# Cal Poly Multidisciplinary Renewable Energy Laboratory for Research and Education

**Jacques J. Belanger**
**California Polytechnic State University, San Luis Obispo**

**Andrew Davol**
**California Polytechnic State University, San Luis Obispo**

**Huy Duong**
**California Polytechnic State University, San Luis Obispo**

**Trent Hamilton**
**California Polytechnic State University, San Luis Obispo**

*A multidisciplinary renewable energy laboratory has been established at Cal Poly, San Luis Obispo to offer students the opportunity to work on projects related to the energy field that span several disciplines. Currently projects involving five engineering disciplines are being pursued with undergraduate and graduate students being advised by faculty members from across the college. We are utilizing many of the instructional modes available to us spanning from a single unit independent study to a master's thesis. This paper details some of these projects, highlighting the multidisciplinary nature of the energy field and the quality of the student experience.*

*Keywords: renewable energy laboratory, multidisciplinary laboratory, micro-grid laboratory, solar field power optimization, solar trackers, cloud coverage forecasting, Solar energy forecasting*

## INTRODUCTION

Renewable energy is a topic of increasing importance for students in several engineering disciplines. Solar and wind in particular are fields of high interest. In response to this demand, the mechanical engineering department at Cal Poly has created an Energy Concentration to allow students to focus on energy production, transformation and transport (Energy Resources Concentration, 2020). The concentration includes a wide variety of courses related to the energy field so students can acquire a broad expertise. In evaluating our courses, along with courses offered by other departments, we realized that they tend to focus on the discipline related to the department providing the course and that the multidisciplinary aspect of the energy industry is often lost. These courses, being focused on one discipline, also tend to limit the possibilities for exploring open ended questions.

In response to these concerns, we have created a renewable energy research and education laboratory to help students develop skills in the energy field, but more importantly to expose them to the challenges created by their knowledge gaps that are exposed by the multidisciplinary nature of the industry. For most of the students this is their first real experience on a multidisciplinary project. The goal is to expose as many students as possible to fields like solar and wind energy, energy storage and microgrid technologies. That experience will present them with real life challenges that will help them solve problems that arise in a multidisciplinary setting. To help create that setting, students and professors from several disciplines have been included. To date, students and faculty involved in the program come from mechanical engineering (ME), civil engineering (CE), electrical engineering (EE), computer science (CSC) and computer engineering (CPE).

The current resources available for the lab include a microgrid with its renewable energy sources and a utility scale 4.5 MW single-axis tracker solar farm (Veium, 2019) that was built on our campus. Although the primary role of the solar farm is to produce electricity, around 25% of the campus demand, it was built with research opportunities in mind so a tremendous amount of data coming out of the field is available to us. This data includes information about every inverter, every tracker, every transformer and the weather conditions, including irradiation and total sky images.

Using these tools, we have been able to develop a number of projects exposing students to challenges that the renewable energy industry is confronted with on a daily basis. This paper will discuss some of the most important projects undertaken to date. A brief description of each of those projects will be given with a focus on the challenges involved and how the students responded to those challenges. Overall, the feedback we received from the students involved in the program has been very positive.

The renewable energy laboratory officially began in the summer of 2018 with a team of professors and students working on the control system for a two-axis solar tracker. Since that summer a comprehensive plan for the implementation of a fully integrated microgrid was completed and it is currently under construction. The system includes a small wind turbine, fixed mount and tracking solar panels, a battery pack and a programmable load capable of simulating different electricity loads; for example, the demand required by a small off grid home.

Students and faculty from this lab have also been involved in a project to improve the power generation of the campus' 4.5 MW solar farm. Self-shading of the solar panels is occurring due to the uneven ground and that shading is impacting the power output of the field. The first goal in this research project is to better understand the issues related to the self-shading of the panels. That information will help us find ways to modify the tracking algorithm to minimize self-shading in the future so as to maximize the power output of the array.

Since the start of our program, the lab activities have included two graduate students, three senior projects, two in ME and one in CPE, two international students, three summer undergraduate research students, two ME students doing independent studies and two student clubs.

