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Adapting Capstone Design for the Solar District Cup Competition

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Abstract

The US Department of Energy Solar District Cup is a nationwide solar design competition for engineering students. This article describes one faculty member's experience integrating the competition into a capstone design course for the first time. Some key challenges were adapting the course assignment structure to match the overall proposal report requirements and taking advantage of the competition timeline regarding how to best structure the course instructional time. Besides developing students' experience with solar design, some advantages of the competition were the availability of access to professional design tools, support from the competition in the form of training materials and office hours with professionals, and the overall breadth of design aspects that students were expected to consider. In addition, the inclusion of distributional energy equity as a component of the proposal presents a strong opportunity for instruction and assessment related to ABET Student Outcomes. The Solar District Cup was a positive design experience for students and the lessons learned as described in this paper may help aid others integrate it into capstone design courses.

Introduction

The world is undergoing an energy transition, motivated by both climate and economic incentives. Recent studies show that as compared to a baseline of continued fossil fuel use, trillions of dollars of global savings are available by pursuing a fast transition to renewable generation [1]. Declining costs are expected to continue [2], [3] and further promote this transition. Solar energy represents a contribution towards such a transition and is a major growth area for energy generation in the United States. The Inflation Reduction Act, passed in summer of 2022, has allocated hundreds of billions towards clean energy incentives [4] that will stimulate growth of renewable energy in general, including solar photovoltaics (PV). The Department of Energy estimates that the US will need 1,600-3,000 GW of total installed solar capacity by 2050 to meet climate goals [5]. Reaching this amount would necessitate quadrupling the current annual solar deployment rate. Growth in solar jobs to meet these needs is already happening [6] and is expected to continue.

Because solar represents an intermittent source of electricity generation, the growing share of solar and other renewables on the grid presents a variety of operations and stability impacts. A new generation of engineers needs to be trained to meet these challenges, in order to enable this transition to renewable, carbon-free electricity generation. Since the challenges posed by renewables are multidisciplinary in nature, it is necessary for faculty to think outside the box of traditional engineering disciplines and look at the ways that cross-disciplinary training is necessary to prepare these graduates.

Penn State University's Hazleton campus offers a multidisciplinary undergraduate engineering program with a specific focus on alternative energy and power generation. This program had its first graduates in 2014. Since then, we have undergone a continual growth process for Capstone Design, consisting of efforts to better integrate real-world projects that have a strong alternative energy focus and that can prepare graduates to work in the renewable energy sector. In the 2022/2023 school year, capstone faculty became aware of the US Department of Energy Solar District Cup [7], [8] competition and went through a process to integrate this competition into the program's Capstone Design. Several challenges were encountered during the process, leading to the goal of this paper: to share an overview of faculty experiences integrating this competition into Capstone Design and provide a few lessons learned that may help smooth the adoption for others.

Background

What is the Solar District Cup[1]

The Solar District Cup [8] is a design competition, targeted to "multidisciplinary teams of upper-level undergraduate students," though graduate students are also eligible to participate. Teams are challenged to design a solar plus storage system for a district use case (DUC), including considerations of engineering, economics, sustainability, energy equity and others. The teams were either assigned a structured DUC for the competition, or could define their own, subject to terms set by the organizers. The assigned cases included a description of the district/client, along with site geography, transmission infrastructure and the electrical demand. Teams were provided with access to software tools that could be used for technical and economic analyses including: Aurora Solar, REopt, Energy Toolbox, System Advisor Model (SAM) and OpenDSS. Participants were also provided with a spreadsheet-based finance model for solar development based upon typical investor/customer relationships for solar projects. Organizers of the Solar District Cup held periodic training sessions and "office hours" for participants to learn more about these tools and ask questions. They also provided an extensive set of archived training materials.

Teams were able to choose between participation for the full academic year, or participation for only the spring (beginning in January, 2023). The team described in this study participated for the full year, so the following description is somewhat focused towards the full-year process. Initial communication to teams began on August 26, 2022, with assignment of the use cases provided on September 7th. The team was required to submit a "Progress Deliverable Package" on November 17th. The competition provided detailed feedback on December 15th, 2022. Teams who submitted a complete package were moved onto finalist status for the spring, joining with teams who only participated for the spring semester. During the spring, teams produced a "Final Deliverable Package," with a due date of April 20th, 2023. A virtual presentation for the competition judges was assigned for April 27th. During the Progress Deliverable Package phase, inclusion of storage (i.e. batteries) was an optional part of the

[1] Disclaimer: Descriptions in this section are intended to provide context based upon the information provided to a faculty advisor for the 2022/2023 competition. Any interpretation of the rules, or plans for future changes to the competition, are at the discretion of the organizers.

competition. However, design and discussion of storage was a mandatory component of the design for the Final Deliverable Package in the spring.

