Training a new generation of solar developers with the latest tools and practices provided by DOE's professionals: The UPRM experience

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***Abstract*— This innovative practice full paper presents the Solar District Cup Collegiate Design Competition (SDC), sponsored by the U.S. Department of Energy (DOE), and how the National Renewable Energy Laboratory (NREL) is providing tools, training and advisory to the participating teams on how to develop forward-thinking designs for an optimized distributed energy system. The SDC competition provide access and trainings to premium software platforms like Aurora Solar for system designs and to open-source platforms like OpenDSS for impact analysis, System Advisory Model (SAM) for financial analysis, and to the Renewable Energy and optimization (REopt) tool to obtain recommendations on how to find the optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings, resilience, and energy performance goals. The purpose of this paper is to share the knowledge acquired by the authors by participating in the competition, described how this project was integrated in an engineering curriculum as a Project-Based Learning (PBL) elective course and its benefits, and to incentivize other universities to participate in future SDC competitions.**

Keywords*— *Solar Development, Energy Storage, Renewable Energy, System Design, Project-Based Learning

I. Introduction

The Solar District Cup Collegiate Design Competition (SDC) was first announced on May 30 of 2019 by the Department of Energy (DOE) of the United States as a way to train the new generation of professionals that will be in charge of transforming the nation electricity grid and to address the structural employment gaps for professionals in the energy industry [1, 2]. The competition is managed by the DOE's National Renewable Energy Laboratory (NREL), and they encourage all engineering students to participate as well as students from finance, urban planning, sustainability, and other disciplines or degree programs that can contribute to the energy industry [3]. The SDC invites participation of teams composed of at least three students enrolled in accredited U.S.-based collegiate institutions. Students must be enrolled in at least one class and be pursuing a degree for the duration of the competition. Students and faculty advisors are not required to be U.S. citizens at the time of the competition. Members of the judging panels, competition organizer staff, and DOE and national laboratory employees are ineligible to compete.

The SDC challenges multidisciplinary collegiate student teams to develop forward-thinking designs for optimized distributed energy systems, therefore, teams must assume the role of a solar-plus-storage developer and present a proposal of the most reliable, resilient, and cost-effective system possible for the district use case assigned by the competition organizers. District use cases are entities (e.g., urban districts, universities, etc.) interested in pursuing distributed renewable energy solutions who are willing to collaborate with NREL by providing energy use data for multiple buildings, electrical infrastructure, and master plans to serve as the basis for the solutions of the teams participating in the competition. Each team competes against other teams in one of three divisions, each division is structured around a single district use case. A division judging panel selects winning teams after the teams submit their final deliverables and present their designs via live video conference. In the 2019-2020 SDC edition, the three voluntary district use cases were Crystal Parks in Arlington, Virginia, New Mexico State University, and Ball State University in Indiana. For the 2020-2021 SDC edition, the three voluntary districts were the University of Central Florida, the

University of Nebraska Lincoln, and the City of Denver and Auraria Higher Education Center (AHEC) in Colorado. The following sections will discuss how this competition was integrated in an engineering curriculum elective course and the educational content that was provided in the competition by the organizers. For purposes of this paper the district use case of the City of Denver and AHEC was used to illustrate the topics discussed.

II. Project-Based Learning Course Integration

Everyday more and more industries throughout the world are demanding engineering graduates to have real-world experiences and to be better prepared to support their organizations. The incorporation of real-world projects into technical engineering curricula provides a unique and invaluable enhancement to the educational experience of students. Project-Based Learning (PBL) courses have been reviewed extensively and they have shown to prepare students better for the industry than traditional engineering program courses since it teaches them more in-depth technical skills about specific topics, how to solve ill-structured real industry problems, and how to work in collaborative environments [4 - 11]. By participating in this competition students have the opportunity of working in real-world solar projects and experience the problems that solar developers in the industry face every day. They will learn how to choose the optimum location to place a photovoltaic system, how to design a photovoltaic system, how to assess the impact of the proposed system, how much it costs to construct that system and how to make an official proposal of a system to a client. The skills that students will learn in this competition are not being teach in many traditional engineering programs around the world and it would be beneficial to include this project in their curriculum as a PBL course. The project could be integrated into a senior design course or capstone project, count as an elective course or an independent study course, be added to the curriculum of existing classes, or be considered an extracurricular student activity.