After laying out below the different modes of student participation we have explored, we will present a few of the projects in more detail and assess the perceived value of the students' experiences. Finally, we will present some of the current projects we are supporting through this program, highlighting the multidisciplinary aspects of each one of them.

## MODES OF STUDENT PARTICIPATION

### Senior Project

The senior project class used to support the microgrid development effort consists of a team-based design/build/test sequence that runs the entire academic year. The typical team size is 3-4 students. The students are presented with a large number of projects to choose from the first week of class and then teams are formed based on student preference and skill set. The students have 6 hours of lab per week coordinated by a senior project instructor that teaches this course as part of their normal teaching load. The course leads the students through the design process from identifying customer needs to testing of the final prototype. Many but not all of the learning outcomes of the course are accomplished through the project. All design reports and presentations are evaluated and graded by the course instructor. As a project sponsor, the microgrid team was responsible for providing an initial project description, giving feedback to the team through all stages of the design process, and providing funding for construction and testing of the prototype.

### Master's Thesis

Our master's program is 45 units and can be completed with 45 units of coursework and an exit exam or with 36 units of coursework and 9 units coming from a thesis project. The student can spread out the 9 thesis units to match the demands of the project. A thesis committee is established with 3 professors and the student must do a public presentation of the work and publish their thesis in the library.

### Independent Study

A student can register for 1-4 units of credit in an independent study course. A contract is developed between the student and the faculty outlining the work to be done. Each unit of independent study should be approximately 3 hours of work per week. These units are applicable as a technical elective.

### Summer Undergraduate Research Program

Our Summer Undergraduate Research Program (SURP) has been in place for the College of Engineering since the summer of 2018. In this program, faculty propose projects to be worked on by undergraduate students over the summer. Students then apply to work on the projects and are selected by the sponsoring faculty. University funding pays the students involved for 20 hours a week over 8 weeks. There is also a small stipend for the faculty sponsor. In the fall the students present their work in a poster session on campus.

### Student Clubs

Our university is known for the excellence of its student clubs. These clubs are required to have a faculty advisor but are normally motivated and run by students. Normally, there is no university credit given for club participation and the projects pursued by the clubs are staffed by volunteers. We envision the microgrid project as being attractive to several of the existing clubs including the Wind Energy Club and the Renewable Energy Club.

### International Students

We have had several international students involved in our lab. Their participation depends largely on their home university and what the individual student is trying to get from their experience. We had a student that worked in the lab for a whole summer and other students coming during the school year to take advantage of some of the courses we offer.

## EXAMPLES OF STUDENT PARTICIPATION TO DATE

One project we would like to highlight is the development of the controls for the dual-axis solar tracker. A senior project team associated with an earlier version of this lab designed and built a dual-axis solar tracker in 2016 (Mayer, 2016). This project focused on the physical structure of the tracker, not the controls. Initially the students had to study solar paths and environmental conditions to develop a set of customer needs. The customer needs then drove the design. Throughout the project the team was exposed to real-world constraints imposed by a limited budget and a firm schedule. Structural analysis was performed on the support structure and motion studies were used to select appropriate actuators for the two axes we needed to control. The students built and tested the structure shown in FIGURE 1.

**FIGURE 1**
**DUAL-AXIS SOLAR TRACKER WITH AUTOMATED CONTROLS BUILT BY A SUMMER UNDERGRADUATE RESEARCH TEAM IN 2018**

The controls for the dual-axis tracker where tackled by a team of two students involved in the SURP program. One mechanical engineering student and one computer engineering student. These students developed an Arduino based controller in the summer of 2018 that was completed during the fall and winter quarters of 2018-2019.

