Industry Informed Curriculum Development in Engineering Technology: Solar PV Planning and Installation

Mohsen Azizi

New Jersey Institute of Technology

Introduction

The power generation industry has been gradually switching from traditional fossil generators to renewable energy systems (RESs), which are more efficient and environmentally friendly, in the past two decades. This trend has given rise to the job market demand for a new generation of engineers and technicians from science, technology, engineering, and mathematics (STEM) fields, who are specifically trained for renewable energy industries. In this National Science Foundation (NSF) sponsored project, state-of-the-art equipment and laboratory materials are designed and developed for the engineering technology students to get exposure to the relevant theories and get hands-on skills on the functional knowledge of solar Photovoltaic (PV) systems. The new course "Solar PV Planning and Installation" and the associated laboratory experiments are designed, developed, and continuously improved in collaboration with the external advisory committee (EAC) including industrial partners. This new course provides the students with the practical and experimental skills required by the industry jobs in the field of solar PV design, installation, and troubleshooting.

This project is conducted at New Jersey Institute of Technology (NJIT), which is a public university located in Newark, New Jersey. It is home to 18% Hispanic, 9% other minorities, and 28% female students as of 2021. The School of Applied Engineering and Technology (SAET) at NJIT develops strong connections with the community colleges and industries, and offers ABET accredited programs with significant hands-on laboratory experiences and applied research opportunities. These opportunities complement the classroom experience in preparation of students for careers in a wide range of industries. The principal investigator of this project has expertise in the field of solar PV and power systems [1]-[8], has supervised several research and development projects and graduate theses in the domain of renewable and solar PV systems [9]-[11], and has a prior experience of laboratory and curriculum development [12], [13].

In this paper, the overview of the developed new course and laboratory are presented, which includes the lecture topics and laboratory equipment and experiments. Moreover, the comments and feedback from the EAC including industrial partners are presented. Their major comment for modification is highlighted, and it is explained in detail as how it was addressed. In addition, the description of the offered faculty development workshop is presented, which includes the lecture topics and hands-on laboratory activities, and finally an overview of the participants' feedback is explained. The following new website is developed which includes all the information about this project and the developed materials and modules: https://research.njit.edu/rest.

New Course and Laboratory Development

The new course "Solar PV Planning and Installation" is developed at NJIT to train students for engineering and technician jobs in solar PV technology, installation, and troubleshooting. This is a three credit hours course with two hours per week of recitation and two hours per week of laboratory experiments. This course is open to sophomores or higher, and the prerequisite course is Circuits II. The course learning outcomes include:

1. Learn solar energy systems, DC/AC solar PV systems, and solar PV industries.
2. Learn solar irradiance and sun path characteristics.
3. Learn solar panel orientation and site measurements.
4. Perform array site planning.
5. Perform load analysis, interpret component specifications, and design the optimal PV system.
6. Draw circuit diagrams, assemble a PV array and a mounting system, and install conductors.
7. Select and install grounding and surge protection systems.
8. Perform pre-startup PV system checkout and initial startup, and connect/tie an interactive PV system into the grid.
9. Connect and commission DC stand-alone and AC stand-alone/grid-tied PV systems with/without battery backup.
10. Troubleshoot and operate solar PV systems, and learn their safety rules.
11. Financial benefit of residential solar PV systems and their payback period.

Based on the textbook [14] selected for this new course, the developed lectures are demonstrated in the following Table 1.

Table 1. Lecture notes developed based on the textbook [14].

