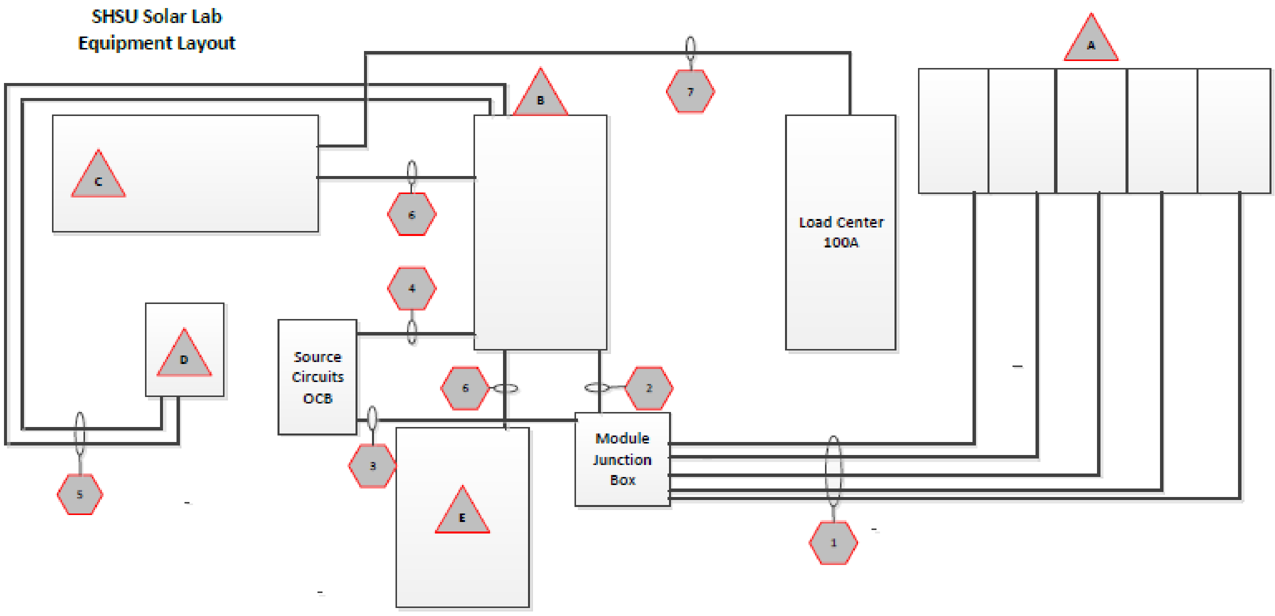
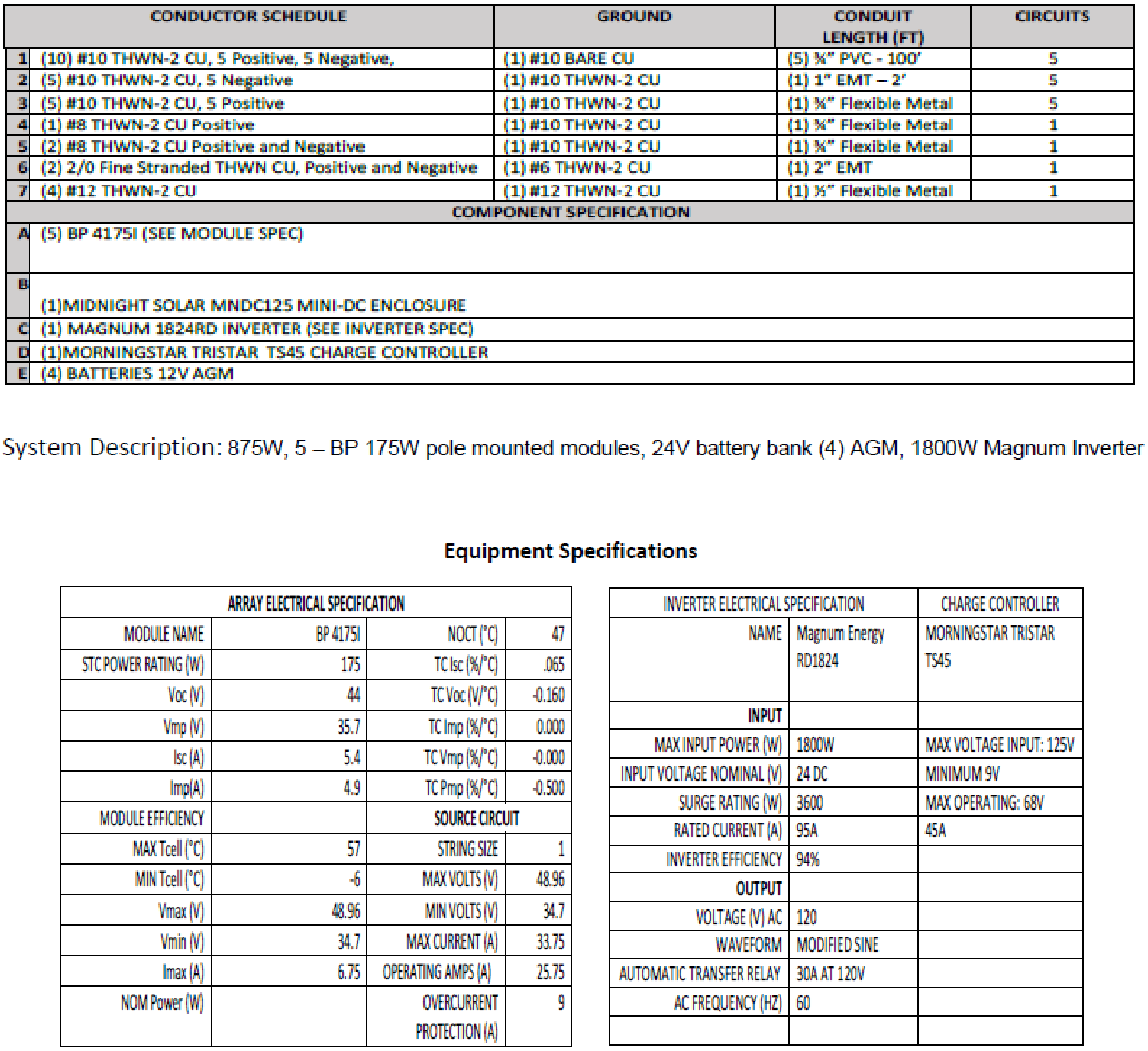


