AC 2012-4909: DESIGN AND DEVELOPMENT OF A PV ENGINEERING COURSE: FIRST YEAR EXPERIENCE

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Hirak Patangia is a professor of electronics and computers in the College of Engineering and Information Technology at the University of Arkansas, Little Rock. He has served the University in various administrative positions including Interim Dean, Associate Dean, and Department Chair before returning to full-time teaching and research. He is a strong proponent of undergraduate research and STEM education in high schools. With NSF funding, he developed a project-based freshman engineering course for engineering and other university students who want to explore engineering as a career path or for personal enrichment. He has written a textbook and a laboratory manual for the course ”Introduction to Electronics and Electrical Systems: A PBL Approach.” He has received numerous awards for teaching excellence at UALR, including the Donaghey Outstanding Teacher Award. He has also received recognition for research excellence from the chancellor and college. His research interest is in the general area of signal processing (analog/digital), and he is working on new approaches in inverter design and solar controller to improve efficiency of solar energy conversion. Another area of interest is engineering education research. He received a bachelor’s degree with honors from the Indian Institute of Technology, Kharagpur, and a Ph.D. degree from McGill University, Canada, all degrees in electrical engineering.

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Abstract

A CCLI Type I NSF proposal under the title "Development of Novel Learning Materials for Green Energy Education Centered around a PV Test Station" was awarded in August, 2010 to develop expemplary learning materials and laboratory modules for PV engineering at the undergraduate/graduate levels. The paper discusses the draft of the course modules developed as of now, the laboratory facilities and experimental projects, and student evaluation of the course modules through field-testing.

Introduction

With energy cost rising and the dangers of climate change due to energy-related greenhouse effect, there has been a great national interest in renewable energy. Energy security has been a public concern. Among the clean and green power sources, the photovoltaic solar power has the potential to supply a significant fraction of electrical energy need. With the sky rocketing gas price of past years, people are paying serious attention to alternate energy and this enthusiasm must be carried on to undergraduate engineering education. As a cornerstone of his energy, environment, and economic plans, President Barack Obama urges the country to transform its energy system to make it greener and smarter. This project seeks to address such a challenge with contemporary courses on alternate energy harnessing and electric smart grid (ESG).

A couple of web search shows that many universities across the nation have been engaged in solar energy research. One of the goals is to improve physical properties of silicon cells to improve panel efficiency. Application of nanotechnology to improve the conversion efficiency of incoming light photons to electrical output has been a topic of high interest. Optical concentrators have been researched to improve panel efficiency. However, undergraduate courses that focus on the practical design and implementation of solar system starting with the panel to end user are virtually absent in the literature. Many courses across the nation are ME courses that focus more on solar radiation and the thermal aspect. A few EE courses devote about fifty percent of the course to semiconductors and the remaining to system hardware. The fundamentals of the system components are covered in other courses in EE curriculum and no focus on integration to solar conversion is presented. However this approach needs serious revision in view of the importance and national focus on harnessing alternate energy, and the need for graduates trained in this field. In the design of the proposed course materials, emphasis is to be placed on the hardware side starting from the solar panel output to end user and grid connectivity. Physics of panel semiconductor will be left to other courses. Integration of our research finding from previous and current work will be a major factor in the course design**.** The paper presents a summary of the preset state of the course development.

Project Goal:

The overall goal of the project is to develop exemplary course materials on photovoltaic engineering to be supplemented by hands-on laboratory work. The course topics to be focused are illustrated by the following block diagram:

