Design and Development of a New Course and Laboratory: Solar PV Installation and Troubleshooting

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Abstract

Renewable energy systems are more efficient and environmentally friendly power generation solutions as compared to traditional fossil generators, and as a result have created a continuously expanding job market. The global investment in solar photovoltaic (PV) systems has gone through a mostly increasing trend in the past ten years, which implies that solar PV systems will own a major share of the power generation and distribution market in the near future. This multi-billion-dollar market requires a significant number of science, technology, engineering and mathematics (STEM) graduates specifically trained to handle the technical challenges and meet the job market demand of renewable energy industries.

This project was funded by the National Science Foundation (NSF). In this project, the new courses on solar PV installation and troubleshooting and the associated new laboratory were designed and developed by using the state-of-the-art equipment. This project was conducted collaboratively at New Jersey Institute of Technology (NJIT) and County College of Morris (CCM), in collaboration with industrial partners in order to meet the knowledge requirements established by the North American Board of Certified Energy Practitioners (NABCEP). These new courses are being offered to the engineering technology students at both institutions. This NSF-funded project significantly contributes to the renewable energy workforce training by providing functional knowledge and understanding of solar PV systems integration, installation, startup, commissioning, protection, and troubleshooting. The new courses and laboratories target real industrial demands in this field, and hence were designed and developed, and are being continuously improved and enhanced in close collaboration with industrial partners.

Introduction

Renewable energy systems (RESs) are the new power generation technologies which are widely used as alternative power solutions for residential and industrial sectors. Compared to traditional fossil generators, RESs are more efficient and environmentally friendly. Due to the relatively young age of these technologies, there is still a big gap between the relevant job market and educational programs, which call for engineers and technicians specifically trained to meet the new market demands of these new technologies. The global investment in RESs has gone through a mostly increasing trend in the past ten years [1], which implies that RESs will own a major share of the power generation and distribution market in a near future as compared to fossil fuel, large hydro, and nuclear generators. This multi-billion-dollar market requires a

significant number of engineers and technicians specifically trained to handle the technical challenges of these alternative energies.

The renewable energy share in the U.S. energy production market is growing rapidly, while the fossil energy share is declining [2], [3]. These trends are depicted in Figure 1 for the time span of 1998-2017. The percentage of renewable energy production (out of the total energy) has risen from 7.7% in 2001 to 17.12% in 2017. Due to the advancement of relevant technologies, it is expected that these trends will continue with steeper slopes in the following decades.

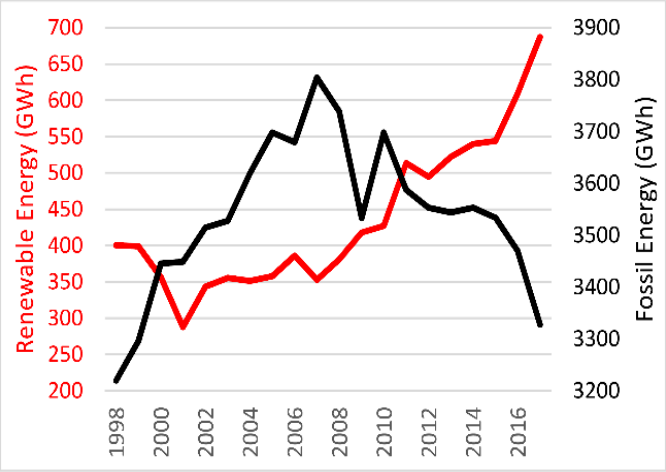

Fig 1. Renewable and fossil energy production trends in U.S., 1998-2017 [2], [3].

Renewable energy resources encompass several technologies mainly including hydroelectricity, wind farms, solar photovoltaics, biomass (wood is the largest biomass energy source), and geothermal power plants. The energy generation growth of these individual renewable energy technologies is depicted in Figure 2 for the time span of 1998-2017 [2], [3]. As indicated in this figure, “hydro” has constituted a major share of the renewable energy generation, but its trend over the years has been almost constant. The same constant trend is observed for “wood”, “other biomass”, and “geothermal”. However, the share of “solar” and “wind” has been considerably growing in the past few years, and the trend is increasing over time. Therefore, it is predicted that in a few years, there is a high demand for technicians and engineers with hands-on skills in installation and commissioning of these two renewable technologies, solar and wind. In this project, the focus was made on the solar photovoltaic technology, by developing the state-of-the-art laboratory and curriculum to train the engineering technology students with the hands-on skills required to fill the gap between the market demand and workforce and fill the relevant industry positions.