After evaluating the project, the University of Puerto Rico at Mayaguez Campus (UPRM) concluded that the integration of this project into an elective course for engineering students satisfies all the evaluation criteria of the Engineering and Technology Accreditation Board (ABET), therefore, a renewable energy systems elective course was created in which 6 engineering students from different fields enrolled in it and 5 more students participated in the project as volunteer researchers [12, 13]. To provide support to the undergraduate students and help the professor in the course management activities, 3 graduated students provided support to the professor as teacher assistants (TA) and they were in charge of organizing weekly meetings, clarifying doubts, provide technical advisory, and monitor student participation and task completions. The grade of each student was given based on participation, tasks completion, team members evaluation, and feedback of their work from the judges of the competition.

The competition was hosted in Herox webpage, and the educational content was provided by NREL through the Heatspring educational platform [14, 15]. All the training sessions were provided live on a weekly basis, recorded, and made available in Heatspring days later, along with trainings given the previous year for the use of the participants. All the training sessions were divided into the steps of the recommended approach for a solar development project. The recommended approach to execute the project was defined by the training providers as a waterfall 4 step process (a macro view) which can be defined as: 1) Conceptual System Design, 2) Distribution System Impact Analysis, 3) Financial Analysis, and 4) Development Plan. As it can be seen in Fig. 1 the outputs from the steps 1 and 2 are evaluated by their next step and if they do not pass certain criteria the team must go back to the previous step and make changes to the current solution until the criteria of the next step is met.

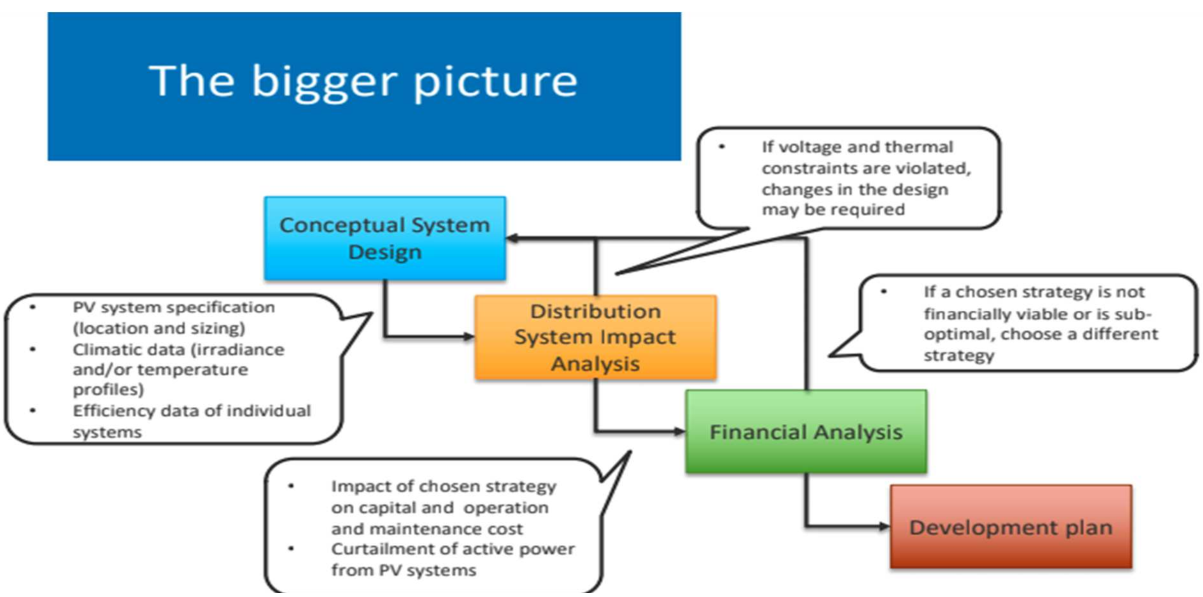

Fig. 1: Four-step waterfall process to develop a distributed energy system.

Each division had professional experts who provided office hours to clarify doubts, provide insight, and answer student questions. For each section there were also optional assignments that the student can do for further practicing. At the end of the competition the student is quizzed to evaluate the knowledge acquired during the semester. If the student did pass the quiz, he/she would be given a certificate of completion. In the next section the methodology and best practices provided by NREL will be discussed, is important to mention that this is a general approach to develop a distributed energy system and not an exhaustive list of things to do since each project will have different variables like requirements, goals, location, applicable laws and regulations, weather, etc.