We prompted the two students that worked on this project to provide feedback on their experience so we could improve learning outcomes in the future. Student 1 was a female 2nd year computer engineering major and Student 2 was a male 1st year mechanical engineering major participated in the 2018 SURP program and both returned for independent study in the summer of 2019. The first summer focused primarily on developing the controls for our dual-axis tracking system. When the students came on board a small benchtop mock-up of the controls had been completed utilizing a wiPy microcontroller programmed in Python. The tracking algorithm was based on open source code (Willmott, 2017) that would provide the sun position based on latitude, longitude and time of day. The open loop control system was designed to determine the position of the tracker based on hall sensor output from the positioning motors. To avoid accumulated error through time the system reset each day starting from a known datum. The students were tasked with taking this prototype and developing the control system for the actual tracker which operated with a slew drive for azimuth control and a linear actuator for elevation. Other topics explored by the students included wireless communication between the controller and a base computer and the electrical connections required to get the power from the tracker into the microgrid.

The interdisciplinary nature of this project quickly paid dividends as we granted the students total freedom to design the hardware and software necessary to control the tracker. Student 1 requested to switch to an Arduino microcontroller due to her familiarity with this board and through consultation in her (CPE) department suggested we switch out a dedicated motor controller for less expensive relays.

Student 1 related her experience on the project:

> *"The SURP program gave me a chance to work with another student studying a different major. Because of that, we were able to share our expertise and knowledge of our field with one another. For example, Student 2 shared with me his understanding of the gear ratios inside the actuator and slew drive while I explained to him the behavior of different electronic components and how to solder them together. In addition, we discussed and*

*checked the Arduino code together to make sure that its logic was sound. Lastly, we also checked different criteria such as customer reviews, prices and usage popularity before purchasing new components."*

She also related challenges that she encountered during that first summer.

*"One downside of the project is that there wasn't a schedule for us to follow, so it was hard to keep track of where we were in the project or how close we were to the finish line. To cope with this, I kept in mind the goal of making a solar tracking controller, discussing next steps with Student 2 to move forward to our goal."*

Student 2 provided us with the following reflection:

*"I worked on the SURP project the summer after my first year, so I had not previously had much experience working on a larger project. Initially, the scope of the project we were given was seemingly very large, and it was difficult to see where to begin. Additionally, it was difficult to see our progress in terms of the end goal. However, the project was run in a way that gave Student 1and me authority over how to accomplish the goals of the project. The guidance we were given often pointed us in the direction of where to look for information, rather than being told explicitly what or how to do it. I found this method very beneficial, as it helped me to learn how to better form questions when seeking advice, whether from literature or from a professor. Additionally, I was able to better judge when I need to ask questions or seek help.*

*The interdisciplinary aspect of the project exposed me to directions I had not known I could go with my major. Since the project, I am now concentrating in mechatronics and minoring in computer science. This is in part due to the exposure to these fields I was given through working with Student 1, a computer engineering major. We had to find a way to communicate our ideas with respect to our different educational backgrounds, and she taught me about both her hardware and software knowledge. For example, I had never soldered before or used a microcontroller.*

*Throughout my time working on the project, I was better able to picture myself as an engineer in my professional career, and I become more confident in being able to share my ideas."*

From these comments it is clear that the open-ended nature of the project was seen both as a great advantage, as it offered some of the best life-long learning opportunities, and a great challenge as it left the students uncomfortable about their ability to complete the project. After reflecting on this we plan to develop more short-term goals for the next group of SURP students this summer while attempting to maintain the open-ended nature of the project. We understand the inherent challenge in establishing short-term goals that do not imply a solution path for the students and will remain mindful of this.

We expected the interdisciplinary nature of this project to be an invaluable benefit to the students and this is indeed what we found. In addition, we discovered that having a second-year student and a first-year student worked out very well. Student 2 clearly profited from having a student from a different discipline with more academic experience to help him in his career choices and Student 1 got the benefit of acting in the role of teacher/mentor as well as being exposed to more hardware from the mechanical engineering side that helped her decide to pursue a more hardware-based master's thesis.

To help provide more concrete conclusions as to the impact of their learning experience in future projects, we will definitely consider in vivo coding as a more rigorous approach for analyzing the student comments [5].