Lecture 1	Solar energy systems, DC/AC PV systems, and solar PV industries.
Lecture 2	Solar irradiance calculation, peak sun, global positioning, solar time, and sun path diagrams.
Lecture 3	Solar panel orientation, site measurements, and insolation data.
Lecture 4	Site assessment and permitting, array site analysis, component locations, and site layout.
Lecture 5	Maximum circuit voltage and current conditions, wire selection and sizing, ground systems, and lightning and surge protection.
Lecture 6	Solar PV system design overview, mechanical and electrical installation, checkout and startup, and interactive PV system installation.
Lecture 7	PV module operation, I-V characteristics, output measurement, environmental effects, performance ratings, module construction, and array characteristics and connections.
Lecture 8	Battery operation, capacity characteristics, battery types, battery banks, and charging characteristics.
Lecture 9	Charge controller operation and configuration, and charge-controlled PV system operation.
Lecture 10	Stand-alone PV system, grid-connected PV system with battery backup, and grid-connected PV system without battery backup.
Lecture 11	Solar PV system fault types and impacts, and system troubleshooting concepts and techniques.

The following laboratory products from Amatrol Inc. [15] were purchased and utilized in the development of the associated laboratory experiments:

- Solar PV Installation Learning System demonstrated in Figure 1, which includes the following laboratory experiments: Wire Selection and Sizing, Ground and Lightning Protection, PV Installation, and Startup and Commissioning.
- Solar PV Troubleshooting Learning System demonstrated in Figure 2, which includes the following laboratory experiments: PV Module Operation and PV Arrays, Solar Batteries, DC and AC Solar PV Systems, and Troubleshooting.
- Solar Site Analysis Learning System demonstrated in Figure 3, which includes the following laboratory experiments: Site Assessment and Permitting, Array Site Analysis, Component Locations, and Site Layout.

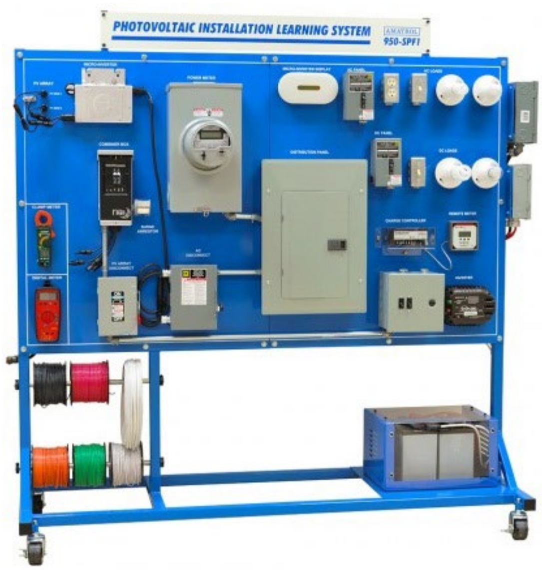


Fig 1. Solar PV Installation [15].

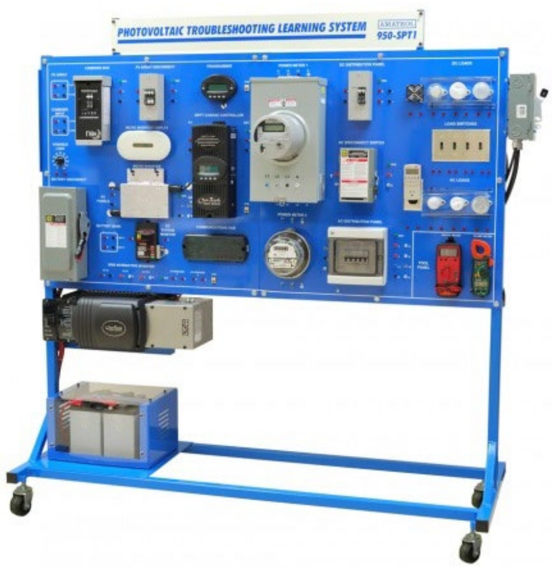


Fig 2. Solar PV Troubleshooting [15].