III. Methodology and Best Practices

A. Identifying project goals, resources and restrictions

Before starting the developing stages of the project is important to identify what are the project requirements, goals, resources, and restrictions. For the case of the city of Denver and AHEC the goal for the project was to develop the most reliable, resilient, and cost-effective system possible and design a battery storage system that could support the Science Building (AHEC) critical loads during a grid outage, these loads comprise 30% of the building load profile and they have an estimated worth of $1,000,000 in equipment. In this case a specific/minimum amount of energy needed to be offset by the system was not specified by the client, but this is not always the case and it depends on the client needs.

The area assigned by the challenge can be seen in Fig. 2 and is divided in the middle by the Speer Boulevard into two different zones, on the left side is the zone of AHEC and on the right side is the zone of the city of Denver. Both zones have their own restrictions regarding solar exports, for AHEC solar exports cannot exceed 25% of the daytime minimum load of the campus at any given 15-minute interval throughout the year and for the city of Denver solar exports are not allowed at all and therefore the system must be developed as a community solar system [16]. These export restrictions vary by state and by service providers.

B. Development Plan - Site Analysis

The Site Analysis is considered to be part of the Development Plan but it is recommended to develop it before the Conceptual System Design since its main goal is to identify factors that could cause permitting delays and could increase development risk, allowing the developing team to discard risky areas before they are taken into consideration in the design stage. The recommended factors to investigate before starting the design stage are:

- Authority Having Jurisdiction (AHJ) – To identify which organization, office, or individual is responsible for enforcing the requirements of solar development in the site area.
- Site Conditions – Investigate the topography of the site to identify if: it is leveled, it has adjacent buildings (commercial and residential), it has interconnection points, it has vegetation surrounding the site, it has abandoned pipelines, wells, or irrigation ditches that could affect the project.

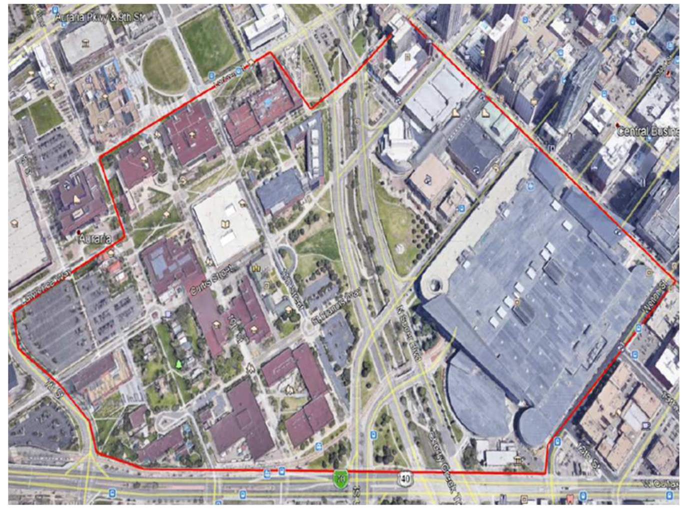

Fig. 2: Assigned competition area for the use case of the city of Denver and AHEC.

- Zoning – To identify the zoning code of the site. Zoning ordinances are written laws that provide specifications according to the zones and ensure that land use is specifically demarcated for a particular purpose. Zoning codes vary between states, in this case, the Denver Zoning Code is used to specify guidelines for future development, identify different types of zones and their purposes, and specify detailed regulations for these zones [17].
- AHJ Land Use Plans – To identify if the proposed system aligns with the goals and land use plans of the AHJ.
- AHJ Transportation Plans – To identify if the proposed system aligns with the goals of the transportation plans of the AHJ.
- Master Plans and Site plans - A master plan provides a comprehensive framework for guiding future growth and development in a specific area and clear specifications on what will happen in the near future. Therefore, can help developers identify how their design could be affected by these future events. In the case of the City of Denver and AHEC, the following documents were used to identify which future development plans could affect the designed systems: the Auraria Higher Education Center Master Plan, Denver Performing Arts Complex Master Plan and Convention Center Expansion [18 - 20].
- Soil study – In case of planning to have ground solar mounts is imperative to do a study of the soil to identify if it is safe to put a system there. Soil conditions impact structural design and site feasibility, for example, if the soil contains caliche or bedrock the system may require costly drilling, if the soils are sandy installation may require deeper post embedment to meet wind and snow loading requirements, and if the soils are corrosive the installation can require measures to protect embedded steel posts.

