AC 2011-2628: EE STUDENTS COMPLETE PHOTOVOLTAIC R&D FOR INDUSTRY IN ELECTRICAL ENGINEERING CURRICULUM

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Kevin Anthony Bellomo-Whitten was born in Philadelphia, Pennsylvania on August 22, 1988. He moved to Cape May, New Jersey in 1989, where he attended all of his schooling. Upon completion of high school, Kevin was accepted to Rowan University's College of Engineering, Electrical and Computer Engineering department. He had the pleasure of traveling to England in 2009 for a course in Sustainable Design in Engineering, where his interest in renewable energy systems began to grow. Kevin has now completed his Bachelors in Electrical and Computer Engineering and work for Ray Angelini, Inc. as a Solar Design Engineer, and hopes to continue on at Rowan University towards completing his graduate degree in Electrical Engineering with a core in renewable energy systems.

EE Students Conduct Photovoltaic R&D for Industry in Electrical Engineering Curriculum

Abstract
Rowan University is committed to providing undergraduate engineering students with experience in real world problems as part of its engineering curricula. Through the participation of Industrial Affiliates, we have been able to involve undergraduate students in a number of renewable energy research and design projects. This paper describes the structure and methodology of Rowan University's Junior and Senior year clinic model as well as a specific clinic project that provides students with the experiential learning opportunity in which they can apply their engineering knowledge and resourcefulness to a real-world project. During the 2010-2011 academic year, Kaneka Corporation of Osaka, Japan sponsored the design, engineering, permitting and installation of a photovoltaic (PV) system test bed located at Rowan University's Rowan Hall, utilizing Kaneka's new multi-junction "Hybrid" amorphous modules. The installation required that all work be completed in accordance with local laws and codes as well as be designed for optimal array output. Working in an engineering clinic environment, modeled after the medical school approach, undergraduate engineering students were charged with design and installation of this system to meet any necessary political and design specifications. This involved every aspect of design, including obstruction shading analysis, PV array layout, single-line design, specification, procurement and purchasing of all required balance of system (BOS) equipment, as well as plan submittals for Rowan University and New Jersey Department of Community Affairs (DCA) approval. Through this engineering clinic model, students learned all the inner workings of how a grid-connected PV array goes from concept to reality, ending with a finished product for the client. Most importantly, the Rowan University clinic experience allowed students to effectively communicate with representatives of the sponsoring agency and report the findings of a semester long research, design and development project.

Background
The four Rowan University Engineering programs offer an inter-disciplinary Engineering Clinic program, which consists of an eight-semester sequence of courses that must be taken by all Engineering students [1]. Freshman students in Chemical Engineering (ChE), Civil and Environmental Engineering (CEE), Electrical and Computer Engineering (ECE), and Mechanical Engineering (ME) take a 2-credit hour clinic during the fall and spring semesters. At this level, the emphasis is on learning the process of engineering through measurements on exemplar engineering systems, and reverse engineering of typical appliances or processes to illustrate key engineering concepts [2]. Students are managed as a class with the composition of each class a mixture of all four disciplines. During the sophomore year, students take 4-credit hour clinics. In the fall, the general education Composition course is integrated with a design project. This emphasizes the importance of technical writing as an integral part of the engineering process. In the spring, the general education Public Speaking course is again integrated with a design project underscoring the importance of oral communication as a vital component of engineering. The final four semesters of Engineering Clinic are designed to provide junior and senior students with the opportunity to collaborate on real world projects for external clients or sponsors and to present solutions by applying multi-disciplinary engineering concepts. Each department sponsors approximately 8-15 projects and solicits students from