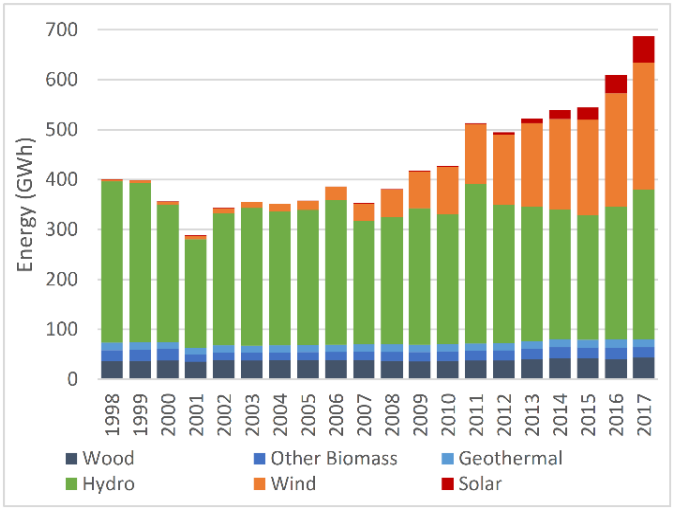

Fig 2. Renewable energy generation growth details, 1998-2017 [2], [3].

According to the Bureau of Labor Statistics (BLS), "solar photovoltaic installer" is the occupation with the highest percentage of employment with the growth rates of 105%, between 2016-2026 [4]. The typical entry-level education requirement is mentioned to be high-school diploma or equivalent, and postsecondary non-degree award. This implies that there will be a significant increase in the job market demand for technicians in this area of engineering technology. Based on the information from the department of energy (DOE) depicted in Figure 3, about 42% (2015), 43% (2016), and 40% (2017) of the job market in electric power generation technology was dedicated to solar technicians, as compared to other technologies including geothermal, bioenergy, hydro, nuclear, fossil (oil, gas, coal), advanced gas, and wind, and all other types of energy resources. These statistical data indicate the importance of curriculum development for solar energy technology to train hands-on students and technicians to meet the future demand of the solar electricity power generation industries.

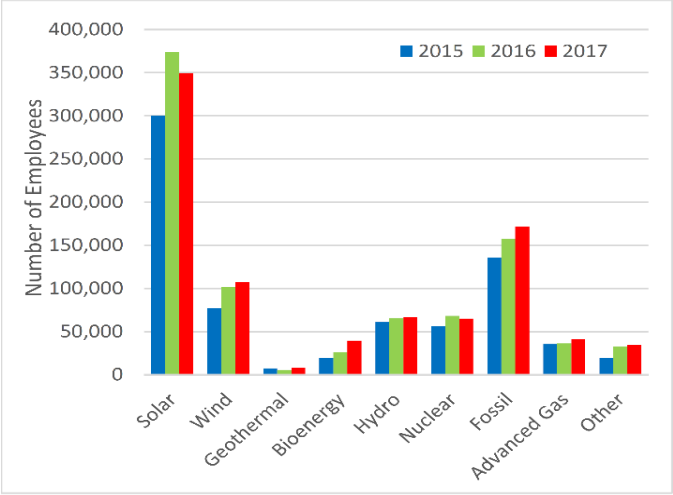

Fig 3. Electric power generation employment [5].

The results of a survey conducted in 2016 indicate that 40% of U.S. employers have difficulty hiring well-trained employees for their open positions [6]. The survey indicates that skilled

electricians, technicians (production, operations, and maintenance), and electrical engineers are among the ten roles that employers find hardest to fill due to major gaps in critical and essential skill sets in U.S. On average, organizations spent $1,273 and 34.1 hours per employee in 2016 on direct learning, which indicates a $21 and 0.6 hours increase as compared to $1,252 and 33.5 hours per employee in 2015 [7]. The statistics prove the considerable increase in the organizations' rates of money and time investments per employee training, which is an indication that the U.S. is not preparing sufficient numbers of students, teachers, and professionals in STEM. Moreover, a critically high replacement rate of STEM professionals has been faced recently by the U.S. employers [8]. This project was specifically structured to meet the educational standards of the solar energy generation industries.

In this project, a renewable energy systems training laboratory and the associated curriculum were developed for training, workshop, and education purposes in the Engineering Technology (ET) Departments at New Jersey Institute of Technology (NJIT) and County College of Morris (CCM), in collaboration with the industrial partners in order to meet the knowledge requirements established by the North American Board of Certified Energy Practitioners (NABCEP) for certified solar photovoltaic system installer. Two new courses were developed to provide foundational trainings that will help students prepare for portions of the solar certification offered by NABCEP. The objective of this project is to provide user friendly RES equipment and experimental materials for the college students and faculties in engineering technology programs to develop the required expertise in this domain. The students get exposure to the relevant theoretical knowledge and get hands-on skills through the practice of RES installation, troubleshooting, and commissioning. This project aims to boost RES training in STEM education by using the developed state-of-the-art laboratory and curriculum that match well with the relevant industry needs.