- Critical Habitats – To identify if there are critical habitats near the site, riparian areas, and endangered species of flora or fauna that may be impacted by the system. Also, the team must verify that construction timelines do not impact nesting seasons.
- Historic and Cultural Resources – To identify if the proposed system affects any historic or cultural resource and if it is permitted to be constructed. In the case that is permitted, identify the additional permits needed for the development of the system.
- Wetland or Floodplains – To identify if there are bodies of water that could affect the system directly or its interconnections.
- Permits for Construction – To identify all the applicable local and federal permits necessary for the construction of the system and the codes to which it needs to comply.

C. Conceptual System Design

All teams in the competition received access to the premium software platform Aurora Solar to work on the design [21]. To start designing in Aurora Solar the location must be input so that the user can see the desire area from above. If the consumption data of the buildings is available, the second step would be to upload the data into the application, but this step is not mandatory. Once this is done the next step would be to model the site, this is done by 3D modeling the structure of the building at scale using the lidar feature, a tool that shows the dimensions of every object on site at scale as demonstrated in Fig. 3. Every object near and on the structure must be included in this model to be able to perform a shading analysis.

After this model is finished the next step is to implement the photovoltaic design using real life components. To do this, Aurora Solar provides a database with multiple models of panels and inverters that can be used in the design. Now, to be in compliance with the International Fire Code (IFC) [22], pathways must be designed in the roof for smoke ventilation, firefighter access in case of emergencies, and maintenance. Once the pathways are designed, the solar panels are placed in the roof, but first a few factors must be considered. These factors are the spacing in between rows of solar panels, the tilt, and the shaded areas caused by roof obstructions, adjacent buildings, or trees. In the case of the tilt, a study can be made in Aurora Solar to compare several variations and combinations of tilt and spacing until the one with the most production can be found. As for the shading caused by surrounding objects, Aurora Solar has a feature where the minimum solar access for the solar panel is indicated, this calculates the percentage of solar access and if is less than the input amount it does not place photovoltaic panels in that area. Additionally, Aurora Solar shows the irradiance levels of the solar panels in the rooftop by color classifications as shown in Fig. 4. Next, the inverters can be placed in the design, the solar panels can be connected to the inverters and Aurora Solar validates the design. If the design passes all the validation, it is then simulated and the generated data can be exported for evaluation.

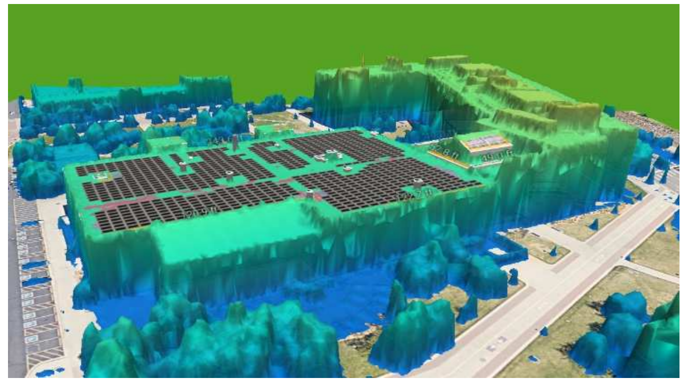

Fig. 3: Aurora Solar lidar tool demonstration.

The simulation output data provided by Aurora Solar is the following: hourly energy production file, system losses, shading analysis, irradiance files, financial analysis, and a line diagram among many other outputs available. The hourly energy production file is then used for the System Impact Analysis.

For the challenge of the energy storage system the tool used was REopt lite [23]. This tool was used to select the optimal mix of energy coming from the photovoltaic system, energy storage system, and electric grid. For example, to do the resilience analysis for the case of the Science Building in AHEC the consumption data of this building was uploaded to REopt, then it was indicated that 30% of this consumption was the critical load needed to be sustained in case of an outage. Then, to select the duration and time of the outage, the worst-case scenario was assumed, which according to the electric provider was a 24-hour outage [24]. Also, to ensure the worst-case scenario, the selected time for the analysis was on the day of most consumption. Finally, the data of the solar system designed for this building was added to the analysis for it to be considered as an energy input.

