Photovoltaic System Optimization through Undergraduate Engineering Clinics

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Abstract

At Rowan University students have been introduced to Photovoltaic System Design, through the Clinic Experience, at both the residential and commercial scale. The Clinic is a project based learning approach based on the Medical School Model [1]. These experiences have included the initial feasibility assessments and continued all the way to system installation, and now include the oversight of operation and maintenance of multiple systems. Rowan University is located in the state with the second highest number of installed Photovoltaic modules in the country and still short of its 2021 goal of 2.12 percent of energy from solar PV[2]. With this installed goal far away, but completion deadline rapidly approaching, the answer may lie in large solar farms. The challenge put forth to Undergraduate Clinic Students this fall is how to optimize Photovoltaic System Designs. Where other undergraduate students are learning the basics of PV, Rowan University Students have potentially had multiple years of experience with PV and are now ready to answer the questions that will shape the future of the industry. Areas of work this semester include, but are not limited to, novel racking design, increased by-pass diode implementation to reduce the effects of shading, and possible novel ballasting systems to lower installation costs and reduce work related injuries. This diverse and broad ranging project will be tackled by an equally diverse team of engineers from all four of the College of Engineering's Disciplines (Chemical, Civil and Environmental, Electrical and Computer, and Mechanical).

Clinic Description

At Rowan University every undergraduate engineering student is required to participate in four years of the Engineering Clinic. This educational approach borrows from the Medical School Model, where students spend the early part of their education in a structured classroom environment learning the fundamentals of their discipline. Once a solid medical, or in this case engineering, foundation has been laid students are ready to put their knowledge to use. The concept of applying knowledge learned in the classroom is by no means unique, but Rowan University's uniqueness is the stage at which these applications of engineering fundamentals are applied. Many engineering curricula culminate in a Senior Design during the final semester, or possibly beginning in the fall of the senior year, and ending in the spring with the final report. By the final year of a student's education only a fraction of the many lessons possibly gained from such a project are achieved. By this time a student has taken to many regimented classes which result in a sluggish ability to draw on that knowledge when finally given a unique problem. The next issue with such a late Design Project is the student may be already looking beyond school at employment possibilities, after years in a classroom the doer personality of many engineering students just want to start doing! The Senior Design Project is not without some educational merit, it does represent the first time the engineering student may do something that more accurately represents what an engineer does.

Clinic Advantage

Where Rowan University differs substantially is their implementation of this "Design Project ", or The Clinic, at the beginning of the junior year. Exposure to a "Real Project" at this point allows a student to see multiple projects instead of just one for a semester during their undergraduate degree. It also allows the individual to develop their professional identity, as well as a portfolio of project experience, prior to graduation. These two qualities are unique to Rowan University Graduates, which allow them to easily differentiate themselves from other degree holders, from other engineering schools. In this competitive job market it is no longer enough to just have a strong collection of course work. Candidates must also be able to show a track record of project experience and success. Which, without the clinic, may mean a graduate would have to work one or multi jobs before getting the most competitive one.

Clinic Structure

We have established that the clinic exposes students to projects in the junior year, but to truly be like the Medical School Model, it also has to cover additional fundamentals. Table 1 summarizes the eight semesters of the clinic experience, along with a short description of each of the core concepts covered through the semester.

Table 1 – The Engineering Clinic Experience at Rowan University [1]

	Fall Semester	Spring Semester
Freshman	FEC I Measurements	FEC II Reverse Engineering
Sophomore	SEC I Design w/written communication	SEC II Design w/oral communication
Junior	JEC I Sponsored Design or Research	JEC II Sponsored Design or Research
Senior	SrEC I Sponsored Design or Research	SrEC II Sponsored Design or Research

Freshman Engineering Clinics (FEC I and FEC II)

As freshman, regardless of discipline, students are introduced to basic concepts that apply to all engineers. Students work on projects that address engineering measurement and reverse engineering. An exemplar task would be to perform systematic testing of existing products with the goal of possibly illuminating areas for improvement [3]. During this year students are also lectured on professionalism and engineering ethics [4]

Sophomore Engineering Clinics (SEC I and SEC II)

By the second year students have an understanding of the basic composition of an engineer; their next area of development is communication. The first semester focuses on written communication, while the second emphasizes oral communication. During both of these clinics the engineering student takes a separate course that teaches the fundamentals of each communication type, a writing/literature course to teach writing and a public speaking course to complement the second clinic. All teams in a specific Clinic will be given the same well defined problem statement that is the subject of the entire semester. The individual student's grade will be based on their performance in both team and individual presentations or writings. At the end of this year students should understand that an engineer maybe called to act as project interpreter and advocate. So their ability to accurately convey knowledge with many different audiences may be directly correlated to their later career success. It is also at this stage that students work in their first inter-disciplinary team, a hallmark of the Rowan Clinic Experience.