New Courses and Laboratories Development

The two- and four-year majors of the ET Departments at the partner institutions, NJIT and CCM, of this project are among the group of disciplines that comprise the "T" in STEM. Our renewable energy systems training project directly targets several objectives of the Advanced Technological Education (ATE) solicitation by educating technicians for the renewable energy electricity industries that drive our nation's economy, and providing the university and community college students with the state-of-the-art laboratory equipment and credit bearing curriculum that are developed in close collaboration and partnership with the relevant industries to directly match the industry expectations and needs. The academic partners in this project come from university and community college. These institutions which are specialize in STEM education are listed below.

New Jersey Institute of Technology (NJIT) is a public university located in Newark, New Jersey. It is home to 17% Hispanic, 8% other minorities, and 27% female students as of 2017. The Engineering Technology (ET) Department at NJIT offers high-quality ABET accredited programs that target the immediate and future needs of industries and is recognized for national leadership in engineering technology and STEM education through excellence in curricula, teaching, laboratory development, and service. The ET Department continuously develops strong connections with the community colleges and industries and offers significant hands-on laboratory experiences and applied research opportunities which complement the classroom experience in preparation of students for careers in a wide range of industries.

County College of Morris (CCM) is a community college located in Randolph, New Jersey, serving students in the northwestern part of the state. CCM has recently become a member of the "Achieving the Dream" network for its long-term sustainable commitment to improving student success. The CCM student profile includes 25% Hispanic and 9% other minorities. CCM offers ABET accredited electronics engineering technology and mechanical engineering programs. It also has a certified Center for Cyber Security. The college has its own solar PV array that provides approximately 45% of the college's energy use.

In this project, two identical laboratories were developed, one per each partner institution, to offer the new courses and short courses for the engineering technology and college students. The laboratories provide the state-of-the-art training equipment to teach the installation, troubleshooting, protection, startup, and commissioning of solar PV systems. The new courses were developed to train the students with the skills immediately required by renewable energy power companies. These hands-on courses target the real industrial demands in this field, and hence are designed, developed, improved, and enhanced continuously in close collaboration with the partner energy and power industries. Using the new laboratories and the associated developed courses for the engineering technology and college students, we envision preparing a new class of engineers and technicians that will be in high demand and able to quickly integrate into the modern renewable energy sector in industry.

In order to develop the laboratory experiments for the new courses, the following products from Amatrol Inc. were purchased and utilized in the new laboratories: "Solar Concepts Learning System (950-SC1)" multimedia software, "Solar PV Installation Learning System (950-SPF1)" demonstrated in Figure 4, and "Solar PV Troubleshooting Learning System (950-SPT1)" demonstrated in Figure 5 [9]. These products include both equipment and multimedia software. The learning software package provides a series of laboratory instructions that were used to develop the laboratory manual for the new courses.

Fig 4. Solar PV Installation Learning System [9].

Fig 5. Solar PV Troubleshooting [9].

The new course at NJIT, "Solar PV Planning and Installation" (3 credit hours, Class 2 hours, Lab 2 hours), was developed to train students for engineering and technician jobs in solar PV technology, installation, commissioning, and troubleshooting. The course flow diagram is depicted in Figure 6. This course covers the following topics on solar PV systems: introduction to renewable energy and PV systems, solar thermal systems, solar radiation, sun path characteristics, solar panel orientation, wire selection and sizing, ground and lightning protection, installation, startup, commissioning, and troubleshooting. It covers several real commercial and residential application topics such as: identify and analyze sites for array locations; develop and implement a site layout; calculate PV circuit voltages and currents; choose, cut, strip, and connect wire; and install components in a PV system. 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 (ECET 202). This course was designed in collaboration with our industrial partners in order to provide foundational trainings that will help students prepare for portions of the solar certification offered by the North American Board of Certified Energy Practitioners (NABCEP) test for certified solar PV system installer.