After the analysis is concluded, REopt lite recommends an optimal size of solar system and energy storage batteries, but in the case of the Science Building of AHEC the size of the photovoltaic array was already indicated, therefore, it only indicated the optimal battery system that met the need of the

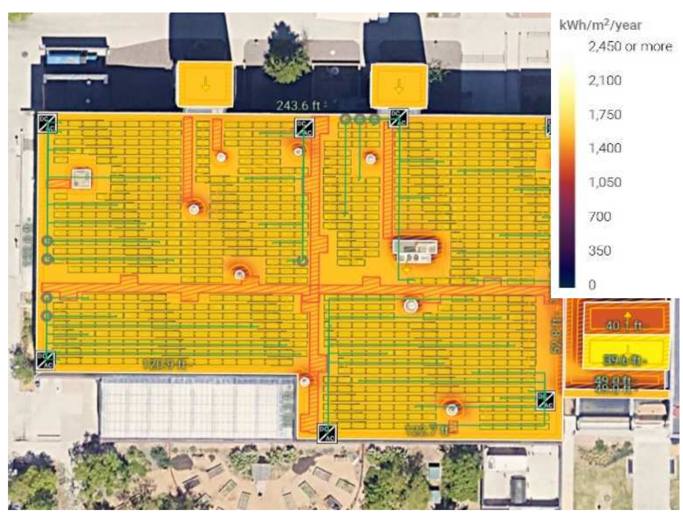

Fig. 4: Aurora Solar irradiation feature.

criteria specified. After the simulation the tool also provides a set of graphs, Fig. 5 and Fig. 6, the first graph shows the behavior of the system when the outage occurs, and the second graph shows the probability of survival that the system has in different intervals of time. Another additional feature that REopt has is the financial analysis it offers.

D. System Impact Analysis

After the Conceptual System Design is completed and the outputs of the system are available is imperative to identify how this new system affects the current electrical grid. To do this the organizers of the competition recommend using OpenDSS [25]. OpenDSS is an electrical power distribution system software (DSS), developed by Electric Power Research Institute (EPRI) for supporting distributed resource integration and grid modernization. A distribution system study identifies the impact a proposed electrical grid expansion, reinforcement, or modification could have on an unchanged electric grid area or Electric Power System (EPS). The OpenDSS program supports nearly all root mean square (RMS) steady state (i.e., frequency domain) analyses commonly performed for utility distribution systems planning and analysis. It is useful for a multitude of system studies, including Distributed planning analysis, Distributed Energy Resource (DER) impact analysis, and even running yearlong simulations to understand impact of inter annual variability. It can also solve both for radial and meshed networks and it has capabilities to analyze power flow, harmonics, snapshot power flow, quasi static time series simulations, and dynamics. All the types of studies OpenDSS offers are done in the frequency domain.

Fig. 7 shows the elements that are included in the OpenDSS library. Elements are group by their main function. The groups' function is self-explanatory given the group's name. Power Delivery (PD) elements connect between two different nodes. Power Conversion (PC) elements connect to a single node. Control elements are for (as the name suggest) controlling elements that are either PD or PC. Metering elements are meant for exporting results on a study that is being conducted to a specific element in the circuit. General elements are for defining characteristics for different elements. An example would be the load shape element that defines the load profile that a building's load must follow, or it is also able to define the irradiance profile for a PV system.

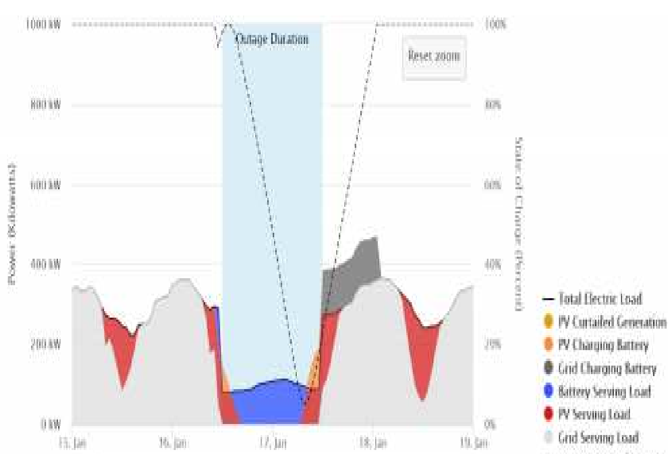

Fig. 5: Example of REopt lite Outage Simulation.