The second project we would like to highlight is the optimization work we are doing on the power output from the 4.5 MW commercial solar array on our campus. This array offers a very unique opportunity for us as we have been given full access to all of the performance data from this array. The array was built on a non-ideal site as the topography is quite skewed (See FIGURE 2).

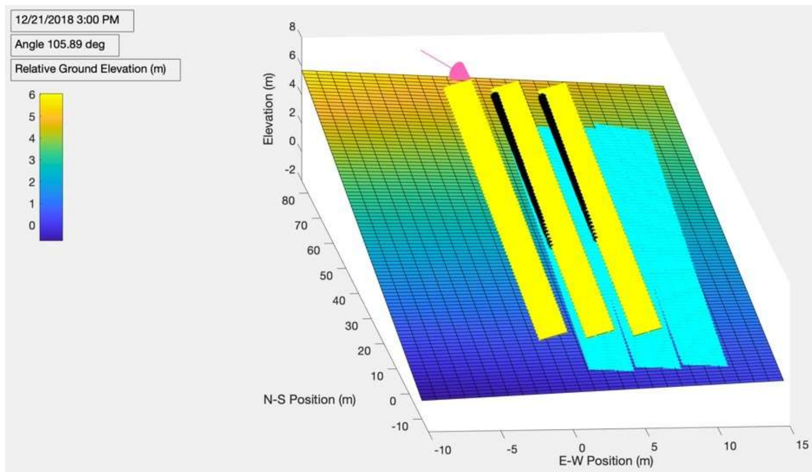
**FIGURE 2**
**TOPOGRAPHY OF THE X SOLAR ARRAY SHOWING THE SKEWED NATURE OF THE SITE**

Commercially available software currently does not have the capability to handle complex topography such as this and the array is underperforming its predicted output due primarily to self-shading issues where one row of panels is casting a shadow on the adjacent row as shown in FIGURE 3. Even minor shading can have dramatic effects on the power generation of the effected panels.

**FIGURE 3**
**EVEN MINOR SHADING FROM ONE ROW TO THE NEXT DRAMATICALLY DECREASES OUTPUT**

Over the past year we have developed a model to better predict these self-shading effects for highly skewed sites. FIGURE 4 shows our prediction for a particularly skewed portion of the array on the winter solstice.

**FIGURE 4**
**PREDICTION OF PANEL SHADING FOR SKEWED SITE ON WINTER SOLSTICE**

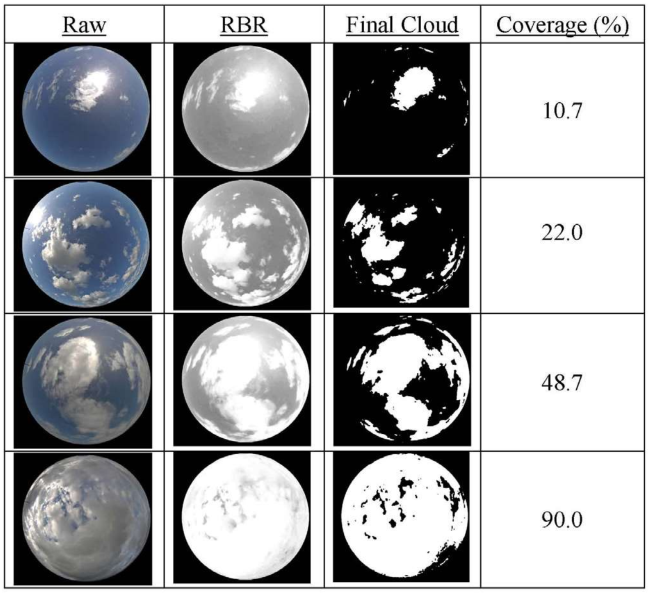



This model currently uses a rough estimate of the actual site topology and does not include power loss estimates based on the predicted shading. To complete a model that can accurately predict the performance of a challenging site like ours we have successfully recruited a CE colleague to help develop an accurate 3-D render of the site and an EE colleague, who has already been doing extensive work on this array, to develop a model to predict power output based on current irradiation, sun angle and the shading pattern on each panel.