The Final Deliverable Package included the following four sections:

Project Proposal

This document included an executive summary, front matter about the team and overview narratives describing the entire proposed design for the district. The virtual presentation was considered part of this package element and consisted of similar content.

Conceptual System Design

This document included a description of the design process followed and details of the system equipment (e.g. one-line diagrams, site layouts), along with models of system performance (e.g. utilizing the analysis tool outputs). An additional section required students to describe the impacts of their system on the interconnected distribution network and its hosting capacity at a high level. Students were also expected to produce a spreadsheet containing calculations of the system's production and battery cycling.

Financial Analysis

This portion of the package consisted of a spreadsheet used for analyzing the financial outcomes of the proposed system from both the developer/investor and customer perspectives.

Development Plan

This document described compliance of the system with codes, regulations, ordinances and standards as well as a timeline and plan for construction of the system. Participants are also asked to describe the design in the context of the client, including distributional energy impacts of the development and a plan for how the affected community will be engaged.

Capstone Design in our Program

In order to understand the lessons that were learned in implementing the project, a description of Capstone Design within our program will be provided. Our Capstone Design consists of four student credit-hours split into a 1 credit fall semester course and a 3 credit course in the spring semester. Students are all in their final year of study in a Bachelor of Science in Engineering program and teams are formed at the beginning of the fall for the entire year. Both fall and spring Capstone courses are important to the program's assessment and data collection related to ABET accreditation for the program, so it is important to maintain several mapped learning outcomes for the course. The course is also specifically designated within the curriculum to include focused outcomes related to writing and communication.

The fall course has historically been focused on literature review and concept generation, culminating in a proposal for a concept that would be designed in more detail during the spring semester. Typical assignments for the fall have included a customer analysis, literature review, concept evaluation and proposal plan. Traditionally, the major spring assignments were focused on communicating the final design, such as creating a poster for the campus research fair event, a presentation for a campus engineering alumni event and overall written report and presentation detailing all aspects of their completed design.

Lessons Learned

Since the faculty member for the course had no prior experience with the Solar District Cup, there were some challenges encountered that made the flow of the fall course less than ideal. Adjustments were made for the spring that improved the integration of the competition into the course. With the benefit of hindsight, the instructor believes that some of the fall challenges could have been ameliorated, leading to a better overall student experience. The intent of this section is to provide some of this insight to other faculty who may wish to participate in the competition such that they can better allocate and optimize their class time for student success.

Find Ways to Emphasize the Design Process through Extra Assignments

As stated, our program's capstone design course was traditionally structured to help students focus on the engineering design process by following a simplified version thereof: Gather Information, Generate Concepts, Evaluate Concepts and Implement the Design. Both the Progress- and Final Deliverable Packages for the competition emphasize the production of a final proposal related to the design. Consequently, requested topics of discussion focus on end products of the design, and need to be a focus as early as the fall semester.

Depending on the course instructor's approach to evaluating student learning, this issue may mean that faculty need to either identify locations where the competition deliverables overlap with existing course objectives, or create additional assignments. For future participation in the project, it is definitely recommended that faculty create separate, smaller milestone assignments that encompass the early steps of the design process to ensure that students don't overlook the importance of these steps. These should be assigned early enough in the semester that they can still be completed incrementally towards the overall project goal. One positive is that the competition-provided training activities strongly encourage students to explain their assumptions and engineering judgments that were made in justifying the design. Thus, students can still be evaluated on these elements of their reasoning about the end product that are incorporated into the competition deliverables.

In the interest of minimizing duplicated or unnecessary student work, it may also be useful to consider the various elements of the Deliverable Packages that may have some overlap with the preliminary and intermediate design process steps. In the case of the Development Plan document, students are asked to reflect on the integration of the design with the community and the overall district development plan. The author suggests this as a good place for integration of assignments related to client analysis. Additionally, evaluation of multiple concepts can be discussed in the Concept System Design document. In any event, faculty guidance is likely required to guide students towards these early as steps in the overall design process, as the deliverable specifications may not naturally lead students to perform these preliminary steps in an appropriate order.

One strength of the detailed structure of the Deliverable Packages is their relationship to real-world report requirements. Professionals commonly need to write documents that are highly structured or subject to a large number of length, style and content limitations. This may be particularly true when considering responses to government or industry requests for proposals, and these assignments represent useful professional preparation for students that can help them develop important communication skills.