Junior and Senior Engineering Clinics (JEC I, JEC II, SrEC I and SrEC II)

Once an upper classman, the student is prepared for full exposure to the most challenging Clinic Projects. At this level the Clinic team receives an open ended problem where the solution is not immediately apparent nor is it well defined. Topics address professor research interests and are often funded from external sources, such as State and Federal Government Agencies but many industrial partnerships have been created through the clinic as well. The process of project selection is also unique, because it relies on a mutual selection process. On the first Tuesday of the semester the Faculty member or Graduate Student, leading the project, presents the project to each engineering discipline at the school (CEE, ChE, ECE & ME). Each engineering discipline stays in a specific room though the process, and receives a slightly different project summary from the presenter. The faculty member or graduate student makes sure to showcase that disciplines potential impact area. Once the presentations are completed each student is required to rank their top three choices based on what they have just seen. It is not uncommon for students to stay intra-disciplinary, but each student is required to take a minimum of one out of discipline clinic. This requirement at times creates a level of disappointment or uneasiness, but can quickly lead to the discovery on an unknown passion. Once all of the selection sheets are submitted a panel of professors makes the final team lists, and by noon on Thursday the teams are announced, and students are to report to their first clinic meeting. Although it may seem chaotic when described it is actually very well orchestrated and serves as a good view into the pace at which project teams may be assembled. This pace and limited initial knowledge introduces them to another vital skill in engineering, confidence. Often the student will have to confidently make decisions after a relatively short learning curve.

Rowan University's Center for Sustainable Design (CSD) Description

At Rowan University, a number of sustainably focused clinics and projects are regularly offered from The Center for Sustainable Design (CSD). The CSD has laboratory space at the Samuel H. Jones Innovation Center, also known as the South Jersey Technology Park. More importantly than its research facility and space, is the CSD professor make up. With professor involvement from all four disciplines of engineering and across various colleges of the university, we are able to consistently offer a diverse suite of sustainably focused projects from numerous funding sources. The CSD's Mission Statement, as it appears on their website is:

> *To actively engage faculty, graduate students and undergraduate students in research and project based learning that will advance the technology readiness and adoption of sustainable energy systems and address the challenges of:*
>
> – *Achieving Grid Parity for Renewable Energies*
> – *Combating Climate Change through:*
>   *Efficiency, Conservation, Increased Asset Utilization*
> – *Creating New Technologies for the Smart Grid*
> – *Building the Business Case for Sustainability*

Rowan University's Center for Sustainable Design (CSD) PV Project List

It is through this passion and collection of professors that Rowan University students have had numerous experiences with photovoltaics in both the classroom and the laboratory. This extensive exposure to such an emerging technology is beneficial educationally and occupationally. Below is a table that highlights the various forms photovoltaics have been presented to students over the last six years.

Table 2. - Exemplar Photovoltaic System Clinic Design Projects [1]

Year	*Exemplar Photovoltaic System Design Projects*
2011	*Freshman Clinic PV System Design Laboratory (Spring 2011)* *Sophomore Clinic PV System Design Experience (Spring 2011)* *1.65 kW Photovoltaic (PV) System Permitting & Construction Rowan Hall (Kaneka)* *10 MW Photovoltaic (PV) System, Rowan University (Internal)* *PV Module shading analysis (internal)*

2010	*1.65 kW PV System Design & Siting Rowan Hall (Kaneka - Japan)* *10 MW Photovoltaic (PV) System, Rowan University (Internal)* *PV Module shading analysis (internal)*
2009	*12 kW Photovoltaic (PV) System SJTP (SunTechnics)* *PV System Design for NJDMAVA Headquarters* *PV System Design for W.J. Doyle Veterans Cemetery*
2008	*3 MW Photovoltaic Power Plant, Falls Twp., PA (SunTechnics)* *1 kW Photovoltaic (PV) System Installation - SJTP (Kaneka Solar)*
2007	*3 MW Photovoltaic Power Plant, Falls Twp., PA (SunTechnics)* *Design of PV Systems for Municipal and School Buildings (Ocean City)* *1 kW PV System Design & Siting (Kaneka Solar)* *Performance Monitoring and Data Analysis (RU Team House)*
2006	*3-kW PV System Construction RU Team House (Internal)*
2005	*Design and Siting of 3-kW PV System at Rowan University (Internal)*

Clinic Team Challenge

With the many projects already offered at various stages in a student's education some upper level students have multiple years of experience with the technology. This both forces, and allows, the faculty to move away from the basics of the technology to addressing the "real issues" of the industry. One such opportunity to address real issues stems from the CSD's repeated cooperation with a major area Solar Installer. The University is in the final stages of finalizing an agreement that will fund research into some of the immediate and future issues of their industry. Students in the ECE-11 photovoltaic system optimization clinic will work on novel designs for both racking and a ballasting alternative. Unfortunately, at the time this paper was written the students were only a quarter of the way into the semester and still in the research phase of the process, so progress on these tasks is minimal.