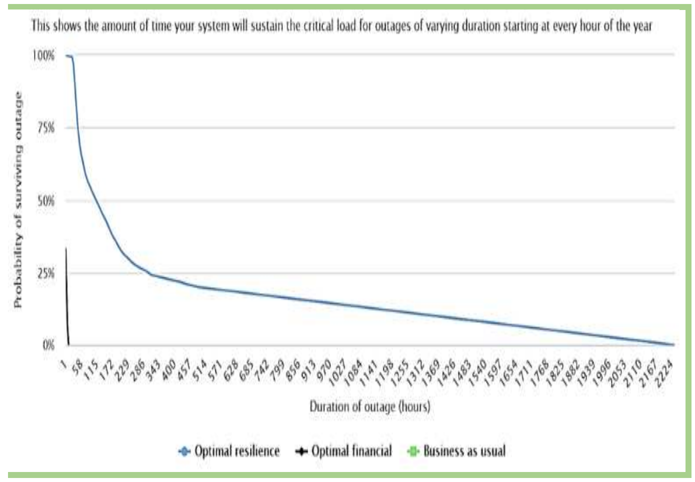

Fig. 6: Example of REopt lite Probability of Surviving Outage Graph.

The goal for the System Impact Analysis stage of the competition was to analyze the impact of an added PV system and/or energy storage to the established electrical grid. Each team was given a pre-made OpenDSS code that simulated the current electrical grid of the assigned district. For both of these systems (PV and battery system), the most important studies taken into consideration were the overloads and voltage exceptions report.

To add the PV system into OpenDSS, the load shape elements that hold the PV systems irradiance profile must be created. Fig. 8 shows what would a year-round simulation for a specific building would look like. The sudden drops in the graph are because of the data points displacement. While the simulation is done on 15-minute intervals, the data given by Aurora has 1-hour interval data points. Next, the load shape created must be assign to a new PV system element. To create a PV system element in OpenDSS, it needs the phases it will have, its kV value, the power factor, the transformer it is connected to (specifically the node), and the load shape that will represent the irradiance profile for the PV system. There are a lot more parameters that can be adjusted, but the necessary ones were mentioned above. After the creation of the PV systems, an inverter controller element must be created to stabilize the PV

Fig. 7: Elements available in the OpenDSS library.

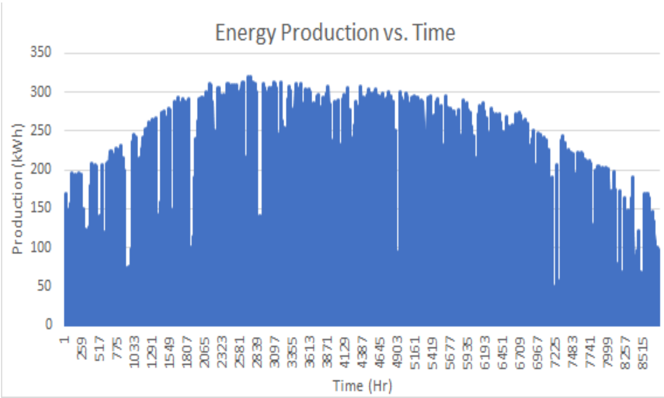

Fig. 8: Energy Production vs. Time (year-round simulation)

system using either a volt-var curve or a volt-watt curve (this can be specified in the internal code of the inverter controller). After this, the overload and voltage exception reports can be performed on the circuit, and they can be analyzed to see if there are any problems with the circuit.

To add a battery storage to the circuit certain parameters of the storage are needed. These parameters are the load shape element that represents the discharge and charge of the battery, the phases the storage is connected to, the node it is connected to, the kV value, the kW rated value of the storage, the kWh rating, the kWh stored at the start of the simulation, the effective discharge, and the effective charge. More parameters can be specified, but these are the main ones. After the storage and the PV system are added, the overload and voltage exception reports can be created again to see if any problems occur in the system. Snapshot studies can also be conducted on the circuit before and after adding the PV and/or storage system.