each discipline as appropriate to the project. Students work in small teams usually consisting of 2-5 students. Their projects are typically sponsored by industry partners, government agencies, or can also be student-led, entrepreneurial efforts. Recent examples of sponsored projects within the Electrical & Computer Engineering department include: development of a statewide energy assurance plan, immersive virtual reality system for storm run-off modeling, algorithm development for early detection of Alzheimer's, and a large number of projects focused on the evaluation, design, and implementation of photovoltaic (PV) systems. Example Clinic projects sponsored by other disciplines, such as the Civil & Environmental Engineering and Mechanical Engineering departments include aquifer recharge analysis, fatigue and fracture mechanics studies on recycled concrete aggregates, and development of an automatic energy harvesting kite. A typical Clinic project sequence includes: development of a clear and concise problem statement, background information search and review; design approach development, analysis and simulation, prototyping, testing, and presentation of results via written report and presentation [3]. There are Professional Engineers (PEs) on the faculty to provide the required supervision for those projects that require sealed drawings, etc. From the engineering curriculum standpoint Clinic projects provide an opportunity to develop many important skills that expand, reinforce, and complement the student's educational experience. The junior and senior Clinic projects help students progress from basic problem solving techniques to the more advanced techniques needed to deliver a professional final product. At the same time, the Clinic experience helps students improve their technical writing and presentation skills as they work with a customer. Clinic also provides opportunities for evaluating economic, environmental, and societal impacts of their work. More details about the Clinic program experience can be found elsewhere [3-6].

Photovoltaic Clinic Project

In September of 2010, Kaneka Corporation, one of the world's largest thin-film amorphous silicon solar module manufacturers, sponsored the development of a research test bed through the Engineering Clinic to evaluate its multi-junction technology solar PV modules. This sponsored project was an ideal fit to Rowan University's Clinic program. A one-year project was defined as a multidisciplinary project available to junior and senior students from the four Engineering disciplines (ChE, CEE, ECE, and ME). The objective of the project was to design, permit, specify, install, and monitor a 1.65kW multi-junction PV system. This Clinic project provided students with the opportunity to research a cutting-edge technology solar module design, implementation, and performance assessment. One of the motivations for sitting the system on Rowan Hall, was to produce energy to offset the electricity cost for illuminate a memorial flagpole for Robert Dusseau, a former Rowan University Engineering student. Once Clinic students complete the design and installation of the array, the system will also generate funds via the Solar Renewable Energy Credit (SREC) program to help supplement a scholarship fund in Robert's name.

Solar PV Engineering Clinic Project Overview

The design of a solar PV system started with a fundamental review. Clinic students researched and reviewed the basic concepts behind solar PV and the theory of the operation of solar modules in order to gain knowledge and prepare for the assigned project. During their research phase, students learned that a PV system refers to the array of solar modules, their orientation and mounting, wiring and connectors, and the other key components (inverter, switches, fuses) that are used to convert sunlight into electric power and provide it to the grid. The multidisciplinary nature of the students group (the team included ECE, ChE, and CEE students) provided students with the opportunity to develop cross-over skills. For example, CEE students learned the dialog of power, and ECE students learned the dialog of structures. The design of the PV system consisted of a series of steps that are critical for determining the efficiency of the system in term of its output and in consideration of the system's installation and maintenance costs. The key steps followed for the design of the PV system at Rowan Hall were:

1) **Maximize Solar Resource -** Irradiance can be defined as the measure of the power density of sunlight and is measured in watts per square meter. Irradiation can be defined as the integration of the irradiance over all daylight hours. On a given time or day, irradiance will vary depending on the time of the day, time of the year, weather and shading. Typically, regardless of weather conditions, irradiance in the middle of the summer is much greater than in the middle of the winter. This is due the orbit and inclination of the earth. The inclination of the earth causes the sun to be higher in the sky in the summer than in the winter and therefore longer days during this period and shorter days during winter. Some of the key concepts students learned as part of the project include: solar modules consist of an array of PV cells, which are constructed of a semiconductor material (usually silicon). Sunlight is made up of energy packets known as photons; each individual solar cell is designed with a positive and negative layer in order to create an electrical field. As photons from sunlight are absorbed into the cell, they provide enough energy to allow for a flow, or current, of electrons towards the bottom of the cell and ultimately through the cell’s junction in the form of electricity. The generated current of electricity comes in the form of direct current (DC). However, electrical grid power is alternating current (AC) and therefore an inverter must be used to convert the current from DC to AC and step the voltage up to the required system voltage level. Efficiency of a PV system depends on the irradiance that it is exposed to. Maximizing the efficiency of a PV system requires that solar modules are installed in an area with no obstructions that may shade the PV array, since shading can significantly decrease the power output of a solar module. The orientation of the PV system is set to optimize the irradiation on the solar panels. Previous analysis performed at Rowan University showed that a 35° mounting angle is optimal for solar panels installed at 39.7°N latitude [7].