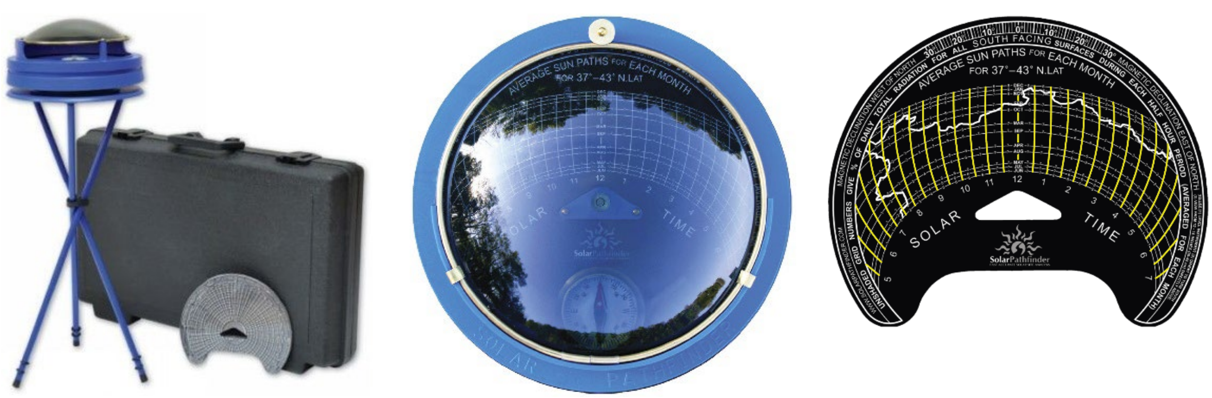


Fig 3. Solar Site Analysis [15].

The assessment method is a combination of knowledge test, hands-on troubleshooting scenarios of embedded faults, and final research project. This course will also prepare the students to conduct their capstone senior design (SD) projects in the field of renewable energies and specifically solar energy systems.

Feedback from External Advisory Committee (EAC)

The course contents and project scope [16], [17] were provided to the EAC along with a feedback form that included the following four questions:

1. Lecture notes: Do they provide the knowledge required in the field? What additional topics/materials can be added to improve and enhance the lectures?
2. Lab experiments: Do they provide the skills required in the field? What additional experiments can be added to improve and enhance the labs?
3. Evaluation (quizzes, tests, review questions, project): Do they provide an effective evaluation of the students? What additional evaluation modules can be added?
4. Please provide your overall evaluation of the new course/lab, and any other comments and suggestions for improvement.

Detailed evaluation reports and comments were received from the EAC members. They mostly included minor technical changes, all of which were applied to the lecture notes and laboratory manuals. The responses to the question #4 above are listed below:

- “In general, the course is very thorough and covers all aspects of work with Solar PV.”
- “I find the course materials very broad and sufficient, and lab setup well-designed to serve the job market demand. I don’t have any suggestion for improvement other than mentioned earlier in previous comments.”
- “I am very impressed by the quality and practicality of the course material, very well fit for a renewable technician training program. The use of audio narration and integrated videos for the lectures made them easy to follow and understand for both in class and remote students. The use of multimedia further helps keep students engaged with the lectures. The lab procedures are very illustrative and detailed, and use of video recordings as supplementary material further helps navigating through the course material. The lab experiments and practices are chosen to train the students for practical installation and maintenance problems and how to proceed in each troubleshooting scenario. This course can be used as a role model for similar technical educational programs.”

The only major comment was to include a PV sizing and siting software or website. Subsequently, this comment was addressed by adding the following three hands-on laboratory experiments: (a) Load analysis, (b) PV system design, and (c) PV site survey, which are presented in Tables 2, 3, and 4, respectively.

In the following Table 2, an exercise is provided to perform load analysis for a small cabin, which is located far from the utility grid, and hence needs to generate all the required electricity from a solar PV system in the stand-alone mode of operation. Load analysis is the first step in a solar PV design process.

Table 2. Load analysis.