E. *Financial Analysis*

After completing the design of the proposed system using the Aurora Solar platform and analyzing the impact it will have in the current electrical grid using OpenDSS and REopt the next step is to perform a financial analysis to decide if the proposed system is economically viable using the System Advisory Model (SAM) [26]. The System Advisor Model is a free software model that facilitates the decision-making process for renewable energy projects. It can model many types of projects such as: photovoltaic systems, battery storage systems, solar water heating and more. SAM also has available financial models for 3 types of projects: residential and commercial, power purchase agreement (PPA), and third ownership projects.

The first step before simulating a system in SAM is to choose the type of project that is being simulated out of the three types available in SAM. The next step is to choose the weather files from the location where the proposed system is to be installed by typing the address. The system will download all the weather files and it will use these to simulate the system design. After this, the module and inverter must be chosen from the options SAM provides. When choosing a module out of the available options, the system provides module characteristics at reference conditions for all the available module options which can be very helpful when deciding which module may be best for the system depending on the requirements for the module.

For the inverters, SAM also provides many options along with their respective efficiency curve and characteristics to facilitate the decision-making process. Although SAM was only used for the financial analysis during the competition, it is important to mention that it can be a useful tool even for deciding which module and inverter to use.

After choosing the module and inverter, SAM requires the inputs from the system design, system costs, incentives, financial parameters, electricity load, and other inputs. For the incentives, it is important to research the incentives from the location where the system is to be installed since this can vary by state. The most common incentive in the United States is the 26% federal tax credit. Other incentives may be state tax incentives, sales and use tax exemptions for renewable energy equipment, reward programs from the utility companies, and SRECs, Solar Renewable Energy Certificates, which is a solar incentive that allows system owners to sell certificates for energy to their utility. One SREC is earned for every 1000-kilowatt hours (kWhs) produced by the system. The value of the SRECs depends on the state and year since not every state has an active SREC market and the value also varies through time which can range from $50 to $300 per SREC. These financial incentives make solar more accessible and reduce the net cost of the system.

Inputting the system costs can be the hardest part since prices for renewable energy equipment are quite hard to find. For the competition, the approach to estimate the system costs was to use benchmark costs to have good cost estimates [27] . After all the inputs are complete, SAM is ready to perform the simulation. The results provide a first tab with a summary of the financial and performance metrics of the system, see Fig. 9, some being the net capital cost, payback period, project IRR%, net savings in the first year, etc. Other metrics can be searched and filtered into a customizable table by selecting from a long list of metrics which is an efficient and useful way of looking at metrics of interest for analysis and decision-making. Another advantage and useful capability SAM provides is being able to create different graphs, see cash flows, time series, statistics and many more ways of viewing the results and analyzing the metrics. The financial analysis is a very important part for solar projects when deciding if the system is economically viable or not, therefore, SAM can be a very helpful tool to accelerate the decision-making process based on financial and performance metrics.

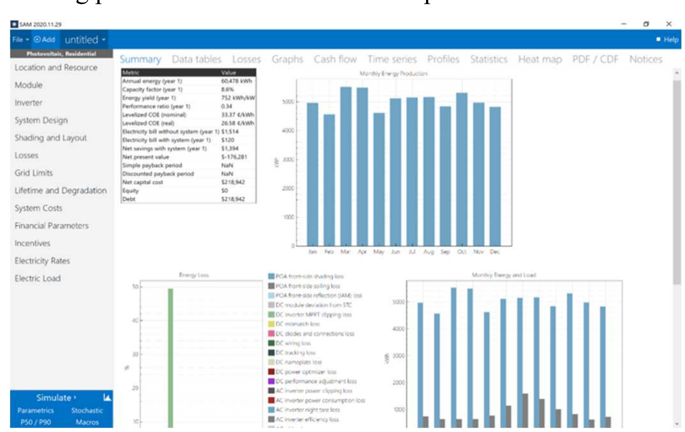

Fig. 9: Result tab after performing the simulation of a system in the System Advisory Model (SAM) tool.

F. Development Plan - Construction Plan

After all the previous steps are completed, the only thing left is to create a plan to execute the project. As it was mentioned in the Site Plan it is important to identify and acquire all the necessary permits for the construction of the system. After obtaining these permits and approvals the next step is to submit the electrical drawings. These must include the design of the system signed by a Professional Engineer and all the specifications of the system. Is important to mention that after the implementation of the system is completed an electrical inspection will be required to confirm everything was installed correctly and the system complies with the requirements stipulated by local authorities.