2) **Site Surveying and PathFinder Analysis -** One of the most important aspects that must be taken into account when designing a roof-top PV system is to identify the feasibility of its installation. During a site survey, the designer must gather as much information as possible about the potential sites where the system may be installed. The information that should be gathered includes geographical location, orientation of the building, available voltage levels, structural characteristics of the rooftop, and dimensions of the rooftop's various physical characteristics. When designing a grid-tied system, it is important to determine the available voltage levels and possible locations where the system could be tied into the grid. The efficiency and installation cost of the system will partially depend on how far the proposed PV system site lies from the grid connection, because the cable run distance is directly proportional to the voltage losses through the system. Thus, cable runs should be as short as possible. Choice of wiring is based on current capacity, impedance, and applicable codes. The Solar Pathfinder [16] is a tool used to determine the times when the PV array will be shaded. This tool may be adjusted depending on the latitude where the site under study is located. Clinic students conducted a Solar Pathfinder analysis to identify the available annual solar window on Rowan Hall based on existing obstructions that cause shading as the sun moves throughout the year.

The Solar Pathfinder equipment and complementary analysis software allowed students to determine feasible locations where solar PV could be installed. The governing constraint for this analysis was the 80% minimum solar window established by the New Jersey Renewable Energy Incentives Program (REIP). In order for a solar PV system to be considered for state and federal rebates and incentives, the average annual solar irradiance per square meter of system footprint must exceed 80%. As determined from the results of the shading assessment, the Rowan Hall roof provides over 4000 square feet of adequate solar window, which is more than enough for a 1.65kW solar PV array (the proposed solar PV array requires approximately 350 square feet of roof-top area). Several Solar Pathfinder readings were taken and were plotted on a scaled AutoCAD drawing of the Rowan Hall roof. The results of the solar window investigation are shown in Figure 1.