In this clinic, students are presented with a specific open ended project, but the potential solutions are vast. Since the students now work in interdisciplinary groups outside the traditional confines of a classroom, they are allowed to take a more individualized approach, however they generally go as follows. Upon forming the 2-5 student team, projects start out with an information search and review, followed by development of a clear and concise problem statement. From that point students research and design solutions to the problem and develop methods for down selecting alternatives, prototyping, testing, documentation, etc [3]. During the semester, students for the most part work independently. Meetings are kept to a minimum, in order to preserve as much of the scheduled Clinic time (3 hour blocks, twice weekly) for project work. At the end of the semester, all the teams that have worked and met independently, will come back together for a final required presentation of their work to a collection of their peers, graduate students and faculty.

When compared to traditional educational approaches, students have significant autonomy, yet teams still receive guidance from a professor and often a graduate student as well. For the second semester in a row, the CSD has four funded graduate students to oversee four different projects. The primary role of the Graduate Student is to help with the day-to-day project management functions in coordination with the faculty principal investigator. Graduate Student involvement in upper level Clinics is not a requirement, but their presence ensures a smoother functioning team and gives the graduate student opportunities to develop project management skills and experience directing a team to achieve well-defined goals within constraints. Undergraduate students benefit from working with Graduate students because fresh graduates are able to relate well to the challenges the Undergraduate students are facing.

By-Pass Diode/ Module Design

In a PV cell, electric generation is proportionally related to the amount of sunlight that reaches the surface of a solar cell and to the area of the cells in a module. Solar cells are typically connected in series to achieve a voltage target—e.g., a nominal 450 VDC string. The disadvantage of this configuration is that an interruption to a single cell in the series can result in the disruption of flow through the entire array. A PV cell is fundamentally a diode; when the diode is illuminated with sunlight, the PV cell becomes forward biased; on the contrary, when the light path is blocked via shadow or other obstruction, the cell becomes reverse biased [5]. What is unknown by most practitioners is just how significant an impact shading presents. Not only does shading negatively affect power output of the PV module, it can also potentially damage individual cells [5]. PV module manufacturers often include bypass diodes as one means of effectively bypassing shaded cells. By-pass diodes can also protect shaded PV cells from destructive reverse voltage. Even though they may increase manufacturing costs their potential positive impact outweighs the financial negatives. Studies conducted at the CSD have shown that the bypass diodes may be ineffective depending on the orientation of the module and the geometry of the shadow cast on the module's surface.

One of the challenges put forth to the clinic team this fall is the design of a more robust photovoltaic module. Students are responsible for the analysis and design of different PV module architectures with diverse bypass diode configurations. These modules will be modeled using appropriate design software, in this case PSpice. Once analyzed and optimized, a prototype PV module will be fabricated then tested in both real world and laboratory settings. Collaboration between students from Rowan University and Bucknell University will perform the tests.

Novel Racking Design

An additional topic for one of our fall clinic teams is the design of a novel racking system. Over the last ten years, the cost of installing solar has decreased by more than 50%, going from over $10 to about $5 /watt [6]. As module technology continues to innovate and prices continue to decrease, there is pressure to innovate on the balance of system (BOS) costs. The physical mounting system—termed "racking"—is one area that has potential for cost reduction. Students will perform a study of existing racking options available to determine strengths and weaknesses. Completing this study will illuminate opportunities for improvements based on material selection, fabrication, installation, power density, and other details that contribute to total cost. Students will complete a design based on the study results and then develop a prototype for testing. Construction will allow them to take the project from concept to full size physical model.

Novel Ballast Design

The final area for potential work this fall is the development of a novel ballasting option. When anchoring a system in cases where roof or ground penetration is not feasible, alternative means are required. Ballasting refers to the process of weighting the solar rack system to provide sufficient force to exceed anticipated wind loads. The amount of ballasting required is determined through an analytic assessment of the mass required to counteract the systems potential uplift. In a ground mounted system, perhaps installed over a closed landfill where penetrating the cap is a concern, large concrete blocks are often the preferred method of providing ballast. These large blocks can be easily positioned and placed with machinery. However, for a roof top system, many small concrete blocks are typically used to supply the necessary mass. The conveyance of the required block becomes an obstacle and poses risks of injury to the workers that must transfer and place the ballast. Students will be working on devising a system that offers an equivalent mass while minimizing the potential risk to workers.

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