Perform load analysis and compute the total load requirement using the following website: https://gensizer.assurancepower.com/index.php?option=com_aps&view=calculator&layout=wholehouse&Itemid=55 Consider a small cabin with the following eight electrical appliances and equipment: (i) Refrigerator/freezer, 15 hours per day, (ii) Radio/CD-player, 2 hours per day, (iii) Cristen pump, 2 hours per day, (iv) Eight compact fluorescent lights, 5 hours per day, (v) Ceiling fan, 10 hours per day, (vi) Radio/alarm clock, ON at all times, (vii) Microwave, 20 min per day, and (viii) Computer, 4 hours per day.

In the following Table 3, an exercise is provided by using an online tool for solar PV site analysis based on the specific geographical location on the map and shape of the area specified for the PV panels. The online tool calculates the DC System Size, AC Energy, and Solar Radiation, which are the key information for designing a PV system.

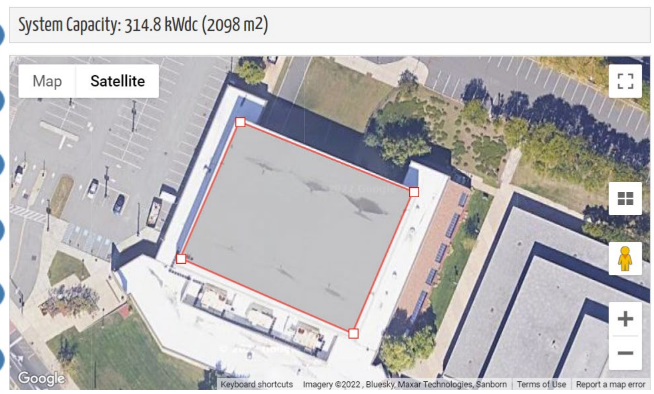
Table 3. PV system design.

The PVWatts calculator is a website where an optimized PV system can be designed. The location considered in this part is: 303 University Ave, Newark, NJ 07102.

Step 1- Open the website https://pvwatts.nrel.gov and search for the address above.

Step 2- Click on "System Info". In order to determine the DC system size, the available area for the solar panels should be specified first. Therefore, in the "Draw Your System" section, customize the allocated area on the map as demonstrated in the figure below (right side).

DC System Size (kW):	314.8
Module Type:	Standard
Array Type:	Fixed (open rack)
System Losses (%):	14.08
Tilt (deg):	20
Azimuth (deg):	180



Step 3- Click on "Results". The following table shows the values of the Solar Radiation and AC Energy for each month as well as their total annual values. This table can be generated for different values of "Module Type" and "Array Type" in the above table (left side).

RESULTS

Print Results

416,179 kWh/Year*

System output may range from 400,322 to 435,947 kWh per year near this location. Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.86	23,418
February	3.88	28,079
March	4.86	38,632
April	5.47	39,458
May	5.84	42,939
June	6.35	43,544
July	6.43	44,877
August	5.88	41,156
September	5.39	37,613
October	4.13	30,922
November	3.22	24,304
December	2.62	21,237
Annual	4.74	416,179

Location and Station Identification	
Requested Location	303 University Ave, Newark, NJ 07102
Weather Data Source	Lat, Lng: 40.73, -74.18 0.6 mi
Latitude	40.73° N
Longitude	74.18° W
PV System Specifications	
DC System Size	314.8 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2
Performance Metrics	
Capacity Factor	15.1%

In the following Table 4, the same procedure as in Table 3 is repeated multiple times to find the optimum tilt angle for the solar PV panels.

Table 4. PV site survey.

The purpose of this experiment is to set the tilt angle of the PV arrays to its optimum value.
The location considered in this part is: 1200 Harrison Ave, Kearny, NJ 07032.
The instructions for this part are similar to those in Table 3.

Step 1- Open the website https://pvwatts.nrel.gov and search for the address above. Customize the allocated area on the map.

Step 2 - Set the tilt angle to 70 (deg) and record the Annual Solar Radiation and AC Energy values.