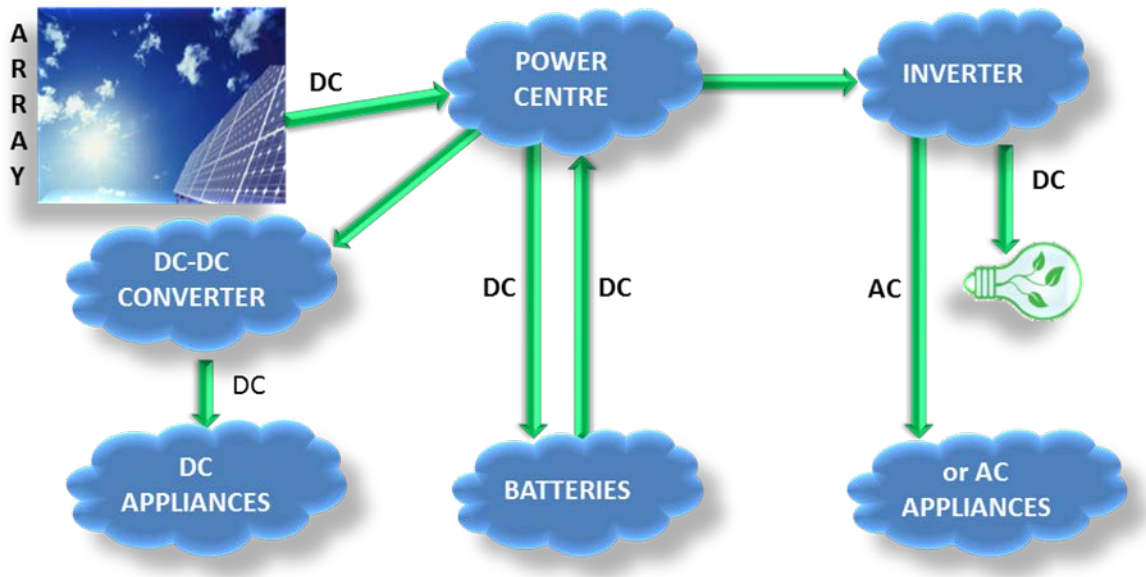

Fig.1 Block diagram showing various components of a solar photovoltaic system

The laboratory activities will correspond to each or a combination of the topics and to be culminated by the design and testing of a stand-alone/grid connected PV system. Laboratory activities will include simulation, modeling, and experimentation using commercial size panels. The PV voltage of the panels mounted on building rooftop will be fed directly to the laboratory. This will facilitate experimentation under varying insolation and weather condition.

Course Module Development Activities

A comprehensive research on the published books and materials was undertaken to examine the current state of available literature in this field. There is no single book or textbook that includes all the topics planned for our development. A tentative course syllabus was developed and power point slides for each of the topics has been compiled based on the research of existing books and journal/conference publications. The PI has practical experience on PV systems through three projects he completed for Arkansas Highway and Transportation Department (AHTD) and DOE, and that experience has been embedded while designing the power point presentation. The course topics and a summary of the power point slides for each module are presented in the following:

Course Module Topics

1. Solar Resource and Renewable Energy
2. Introduction to Photovoltaic Systems

3. Photovoltaic Materials & Semiconductor Physics
4. Single Photovoltaic (PV) cell and its Model
5. Electrical Characteristics of the PV cell
6. Solae Cell Arrays, PV Modules and PV Generators
7. Power Electronics and Interfacing PV modules to Load
8. Power Conditioning and Inverter Design
9. Maximum Power Point Trackers and DC to DC Converter
10. Battery Characteristics and Energy Storage (Super Capacitors)
11. A Complete Residential PV Systems and Demonstration
12. PV System Sizing and Trade Off
13. Grid-connected PV Systems
14. A Standalone PV System.

Power Point Presentation Slides:

1. Solar Resource and Renewable Energy:
An introduction to solar resource, and important concepts like solar irradiance, solar insolation, Air Mass ratio, solar window etc. A discussion on the impact of these concepts on available solar power at various times of the day and year, and other panel characteristics such as efficiency. Brief discussion about other types of renewable energy- definition and basic characteristics.

2. Introduction to Photovoltaic Systems, Materials and Semiconductor Physics (Band Gap Energy):
The presentation covers in depth about the photovoltaic systems and technology till date, about the types of materials used in photovoltaic manufacturing industry, and the differences between them. As the students might not have complete awareness about band gap theory, discussions on all the relevant topics about semiconductor physics and the impact of band gap for a material to be useful in solar cell manufacturing industry have been included.

3. Single Photovoltaic (PV) cell, its Model and electrical characteristics:
As a continuation to the previous presentation, this is more towards the electrical side rather than physics. The main focus is on the internal parts of a solar cell, it's equivalent electrical model and the basic electrical characteristics like Maximum Power Point, Fill Factor, I-V and P-V curves, impact of internal resistance of a solar cell with emphasis on series and parallel leakage resistance, voltage and current equations etc.

4. Solar Cell Arrays, PV Modules and PV Generators:
This presentation covers the transformation of solar cell to module to array- effect of number of cells in a solar module, a comparison of I-V curves of modules containing different number of cells; parallel, series and hybrid combination of solar cells and the variation in I-V and Power curves. An in depth discussion about temperature and insolation impact on I-V curves, shading effects, methods to minimize shading effects-use of bypass diodes and blocking diodes were a major part of the module.

5. Power Electronics and Interfacing PV modules to Load:
A basic introduction to power electronics and interfacing of various loads with the PV modules are discussed. An in depth presentation on operating point of various loads, its definition and

variance in position under different insolation is part of the module. The presentation includes the I-V curves and power curves showing operating points under different solar insolation for simple resistive load, dc- motor, and battery.

6. Maximum Power Point Trackers and DC-DC converter:
This section of the modules emphasizes on maximum power point trackers (MPPT), the research that's going on in this topic as well as its design and construction. Various methods that include dc-dc buck, boost, and buck-boost converter-their voltage, current and power equations, practical design, effect of temperature on duty cycle parameter, hourly I-V curves are included. Hill climbing MPPT method which is often used in commercial system is emphasized.