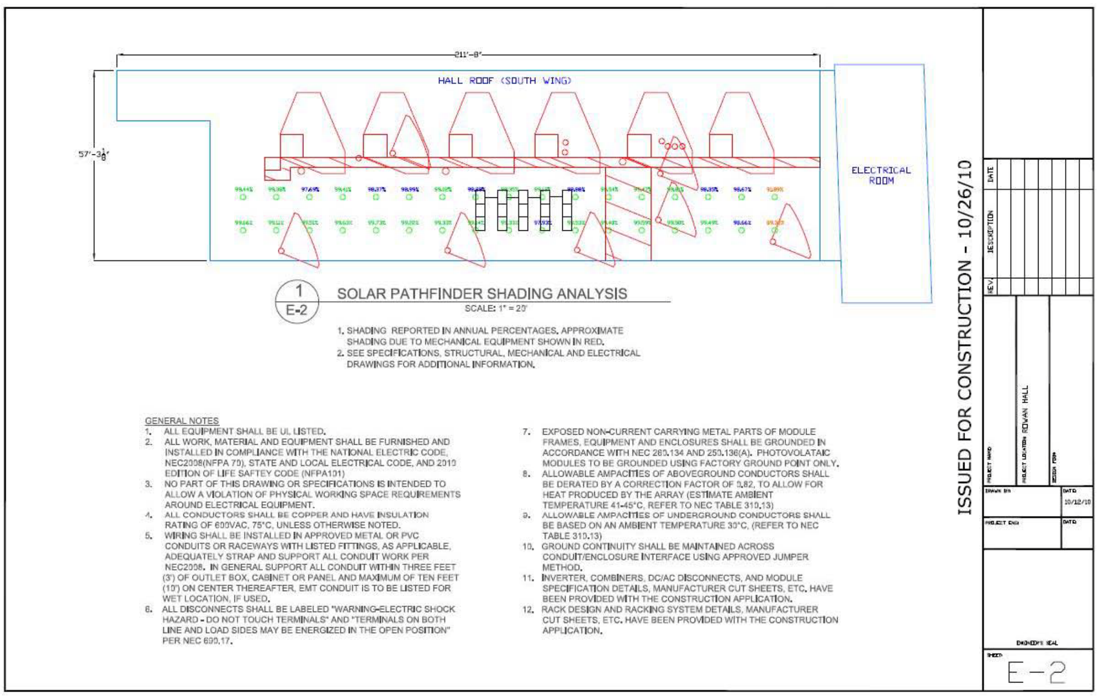

Figure 1: Solar Window Analysis Completed by Engineering Clinic Team

3) **System Design and Plan Development –** In order to develop the engineering design, the Clinic students carefully surveyed the Rowan Hall roof, to identify the locations of all shading obstructions. They prepared a mechanical layout in addition to the Solar Pathfinder analysis drawing. Transposing the Solar Pathfinder analysis results onto the mechanical layout drawing of the roof allowed clinic students to accurately identify feasible locations atop the Rowan Hall roof where the PV array could be installed. Due to the narrow nature of the Rowan Hall roof, students determined that the best array configuration for the required 15 modules would be five rows of three. Scaled drawings of the proposed PV system layout were developed after consulting the Rowan University Campus Engineer for recommendations and to ensure all system designs conformed to the NJ Uniform Construction Code. An example of one part of the

design is shown as Figure 2. The student team prepared a complete set of drawings as part of a proposal package to be sent to the NJ Department of Community Affairs. Design drawings included site and aerial plans, Solar Pathfinder analysis results, a mechanical layout drawing, a single-line diagram, a drawing of the electrical room where grid-tie will be made, and a structural comments section detailing the structural considerations for the roof ballasted system. The single-line diagram was prepared in accordance with the National Electric Code NEC 2008 handbook [8] and is shown in Figure 3. Figure 4 details the proposed electrical room where the grid connection will be made.

Figure 2: Sample Engineering Design Drawing Developed by Clinic Team

The engineering analysis included required Building Code structural considerations that needed to be addressed by the team. Expected live loads on the roof were calculated based on the weight of the system and in consideration of wind loads based on a 90mph wind regime given by a DCA wind map.

4) **Equipment Specification and Procurement** - Taking cost and compatibility into account, the Clinic team carefully compared all elements of the proposed system and contacted the appropriate parties to order the system components separately.. A KACO 1502xi Blue Planet grid-tied inverter was specified to convert the DC power from the solar PV array to AC power at the 208 VAC service level required by Rowan Hall. The selected KACO 1502xi inverter can accommodate up to three strings of solar PV; the proposed array can easily be configured in three strings although their physical configuration will be as five rows of three. Other inverters seemed to provide similar compatibility, but the KACO 1502xi was the best choice based on service and interface. Another task was to identify and procure data logging software and hardware. This consisted of a KACO pro-Log XL and both temperature and irradiance sensors.