RESULTS

Print Results

397,767 kWh/Year*

System output may range from 382,612 to 416,661 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.84	33,358
February	4.86	37,284
March	4.72	39,729
April	4.28	32,999
May	3.74	29,058
June	3.84	28,338
July	4.09	30,533
August	4.32	32,398
September	4.80	35,626
October	4.51	35,473
November	4.09	32,561
December	3.56	30,411
Annual	4.22	397,768

Step 3- Repeat step 2 for the tilt angles of 20, 25, 30, 35, 40, 45, 50 (deg). Then, plot two graphs for the Annual Solar Radiation and AC Energy values versus the tilt angles. Use these graphs to determine the optimum tile angle.

Step 4- Repeat step 2 for the following array types and compare the results: Fixed (open rack), Fixed (roof mount), 1-Axis Tracking, 1-Axis Backtracking, and 2-Axis Tracking.

Faculty Development Workshop

The "Solar PV Installation and Troubleshooting Workshop" was offered to the faculty members and instructors from 2- and 4-year institutions from all over the US. This one-day workshop included 2 hours of lecture and 6 hours of hands-on laboratory experiments. The lecture topics included:

- Certification programs, and electrical codes and standards
- Solar panel ratings, types of PV systems, and parts of a PV system
- Determining load and sizing the PV array
- Conducting a site survey, determining available sunlight, and orientation of the array
- Financial overview and benefit

The laboratory experiments were conducted in three parts including:

- Lab 1 (PV Lab): Measuring the open-circuit voltage, short-circuit current, and operating point of a PV module; Connecting and operating a stand-alone AC PV system.
- Lab 2 (PV Lab): Troubleshooting a stand-alone AC PV system.
- Lab 3 (Computer Lab): Using the online tool presented in Tables 2, 3, and 4 to design a residential PV system.

The information was provided to the participants as how to design and develop a similar course and laboratory at their own institutions, and how to plan for budget, equipment, and course materials. Based on the comments from the participants, the one-day workshop was very helpful for them to get exposed to the principles of solar PV systems, specifically in the stand-alone mode of operation. They provided feedbacks to offer longer workshops in the future to include the grid-connected and grid-interactive modes of operation as well.

Conclusions

In this NSF-funded project, the new course entitled “Solar PV Planning and Installation” and its associated laboratory were designed and developed for the engineering technology students. This new course and laboratory are being continuously improved and enhanced in close collaboration with industrial partners to target the real industrial demands in this field. The contents of the course lectures and laboratory experiments are presented in this paper. Moreover, the feedback and comments from the EAC are explained, their major comment for modification is highlighted, and the developed materials to address their major comment are described in detail. The faculty development workshop, its contents, and the participant’s feedbacks are also presented. This new course prepares the students for the relevant jobs including but not limited to solar PV project developer, solar PV field technician, and solar PV installer.

Acknowledgement

This material is based upon work supported by the National Science Foundation (Advanced Technological Education program) under Grant No. 1902442.
The author would like to thank the external evaluator, Dr. Barbara Moskal, for her valuable comments and continuous support; and the external advisory committee, Dr. Saeed Kamalinia (S&C Electric Company), Dr. Iman Naziri (Energy Vault), and Dr. Amir Kazemi (GE Power), for their valuable feedback.

References

[1] S.M. Azizi, “Geometric Fault Detection and Identification in Power Inverters with High Order Filters”, IEEE American Control Conference (ACC), pp. 6761-6765, 2018.
[2] N. Ashtiani, S.M. Azizi, and S. Ali Khajehoddin, “Robust H∞ DC Link Control Design for High-Power Density Converters with High-Order Filter in PV Systems”, IEEE Energy Conversion Congress and Exposition (ECCE), pp. 58-63, 2017.
[3] N. Ashtiani, S.M. Azizi, and S. Ali Khajehoddin, “Control Design in μ-Synthesis Framework for Grid-Connected Inverters with Higher Order Filters”, IEEE Energy Conversion Congress and Exposition (ECCE), pp. 1-6, 2016.
[4] S.M. Azizi and S. Ali Khajehoddin, “Robust Inverter Control Design in Islanded Microgrids Using μ-Synthesis”, IEEE Energy Conversion Congress and Exposition (ECCE), pp. 1-5, 2016.