Figure 7. Layout drawing for the location of the light poles, power house, conduit

In Figure 8, the Microsoft Visio drawing of the complete solar PV training system and all the component specifications are shown.





	CONDUCTOR SCHEDULE	GROUND	CONDUIT LENGTH (FT)	CIRCUITS
1	(10) #10 THWN-2 CU, 5 Positive, 5 Negative,	(1) #10 BARE CU	(5) ¾" PVC - 100'	5
2	(5) #10 THWN-2 CU, 5 Negative	(1) #10 THWN-2 CU	(1) 1" EMT – 2'	5
3	(5) #10 THWN-2 CU, 5 Positive	(1) #10 THWN-2 CU	(1) ¾" Flexible Metal	5
4	(1) #8 THWN-2 CU Positive	(1) #10 THWN-2 CU	(1) ¾" Flexible Metal	1
5	(2) #8 THWN-2 CU Positive and Negative	(1) #10 THWN-2 CU	(1) ¾" Flexible Metal	1
6	(2) 2/0 Fine Stranded THWN CU, Positive and Negative	(1) #6 THWN-2 CU	(1) 2" EMT	1
7	(4) #12 THWN-2 CU	(1) #12 THWN-2 CU	(1) ½" Flexible Metal	1
	COMPONENT SPECIFICATION			
A	(5) BP 4175I (SEE MODULE SPEC)			
B	(1)MIDNIGHT SOLAR MNDC125 MINI-DC ENCLOSURE			
C	(1) MAGNUM 1824RD INVERTER (SEE INVERTER SPEC)			
D	(1)MORNINGSTAR TRISTAR TS45 CHARGE CONTROLLER			
E	(4) BATTERIES 12V AGM			

System Description: 875W, 5 – BP 175W pole mounted modules, 24V battery bank (4) AGM, 1800W Magnum Inverter

Equipment Specifications

ARRAY ELECTRICAL SPECIFICATION			
MODULE NAME	BP 4175I	NOCT (°C)	47
STC POWER RATING (W)	175	TC Isc (%/°C)	.065
Voc (V)	44	TC Voc (V/°C)	-0.160
Vmp (V)	35.7	TC Imp (%/°C)	0.000
Isc (A)	5.4	TC Vmp (%/°C)	-0.000
Imp(A)	4.9	TC Pmp (%/°C)	-0.500
MODULE EFFICIENCY		SOURCE CIRCUIT	
MAX Tcell (°C)	57	STRING SIZE	1
MIN Tcell (°C)	-6	MAX VOLTS (V)	48.96
Vmax (V)	48.96	MIN VOLTS (V)	34.7
Vmin (V)	34.7	MAX CURRENT (A)	33.75
Imax (A)	6.75	OPERATING AMPS (A)	25.75
NOM Power (W)		OVERCURRENT PROTECTION (A)	9