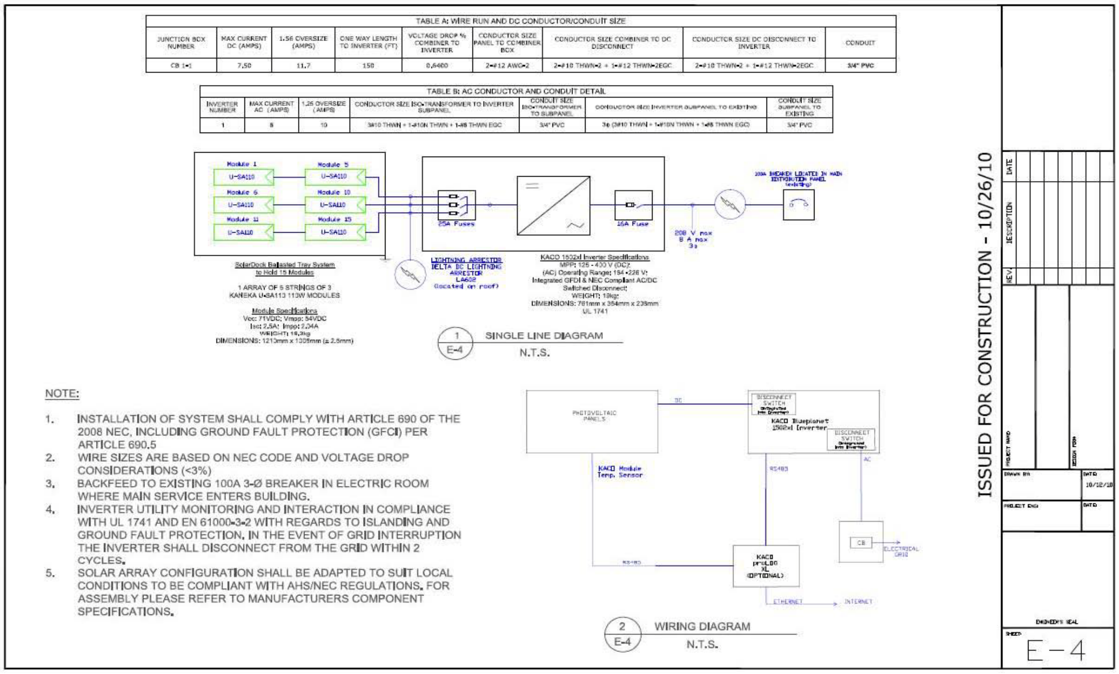

Figure 3: Single Line Diagram

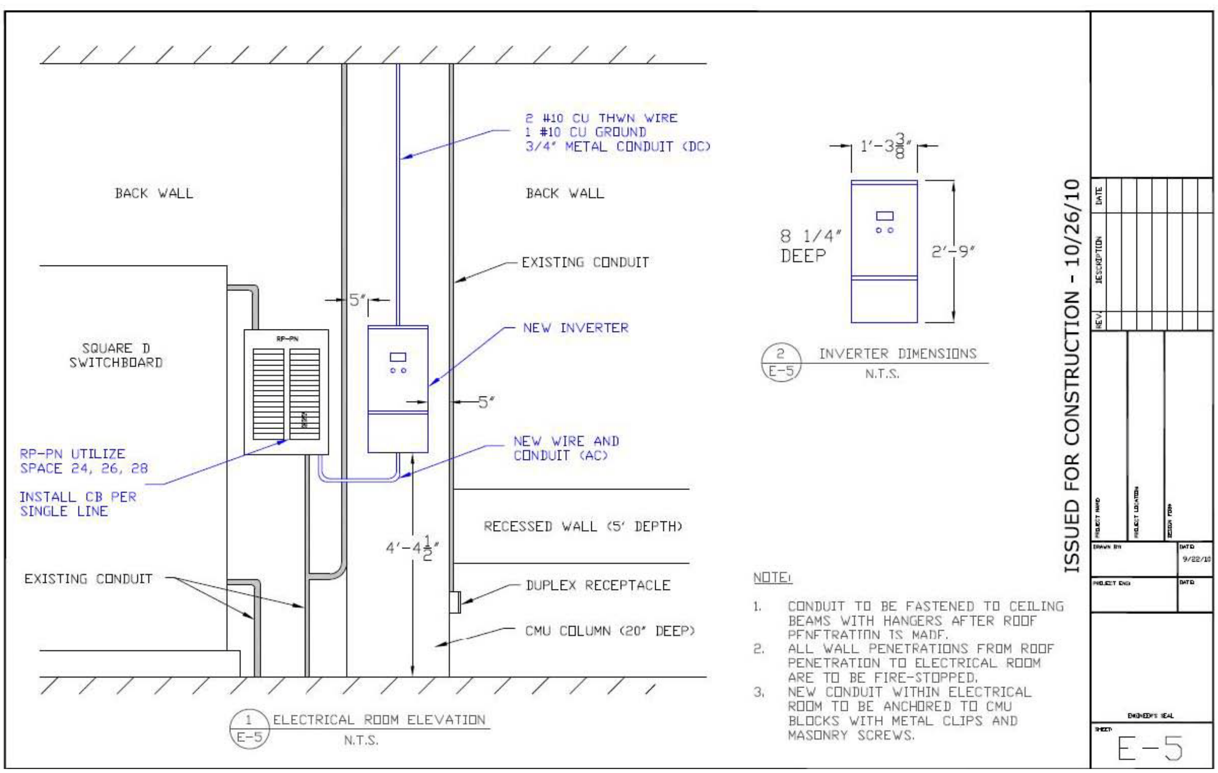

Figure 4: Electrical Room Interconnection Detail

SolarDock was consulted to fabricate the racking system to support the solar modules. Generic system components, including ballast, conduit, struts, wiring and other hardware are the part of ongoing project efforts. Preliminary wire-runs have been completed to estimate wire lengths required to tie the solar PV system to the grid. Other balance of system (BOS) elements will be procured locally.