[5] S.M. Azizi and S. Ali Khajehoddin, "Robust Decentralized Voltage and Frequency Control of Generators in Islanded Microgrids Using μ-Synthesis", IEEE Energy Conversion Congress and Exposition (ECCE), pp. 1-8, 2016.
[6] S.M. Azizi and S. Ali Khajehoddin, "An Optimization Approach to Design Decentralized Load Frequency Controllers for Generators in Islanded Microgrids", IEEE Industry Applications Society (IAS) Annual Meeting, pp. 1-7, 2016.
[7] S.M. Azizi and S. Ali Khajehoddin, "Robust Load Frequency Control in Islanded Microgrid Systems Using μ-Synthesis and D-K Iteration", IEEE International Systems Conference (ISC), pp. 1-8, 2016.
[8] N. Ashtiani, S.M. Azizi, and S. Ali Khajehoddin, "Robust Control Design for High-Power Density PV Converters in Weak Grids", IEEE Transactions on Control Systems Technology (TCST), Vol. 27, No. 6, pp. 2361-2373, 2018.
[9] A. Savasci, "Grid-Aware Optimal Demand Response Management of Smart Homes", MSc Thesis in Electrical and Computer Engineering, Michigan Technological University, 2018.
[10] M. Buyuknalbant, "Consensus-Based Proportional-Resonant Control of Renewable Energy Generators", MSc Thesis in Electrical and Computer Engineering, Michigan Technological University, 2017.
[11] S. Ahmed Fuad, "Consensus-Based Distributed Control in Micro-Grid Clusters", MSc Thesis in Electrical and Computer Engineering, Michigan Technological University, 2017.
[12] A. Sergeyev, N. Alaraje, and M. Azizi, "Michigan Tech and Nucor Steel Partnership: State-of-the-Art Industrial Control and Automation Laboratory", ASEE Conference for Industry and Education Collaboration (CIEC), ETD 335, 2016.
[13] A. Sergeyev, N. Alaraje, M. Azizi, J. Frendewey, and D. Fuhrman, "Academia and Industry Partnership: Building State-of-the-Art Industrial Control and Automation Laboratory", ASEE Annual Conference and Exposition, Paper ID #12599, 2015.
[14] Jay Warmke, Understanding Photovoltaics: An Easy-to-follow Study Guide for Solar Electric Certification Programs, 8th Edition, 2021
[15] Amatrol Inc., Jeffersonville, Indiana, [website] www.amatrol.com
[16] M. Azizi and V. Fuentes, "Solar PV Installation and Troubleshooting Course Development", ASEE Annual Conference and Exposition, Paper ID #38249, 2022.
[17] M. Azizi and V. Fuentes, "Design and Development of a New Course and Laboratory: Solar PV Installation and Troubleshooting", ASEE Conference for Industry and Education Collaboration (CIEC), 2022.

Biography

MOHSEN AZIZI is an assistant professor in the School of Applied Engineering and Technology at New Jersey Institute of Technology (NJIT). He received the M.Sc. and Ph.D. degrees in electrical and computer engineering from Concordia University, Montreal, Canada, in 2005 and 2010, respectively. From 2010 to 2013, he was an R&D engineer at Aviya Tech Inc. and Pratt & Whitney Canada Inc., Longueuil, Canada, where he designed and developed control and fault diagnosis systems for jet engines. His research has been focused on decentralized control and fault diagnosis techniques in microgrids, renewable energy systems, mechatronics, and aerospace.