INVERTER ELECTRICAL SPECIFICATION		CHARGE CONTROLLER
NAME	Magnum Energy RD1824	MORNINGSTAR TRISTAR TS45
INPUT		
MAX INPUT POWER (W)	1800W	MAX VOLTAGE INPUT: 125V
INPUT VOLTAGE NOMINAL (V)	24 DC	MINIMUM 9V
SURGE RATING (W)	3600	MAX OPERATING: 68V
RATED CURRENT (A)	95A	45A
INVERTER EFFICIENCY	94%	
OUTPUT		
VOLTAGE (V) AC	120	
WAVEFORM	MODIFIED SINE	
AUTOMATIC TRANSFER RELAY	30A AT 120V	
AC FREQUENCY (HZ)	60	

Figure 8. Complete solar PV training system

The solar PV training system allows students to experience the implementation of flexible solar PV connections. There are total of five 175W solar panels available for the system and allow flexibility of series-parallel connection of the solar panels. Students can connect panels in a series or parallel to measure current and voltage changes. The charge controller is selected based on maximum power generation of the solar panels in both series and parallel connections. The LEDs on the light pole are the DC loads for the experiments. There are five units of 12V @ 135Ah deep cycle batteries available for the system which allow any type of connections for the experiments. For example, students can study series and parallel connection of the batteries based on the solar panel input voltage. There are insulated terminal blocks in all the breaker boxes that allow students to make any type connections and get the measurement readings. An experiment/activity sheet consisting of a list of the system components and their specification, wiring diagrams, several scenarios, etc. is provided to student groups. For example, one of the activities based on powering a house. Based on the scenario, a specific house (with pre-determined loads and power consumption) requires X percentage of power from the PV system and reaming from the grid. All the specifications are based on power house needs and existing PV system outputs. Based on the given scenario, students initially draw a draft of the system wiring. After instructor approval, students start wiring all the components to provide required amount of power. In Figure 9, the photo of the completed solar PV training infrastructure for the power house is shown.

Figure 9. A photo of the completed solar PV training infrastructure

Several lab activities are listed using this existing system. There are more experiments will be prepared for students use I the future as part of system expansion.

- Exp. 1 Basic Electricity & Measurements (Voltage, Current, Resistance, and Power)
- Exp. 2 Balance of the System Components (BOS)
- Exp. 3 Overview to Photovoltaic Technology
- Exp. 4 Solar Panel Output Measurements (Voltage, Current, Power, Temperature)
- Exp. 5 Series-Parallel Connections of Solar Modules and Batteries
- Exp. 6 Stand Alone and Grid Tied PV Systems
- Exp. 7 Solar Panel Efficiency – Shading Effects
- Exp. 8 Solar Path Finder - Side Shading Analysis and Solar Tracking
- Exp. 9 Battery Charging & Protection
- Exp. 10 AC/DC Load Characteristics and AC/DC Conversions
- Exp. 11 LED Technology and Comparison to Traditional Lighting
- Exp. 12 Measurements – Light, Temperature, VI, Irradiation

Conclusion

In terms of student learning and satisfaction, the project was a success. With the increasing importance of renewable energy resources in present and future energy scenarios, an ability to design and analyze renewable energy systems becomes essential for engineering and technology educators and students. All students in the projects showed improvement in learning and understanding concepts about renewable energy sources through both the project and the complementary theory-based lecture with hands-on experiments. We are hoping to increase the number of experimental projects and to cover additional renewable sources that complement even more of what was covered previously. The hands-on experience from the projects provided the students with the opportunity to demonstrate the knowledge that they have gained in previous projects. Students learned about various aspects of renewable energy including problem identification, technical, social and environmental constraints, multidisciplinary team management, communications and documentation skills. These projects also provided the students with an opportunity to view their designs from an ethical and sustainability awareness perspective, thus realizing a lifelong learning opportunity. Through practice, the students realized that the key success to a design project is team work, industry interaction, and collaborations. Two renewable energy-related courses were developed and are being offered in the department. One of the courses is a laboratory-based solar and wind energy technology course. Another course is an online general renewable energy course offered every summer session covering main renewable energy systems such as solar and wind energy, electric vehicles, hydrogen fuel cell systems, biomass, solar thermal energy, green building technology, etc.

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