Several parameters need to be considered to achieve compliance with all stages of the project in the implementation process. As part of this effort, a three-stage timeline was proposed. The necessary start and end periods need to be analyzed and identified respectively for each element involved in the construction stage. These three stages were divided into Initiation, Construction of Systems, and Connection. It can be seen in Fig. 10 that each stage has multiple processes included in it and that the construction of the project starts in the summer, this is because this system is going to be constructed in a university and in this time is when then operations of the campus are less affected by the construction. Depending on the type of project, client, location, etc. it is recommended to identify a time slot in which the operations of the client are less affected.

Every efficient and well-structured project must have a detailed risk analysis for a successful implementation. Several risks can always arise in developing an optimized model of distributed energy systems due to both, natural and human factors. Due to the size of the systems, the complexity, and the stipulated construction time, the probability of an instrument being exposed to some risk such as minor damages in the

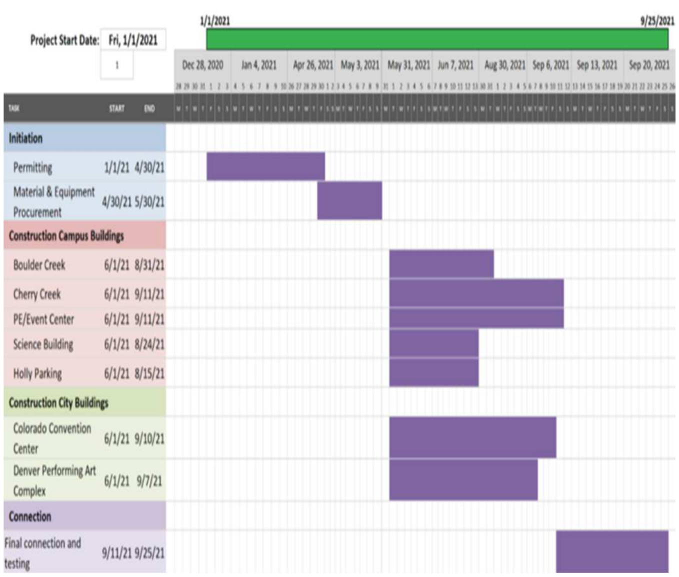

Fig. 10: Timeline with the three main stages of the project implementation; Initiation, Construction, and Connection. In this case there are two construction sections since there are two different systems.

installation process, defects, systematic errors, or others cannot be ignored. These minor damages may directly affect the project, representing a more significant investment depending on the problem's magnitude. However, other types of instrument damage, which cannot be identified in time, can become operational problems and compromise components and the power system. After installing the system, a potential risk could be the overloading of the system due to irresponsible use of energy by the community or the owners of the system. Another recommendation would be to educate the community on how to consume less energy and the benefits that will come along with it. If this is achieved the system could be more efficient, durable and at the same time the owners of the system could have an increased amount of savings in energy consumption.

IV. Skills Developed by the Participants

UPRM used the SDC as an excellent tool for participants to develop new skills that will help them become more competitive candidates in the industry after graduation. Some of the skills learned by the participants were:

- Knowledge of how energy systems work and operate; including but not limited to renewable energy systems and energy storage. Their purpose and what economic benefits they come with.
- Ability to identify, formulate, and solve engineering problems using techniques learned in previous academic courses and DOE's seminars.
- Ability to learn about local codes (i.e. Denver, Colorado) and standards related to interconnection and net-metering required by the local utility (i.e. Xcel Energy).
- Apply logistics and make good decisions on energy security including future local developments and energy need projections at the Aurora District.
- Ability to design and simulate photovoltaic systems with energy storage using state of the art tools (REOpt, Aurora, OpenDss, etc.) to meet the necessary Aurora District energy demands.
- Ability to apply economic analysis and provide viable solutions to lower cost of energy using renewable energy sources and energy storage at the Aurora District.

V. Conclusion

By participating in the SDC and integrating the project in a PBL course the participating students will have the opportunity of learning the latest technologies and best practices in the solar development industry and will be better prepared to join the industry after graduation. In the case of the UPRM team, each member was interviewed after the competition and all students confirmed that participating in the competition was a life changing experience and that they learned more in this course than in other traditional engineering courses, they also added that they would like to take more courses that use the PBL approach. Thanks to the competition, multiple participants of the competition received internship positions in energy related organizations and multiple students in campus have shown great interest in the renewable energy industry and are already volunteering to participate in next year competition.

VI. Acknoledgements

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