7. Power Conditioning and Inverter Design:
This module includes dc-ac inverters-definition and technology as it is one of the main components of a photovoltaic system for grid connectivity. An introduction to Total Harmonic distortion, inverter efficiency, various types of inverters-their advantages and disadvantages, pulse width modulation techniques and its practical implementation is a major part of the unit. The PI also discusses importance of micro-inverter design and the on-going research on the topic as well as the work he is doing related to this technology. A closer look at IEEE publications on inverter design and technology is provided.

8. Battery Characteristics and Energy Storage (Super Capacitors):
The first section of this presentation discusses batteries-classification and important differences between various batteries. Important concepts like battery charging and discharging characteristics, temperature effects, different battery combinations, storage capacity, energy losses, battery sizing, and role of charge controllers are included. The second section includes other emerging efficient energy storage elements like super capacitors- their advantages over batteries, electric al characteristics, methods to measure the capacitance, basic construction and characteristics like ESR, life expectancy, and applications to batteryless PV systems.

9. Grid-Connected PV Systems and Standalone PV Systems:
An in depth discussion about classification of PV systems, types of grid connected systems-single stage and multistage grid systems, various design topologies like CACERES and BARBI, SCHEKULIN, KASA, XUE, Huang et al., etc is a major part of the module. This module also covers a broad discussion on standalone PV system design: examples like solar powered traffic light system, solar powered water pumping and heating system- their design conditions and construction including wire sizing. Role of MMPT and charge controllers, inverter and the situational use of different inverters are explained through exemplary models.

10. PV System Sizing and Trade Off, Complete Residential PV Systems and Demonstration:
The final topic of the course is a real life design that could be implemented for residential purpose. This covers a micro-inverter based design example with all the calculations of PV area, MMPT, inverter design, and the system is based on a 200W micro inverter. The presentation ends with an in depth discussion about BOS selection and design completion-Rooftop junction box, source circuit combiner box and surge arresters, wire and circuit breaker sizing: dc side &

ac side, wiring and standby loads, equipment grounding conductor & grounding electrode conductor sizing.

Laboratory Activities

The College of Engineering has assigned a modern laboratory space for the project implementation. The space has been renovated, electrical connections dropped, and six modern lab tables with storage facility have been installed. Three stations are equipped with test equipment from Tektronix and each station include: Tektronix DMM 4010 5-1/2 Digital Multimeter, Tektronix AFG 3022 B Dual Channel Arbitrary/Function Generator, and Tektronix MSO 3014 Mixed Signal Oscilloscope. DC power supplies are on order. Each station is also equipped with a desktop computer and the computers are interfaced to the equipment through Ethernet cable. Each computer is equipped with latest windows operating system, high speed processor, and major electronic and math software like MatLab, LabView, ArbExpress (interfacing software to Tektronix AFG 3022 B). The software provides the capacity to download simulation or implementation data to the test equipment. The funding for the test equipment has been provided by the College, and the second set of equipment for the remaining stations will be completed as money becomes available this fiscal year. The NSF funding component for equipment has been kept aside to install six 135W panels on the building rooftop and the panel outputs will be fed directly to the lab benches. This has been ordered through a local company. A data acquisition system to monitor temperature and humidity of the panels will also be installed. National Instruments or Keithley Instruments real time PV measurements system will be procured through the grant money.

Couple of experiments related to PV characteristics and MPPT controllers have been completed as of now and the lab activities will be focused on the topics shown below:

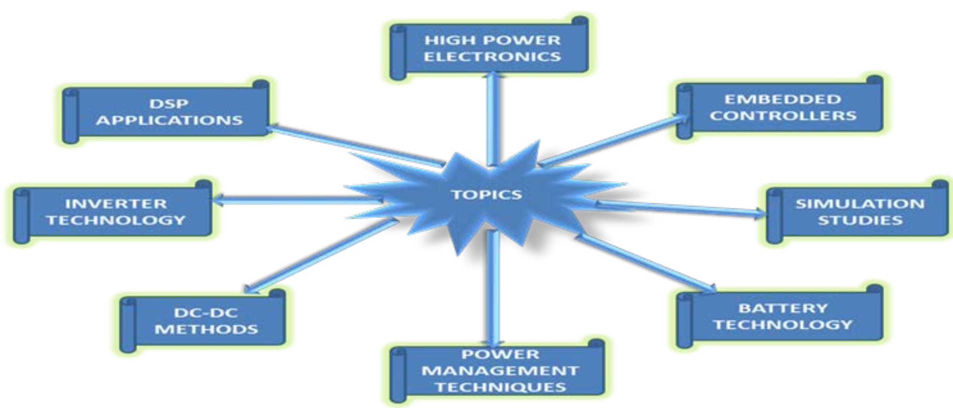

Fig. 2 Planned laboratory topics

Installation of a commercial PV station with funding from the Arkansas energy office has been completed, and the system will be used for teaching as well as for demonstration in outreach activities. The following pictures illustrate the PV system installed and the equipment in the new lab.