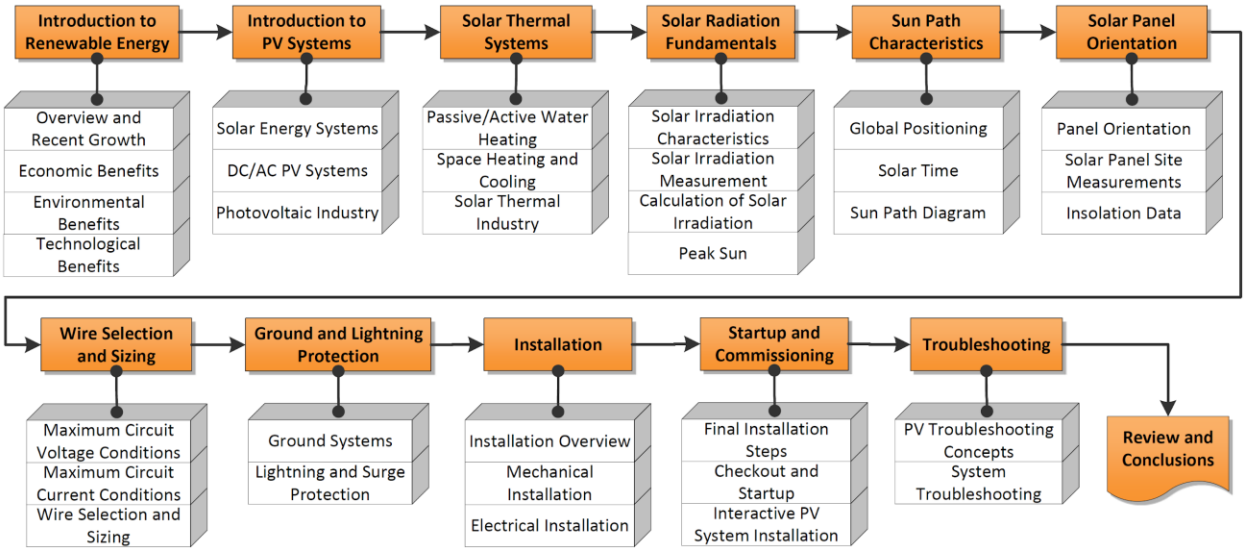

Fig 6. Solar PV installation and troubleshooting course flow diagram.

The new course at CCM, "Solar & Alternative Energy Systems" (3 credit hours, Class 2 hours, Lab 2 hours), is like the one at NJIT, but since the focus of the two-year program is towards jobs as technicians, the decision was made to make the course at CCM more about troubleshooting. As in the course at NJIT, the foundational concepts on PV systems are covered, as well as topics covering site layouts and power demands calculation, but the emphasis of the course is on hands-on laboratory activities with focus on troubleshooting. The prerequisite course is Circuit Analysis DC/AC (ELT 100). The decision was made early on to emphasize design principles in the course at NJIT, so while the two courses do overlap, the one at NJIT goes deeper into areas important for a PV system designer. The level of overlap between the two courses should not deter students graduating from the ET program at CCM and continuing their studies at NJIT and taking the "Solar PV Planning and Installation" course. Taking the two-course sequence would provide a greater understanding of both operational aspects of PV systems, and the design considerations in the development and installation of a PV system.

These courses are currently being offered at NJIT and CCM (in Fall 2021 for the first time). The courses start with five weeks of lectures to build up the knowledge foundation on solar PV systems. Then they provide nine weeks of laboratory work, in which the students practice teamwork in conducting the hands-on experiments. The students analyze and summarize their laboratory findings in the form of reports. The assessment method is a combination of knowledge test, hands-on troubleshooting scenarios of embedded faults, and final research project. These courses will also prepare the students to conduct their capstone senior design (SD) projects in the field of renewable energy systems and specifically solar energy systems (future plan).

The principal investigators of this project have expertise in the field of solar PV and power systems [10]-[17]. They have supervised several research and development projects and graduate theses in the domain of renewable and solar PV systems [18]-[20] and have a prior experience of laboratory and curriculum development [21], [22]. CCM has several solar PV arrays installed on campus that are generating close to 400 kilowatts of electrical energy (approximately 45% of its annual energy need). These PV arrays were used to design hands-on experiments in the new courses, so that the students at both partner institutions can learn to evaluate a real residential PV

system and suggest ways of improving its electric power output based on the theories they learn throughout the new courses.

Conclusions

In this NSF-funded project, the new laboratories and the two new courses "Solar PV Planning and Installation" (at NJIT) and "Solar & Alternative Energy systems" (at CCM) were designed, developed, and are being offered to the engineering technology students at both institutions. These new courses and laboratories are being continuously improved and enhanced in close collaboration with industrial partners in order to target the real industrial demands in this field. The significance of this project is the contribution to the renewable energy workforce training. The new courses and laboratories provide the students with the functional knowledge and understanding of solar PV systems integration, installation, startup, commissioning, protection, and troubleshooting, and trains them to meet the knowledge requirements established by the North American Board of Certified Energy Practitioners (NABCEP).

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Biographies

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.

VENANCIO L. FUENTES is a full professor in the Engineering Technologies/Engineering Science Department at County College of Morris, and is currently serving as the department's chairperson. He received is B.E. in electrical engineering from Stony Brook University and his M.E. in electrical engineering from Stevens Institute of Technology. He is a registered Professional Engineer (PE) in New Jersey and prior to entering teaching, worked as a systems engineer for Sperry Corporation and later for Kearfott Guidance and Navigation, where he was involved in the design of sea, air and space borne navigation systems.