To date one mechanical engineering SURP student, one international student and one mechanical engineering graduate student have been involved in this effort. We plan to add to this team in the near future with students from EE to work on the effects of the shading and sun angle on the power output of the panels and CE to help with the field layout and the "as built" conditions of the field. The students needed are at both the undergraduate and graduate level.

The last project we would like to highlight is the research dedicated to developing a tool capable of forecasting, up to 30 minutes in advance, the actual power generation of a typical utility scale solar field. This would be an invaluable tool for grid operators that need advance notice to bring alternate power sources online when a large solar field is shaded by clouds. As envisioned at this time, the tool would use one or more Total Sky Imagers (TSI) and novel Machine Learning (ML) algorithms, specifically Deep Learning (DL), to forecast future cloud coverage. DL algorithms have been proven to produce good results solving spatiotemporal problems like this one. This approach is used instead of the more traditional method of cloud identification and movement projection. Over the last year and a half, two CPE/CSC students involved in their senior projects have worked on this research. Due to the complexity and the multidisciplinary aspects of the project, they have been working closely with both CPE/CSC and ME professors. An ME student working on an independent study course has recently joined the team to help with the camera optical calibration and other related issues. We are also currently seeking funding for a CPE/CSC master's student to expend this work.

**FIGURE 5**
**EXAMPLES OF THE IMAGE PROCESSING APPROACH**




The first results coming out of the project are very promising. Jonathon Scott, the initial senior CPE student to work on this project, developed a novel image processing approach (Scott, 2019) to analyze the images. FIGURE 5 below demonstrates several examples of the approach he used to analyze the data and calculate the final cloud coverage. Once an image has been trimmed, it is ready to have its Red-Blue Ratio computed and have the resulting image mapped into two categories with the use of a threshold. The final image consists of an image with two pixel values. White pixels show where clouds have been detected and black pixels denote the absence of clouds. FIGURE 5 also shows one of the issues Jonathon encountered in his work, notice that the sun in the top set of images is falsely identified as a cloud using this approach. A way to address this issue will need to be implemented in the future.

**Additional Projects**

In the summer of 2019, Student 1 and Student 2 returned to do more work on the microgrid project. They utilized Homer (Homer Energy, 2019), a software package developed to design microgrids. The software helps to choose appropriate components including an inverter/charge controller and battery banks. A free version of the software (Homer Legacy) is available for educational use. Homer allowed the students to model local weather conditions, including solar and wind resources, to estimate the energy demands of a small family living in a tiny house. Their analysis was used to identify the different components needed for the microgrid.

A mechanical engineering senior project team is halfway through a year-long project designing a fixed-mount for solar panels. This mount will be adjustable so we can measure outputs from a variety of panels for a wide range of sun azimuth and elevation angles. This data is essential to improve the accuracy of our production model for single-axis commercial arrays.

## CONCLUSION

It must be understood that this is a hardware intensive effort and the cost is not trivial. Financially, we have been supported by an important contribution from our local utility and by a number of internal funding sources. The local utility, with its generous support, was actually a key driving force behind the creation of our new Energy Concentration. Additional funding is being pursued at this time on a number of fronts to broaden the scope of the research program and increase the number of students involved. The demand for such a program is coming from a broad range of students that is increasing in number every year. The challenge for us is in partnership with the Energy Concentration program to find the necessary resources to sustain the growth of our research program. On the educational side, we are slowly developing new energy concentration courses focused on renewable energy. These new courses will use the lab for their experimental sections. The demand these days for these new hands on renewable energy courses is very high at our school.

In conclusion, we can claim that the program has been very successful both by the technical accomplishment and the learning experience provided to the students involved. In our view and in the view of the participating students, it is a very effective way to learn how to work on a multidisciplinary team and to learn more about the renewable energy industry. We have plans to expand the scope and the number of students involved in the program both on the educational and research sides. Extra financial and human resources will be needed to implement those envisioned expansions in the near future.

## ACKNOWLEDGEMENT

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