Fig.3. PV System: Panels on roof top and 4KW inverter with battery back-up

Fig.4. Photovoltaic lab equipment and the lab stations

Field Testing of Course Modules (Jul 8 – August 8, 2011)

According to Project Plans, field-testing of course modules was to begin in spring of next year (2012). We decided to have a head start by offering the modules for five weeks as a summer special topic course. The course was made open to students from Systems Engineering, Engineering Technology, and Science. Four undergraduates and a graduate student attended the course and it was an enjoyable educational experience for the students. They really appreciated the offering of the course since the students were highly motivated to learn about renewable energy before their graduation. It also provided insights to the PI for refining and reformatting the modules at an early stage of the project. Students' informal feedback was collected as the course progressed and a formal evaluation was done at the semester end. Students had no negative comments about the selection of course topics and the delivery method. They would like to see more solved problems and design examples. This will be done in the next phase of module development. The power point slides were distributed to the students for every lecture, and the majority of the class would like to see a formal textbook developed for the course. The students completed two lab exercises and they recommend more labs in the MPPT controller and converter area. The PI is also considering a standalone PV system as the course platform. The students will experiment with each component of the system before integrating all of them into building a standalone system. This will be considered as we finalize the laboratory exercise development.

Research Activities

Two undergraduates and a part-time graduate student are supporting the PI with course module development and research related to solar energy harnessing. The graduate student is working on single phase inverter design suitable for solar application. The inverter efficiency has been found to be better 98%. The design will be used for classroom discussion and demonstration, and as a possible project when a follow up course is developed for graduate students. The following is his laboratory set up and the inverter efficiency graph.

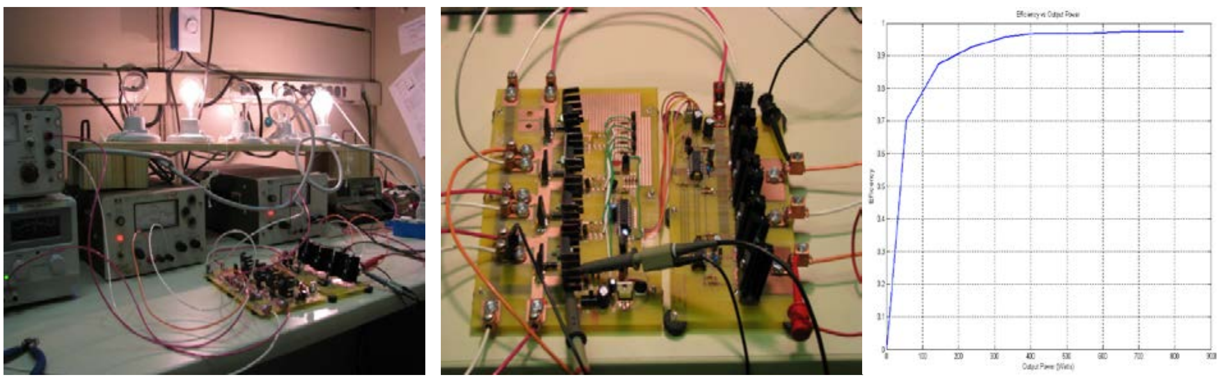

Fig. 5   Experimental Inverter, experimental set-up, and inverter measured efficiency graph

One of the undergraduate assistants is looking into low cost MPPT design. He is developing a temperature based model for the controller. This will be a part of the lab module upon its completion. He is responsible for debugging the lab modules and acquisition of appropriate test equipment for the laboratory.

Another undergraduate is working with the PI in SHE (Selective Harmonic Elimination) type of inverters which is considered for micro inverter applications. It's a novel approach to designing SHE inverters and the results are promising. Two papers on the finding have been submitted for review in international conference and symposiums. The student will join MS program this fall and will continue to work on the project.

Conclusions

The students' high level of enthusiasm in the course indicates that the course has the potential of motivating and attracting students to the field of alternate energy. The preliminary development of the course appears to be in the right direction. The following comments of the students attest to our observation.

Do you feel the course has been meaningful for your career interest? If yes, In what way?
Comments
- I don't know about career but it is of great interest for personal application.
- This course directly matches what my main interests are in engineering career field. I have always wanted to find/work with/ put to use renewable source for energy in future.

- I believe solar panels are becoming more popular every day. Therefore, it is a great idea to learn at least the basics. I've not only learned about PV systems, but electrical circuits such as inverter and DC to DC converters.
- I believe that it has lots of meaning in my career.

Resources used in Course Module Power Point Development

Books

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