Plan for Phased Availability of Tools

Access to some of the tools and the use case assignment were phased throughout the fall semester. For example, in our case, the use case was assigned on September 7th, access to Aurora Solar (the PV design software) was granted on Sept 30th and access to Energy Toolbox (for energy system optimization) around October 31st. Due to inexperience with the competition, faculty did not plan well for this timing when creating the fall course schedule. With the benefit of hindsight, the delayed tool access could have been used to provide more structured 3-4 week "crash course" on design of solar energy systems and provide some more critical background knowledge for the topics in advance.

One example is that the Concept System Design document requested that students produce a spreadsheet with hourly energy production for a sample year. Besides using output for this type of analysis from the Aurora Solar or another tool, developing the equations for a manual form of this spreadsheet would be a good starting point for teaching students about the solar resource, solar position and shading. Such an activity would not require any of the special knowledge related to the ultimate district assignment and could easily be adapted when the final district data becomes available.

A second opportunity for instruction prior to data access is in the area of finance and Life Cycle Analysis. The financial model provided by the competition organizers includes a highly detailed financial analysis from the perspective of the solar developer/investor, but was somewhat simplified with respect to the perspective of the energy customer/off-taker. Some of the other tools such as ReOpt and Energy Toolbase provided more detailed customer analysis approaches. It was found that students required more structured instruction aimed at developing understanding of financial benefits to the various interested, knowledge of different electricity billing schemes (e.g. energy vs. demand charges, time-of-use billing) and how they might impact a design. Instruction on these topics was another area that was identified as a good area to pursue prior to data availability.

One final area of preparatory instruction can synergize well with the previously mentioned need for assignments focused on the preliminary steps of the engineering design process. District assignments were made in about the 3rd week of the semester. This allowed for time to analyze the customer's values prior to students trying to perform a more detailed design using the tools that became available later. A comprehensive customer analysis assignment was used in the fall semester during this time period and was deemed to be a successful part of the project implementation.

Distributional Energy Equity offers opportunity for ABET Assessment

One of the requirements for the Final Deliverable Package (in the Development Plan) was a discussion of Distributional Energy Equity impacts of the design. Our capstone courses implemented a Value Sensitive Design [9], [10] approach to analyzing the stakeholders for the design. Students completed a detailed stakeholder and value analysis for the client, and produced a set of customer needs that was used to guide subsequent stages of the design process. Besides representing a literature-based practice for analyzing the client and impacts of the design, this approach provided useful artifacts for the program's assessment of ABET Student Outcomes 2 (an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety and welfare, as well as global, cultural, social, environmental, and economic factors) and 4 (an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts).

Summary

Faculty hoping to implement the Solar District Cup in capstone design courses can look forward to an engaging, detailed design opportunity for students. Faculty using the project in the fall should prepare for some time at the beginning of the semester during which the competition is still spinning up. Some suggestions for efficient use of student time are: instruction about renewable financing strategies, life cycle analysis and investor vs. customer benefit perspectives, and instruction related to modeling of PV generation using a generic solar array. Additionally, as the district assignments became available well before access to the solar design tools, several weeks are available for instruction related to gathering information about the design, as well as customer analysis. The competition requires deliverables related to many areas of solar development and so it represents a comprehensive design experience for students. One notable deliverable is the discussion of distributional energy equity, which provided an opportunity to integrate the project well with ABET outcomes.

Conclusions

As a design competition focused on renewable energy, the Solar District Cup presents a significant opportunity for students to get involved in design of alternative energy systems. Knowledge in these areas is very important for students with an interest in careers in the energy sector, who will experience impacts due to the world's ongoing alternative energy transition. The Solar District Cup competition was successfully implemented by the author in a year-long Capstone Design course and some lessons learned were described by this paper.

The assignment structure for the course had to be reorganized in order to match with the deliverables for the competition. In particular, customer analysis and literature review sections that had previously been utilized were mapped into the competition's deliverable structure. Additionally, planning ahead for preparatory instruction on the topic of solar energy design is recommended to make good use of time during the fall semester prior to the analysis tool and data availability.

Overall, the Solar District Cup was a rewarding experience for students and provided them with a great deal of content experience in solar energy design, project finance and economics. Besides the educational benefits, the emphasis on energy equity also provided an opportunity for integration with assessment of ABET outcomes 2 and 4, which relate to ethics and design impacts on stakeholders. It is hoped that the experiences students gained during the competition will aid them in pursuing renewable energy careers and helping meet society's future needs throughout the renewable energy transition.

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