Semester Project Progress

In September 2010, Rowan University advised Kaneka Corporation representatives that an estimated three to six month window to complete the system installation could be anticipated. Rowan University was provided with fifteen, U-SA110 multi-junction PV modules, each rated at 110W direct current output, with a total system rating of 1.65kW. The fall 2010 Clinic team completed the obstruction shading analysis, modeled the system layout using AutoCAD, purchased and procured other system elements, and submitted system designs to the NJ Department of Community Affairs (DCA). The DCA establishes and regulates building codes and to protect the health and safety of the public, state institutions and state workers. Any new construction on state owned property must pass design review and inspection through the office of DCA. For the preliminary design review and inspection of a small scale construction like the solar PV installation at Rowan Hall, DCA requires a set of design drawings, all relevant review applications, completed permit fee schedules and a letter of transmittal. All review applications and permit fee schedules were coordinated through the campus engineer. Design drawings were signed and sealed by the Clinic team faculty project manager, who is a licensed PE. The campus engineer completed the letter of transmittal and the complete proposal package was sent to the DCA.

Approximately three weeks after the preliminary submittal to DCA, Clinic students received word that all designs had passed DCA inspection except for the structural considerations. Spring 2011 Clinic students are making changes to the current plans to reflect input from the racking supplier (SolarDock), showing the required structural elements and connections. Once all corrections are made and a complete set of structural design drawings is available, the proposal package will be resubmitted to DCA. A construction permit is expected to be issued to allow construction to commence. Clinic students have made significant progress toward the completion of most of the project's key goals, including: full system designs, component specification, plan development, permit application, and equipment procurement.

Future work

The only outstanding issue before construction can commence is the final construction approval from the DCA. The complete installation is expected to occur midway through the spring semester of 2011. As per the grant contract, Clinic students will then collect data and monitor the solar array's efficiency, performance and resilience based on temperature and solar exposure for a 1-year period. Future Engineering Clinic teams will be responsible for this analysis, system maintenance and any required modifications and/or enhancement to the data acquisition systems or monitored parameters. Communication between Clinic students and the sponsor will be maintained.

Lessons Learned and Clinic Assessment

Rowan University Engineering Clinics provide students with a multi-disciplinary, hands-on experience that complements their classroom and laboratory experience. Rather than relying on laboratory-based testing or experiments that approximate an industrial experience, Rowan bring real-world projects into the Clinic. Benefits to the project sponsor are evident: Companies underscore the value they place on involving engineering students in their research activities. Benefits to the Engineering program also accrue. Resources such projects bring to campus help provide minor equipment and supplies, and can even be used to help provide labor dollars. We think the most significant benefits are realized by our students. Not only are they expanding into areas that are not directly addressed in the curriculum, but they also further hone their technical writing and communication skills as they work with a client. Another major benefit of similar projects is that students have used them as springboards to employment and to graduate studies. The leading solar PV provider in the area currently employs eight Engineers; six are Rowan University graduates that worked on similar sustainable energy projects as the one discussed in this paper.

Rowan University's Engineering Clinics encourage students to step out of their comfort zone and investigate other fields or specialties within Engineering. They have to in order to accomplish the deliverables promised to a real world client. A Clinic project immerses students in the reality of engineering projects, including scheduling, codes, and specifications. Coordinating permits and procuring components is an experience that is difficult to communicate in a classroom setting. In our assessment processes that include alumni surveys and interviews with employers, the Engineering Clinic is consistently identified as the key element that provides our graduates with competitive advantages when entering the job market. And these Clinic returns affect more than those graduates directly entering the industrial work force. The Clinic experience introduces our students to the research process as well. The result is that nearly 50% of ECE graduates continue into graduate degree programs (MS, MBA, PhD, etc.) [9]. A number of Engineering undergraduates have also published on their Engineering Clinic experiences in a range of conference and journal venues [9-15]. The Engineering Clinic also has been shown to provide students with the opportunity to strengthen their core "a-k" ABET competencies. In addition, the Engineering Clinic provides ample opportunities to deal with many of the "other" areas that a program needs to address such as ethics, economic considerations, and societal impacts.

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