Photovoltaic Solar Grill

Mrs. Brittany Weber, Renewable Energy Society

Brittany Weber is an Illinois State University undergraduate student in the Sustainable and Renewable Energy major with a Food Studies minor. She was the president of the Renewable Energy Society and head of the solar grill project from 2019-2020.

Miss Katelyn Renee Dunnagan , Renewable Energy Society

Katelyn Dunnagan is an undergraduate student at Illinois State University, where she is majoring in Sustainable and Renewable Energy. She is currently an executive board member for the Renewable Energy Society and holds a position as a student ambassador for the technology department.

Dr. Matthew Aldeman, Illinois State University

Matthew Aldeman is an Assistant Professor of Technology at Illinois State University, where he teaches in the Renewable Energy and Engineering Technology programs. Matt joined the Technology department faculty after working at the Illinois State University Center for Renewable Energy for over five years. Previously, he worked at General Electric as a wind site manager at the Grand Ridge and Rail Splitter wind projects. Matt's experience also includes service in the U.S. Navy as a nuclear propulsion officer and leader of the Reactor Electrical division on the aircraft carrier USS John C. Stennis. Matt is an honors graduate of the U.S. Naval Nuclear Power School and holds a B.S. in Mechanical Engineering from Northwestern University, a Master of Engineering Management from Old Dominion University, and a Ph.D. in Mechanical and Aerospace Engineering from the Illinois Institute of Technology.

Photovoltaic Solar Grill

American Society for Engineering Education
Energy Conversion and Conservation Division

Abstract

The Office of Sustainability at Illinois State University regularly participates in tailgates at campus events. Tailgating involves cooking food on large gas or charcoal grills, and the events typically last for several hours. To raise awareness of sustainability-related issues, the Office of Sustainability asked the Renewable Energy Society if they would design and build a more sustainable grill for use at these tailgates. The Renewable Energy Society is a student-led organization that is dedicated to the study of renewable energy systems. The students agreed to take on the challenge and formed a team dedicated to the project. After some preliminary research, the students discarded the traditional "solar cooker" design because experience showed that the design does not achieve adequate temperatures to cook meat in a short amount of time. Next the students explored the idea of converting a propane grill to a battery-based solar electric system. The team performed tests by connecting various battery configurations to an electric stovetop burner. After additional research, consulting with system design experts, and obtaining price quotes, the team decided to use an off-grid inverter and a commercially available outdoor electric range. The system is fed from a bank of batteries that is sized to provide 2-3 hours of continuous grilling time. The batteries are charged with a set of PV modules with a portable racking system that can be set up at the tailgate location, or a wall outlet for cloudy days. The group is enthusiastic about using the grill as a branding and marketing opportunity for their student organization. They also intend to use it for fundraising purposes by selling grilled meat sandwiches on the quad during warm weather.

Introduction

Illinois State University started on its path to sustainability in 1989, when it established a recycling program for the residence halls [1]. To help fund student and faculty sustainability projects, an account called the Student Sustainability Fund was established in 2009. The Student Sustainability Fund is run by the Student Sustainability Committee, which is an external committee of the Student Government Association. This fund has helped build a variety of sustainable projects on campus, including water bottle refill stations, bicycle racks to encourage green transportation around campus, upgrades for the solar car racing team, and solar picnic tables that charge students' electronic device while working outside.

In July of 2010 the university established the Office of Sustainability to lead sustainability projects throughout the university. In 2019 the Office of Sustainability gained a new program director [1]. She started a zero-waste campaign for tailgates for the fall 2019 home football games, encouraging and teaching tailgaters of all ages about ways to reduce their waste while tailgating and living their everyday lives. When searching for a zero-waste way to cook food for a crowd, the new director could not find a zero-emission grill. She consulted the Renewable Energy Society student group to see if they had any ideas. The organization came up with the idea for a grill powered by solar photovoltaics, and the Solar Grill project began.

Outline of the problem

The mission of Illinois State's zero-waste tailgate initiative is to educate and encourage people to simply waste less. During fall tailgating events the interns for the Office of Sustainability walked around to all the trash cans throughout the tailgate area and pulled out anything that belonged in the recycling bins, reducing what was put in the landfill. The office set up a tent with zero-waste products like compostable paper products, reusable products, and coolers to win in a raffle. In order to appeal to a wider audience and to call additional attention to their mission, they wanted to purchase a zero-emission grill. This would allow them to be able to make food like a normal tailgate. The Office of Sustainability staff quickly realized that such a product was not commercially available, and that they did not have the expertise to create such a grill on their own. Therefore, they called on the Renewable Energy Society to create a new type of grill for the tailgating event. The requirements specified for the grill were vague, only that it should be able to cook food for a crowd with no emissions.

In 2003, researchers at Oak Ridge National Laboratory published an article titled "Fourth of July- No Picnic for the Nation's Environment". This article focuses on the effects of the biggest grilling holiday for the United States, the Fourth of July. The group noted that there are several of these types of holidays and the environmental effects might be larger than imagined. With only 7% of the nation's grill owners having electric grills, most grills are powered by greenhouse gas emitting fuels. Surprisingly, even though the electric grill produces no onsite emissions, they are the most polluting type of grill because of the greenhouse gasses associated with producing and transmitting electricity in the United States. Every year on the fourth of July, America's grills emit 225,000 metric tons of carbon dioxide [2].

Discussion of similar projects

As the Renewable Energy Society (RES) started to research different solar grills, they soon discovered that there are limited design options. The main design type that the organization came across included a reflective material, such as mirrors, that would be positioned so that the radiation from the sun focused on a compartment that stored the food, more commonly called a "solar oven" rather than a grill [3]. There were many different variations of this design. Some were kits that could be bought, and others were more elaborate portable setups as shown in Figure 1. All had the same basic concept of using mirrors or reflective surfaces for solar thermal heat concentration [4].

There are advantages and disadvantages of this type of design that were discussed and researched. The advantages are the design is simple and easy to replicate, it is very portable, set up is simple, and it has few components to maintain. The disadvantages include the fact that the design wouldn't be able to feed enough people in a reasonable time for a tailgating event, and it would operate well only on clear, sunny tailgating days, which are rare for midwestern fall tailgates. This led to another discussion of how the group could supply enough solar power to feed a large crowd of people during a football game. After looking at the primary design of almost all solar grills, the group came to the conclusion that a different approach was needed: a photovoltaic off-grid battery-storage powered grill.

The group decided to use photovoltaics for several primary reasons: it matches with the objectives of RES, it would be a good learning experience for the students participating in the project, and it would be a good way to draw people into the zero-waste discussion. The group searched for examples of how to build something like this but realized that there was little evidence that this had been created before. Using knowledge gained from the Sustainable and Renewable Energy major associated with the student group and with the support of our advisor, the group began designing the grill.

Figure 1: Typical designs of a solar grill found while researching options

Design process

After considerable deliberation, RES narrowed down the numerous design ideas to four final design plans that could be used for the solar grill (Figure 2). The final design options discussed by the group included: 1) retrofitting a gas grill to work as an electric grill, 2) attaching solar modules to the sides of a retrofitted gas grill, 3) using an electric grill on top of an existing wooden box previously built by the student group or 4) using a free-standing electric grill attached by an extension cord to equipment in the pre-existing wooden box. The group first explored the idea of making our own electric grill from a converted gas grill. In order to achieve this, the group first needed to have an idea of how much heat a stove top burner could produce using a bank of batteries. This would tell us how many batteries we would need and how much solar power generation would be needed in order to charge those batteries for this type of grill. Since it gathered the most support, this is where we started the testing process.

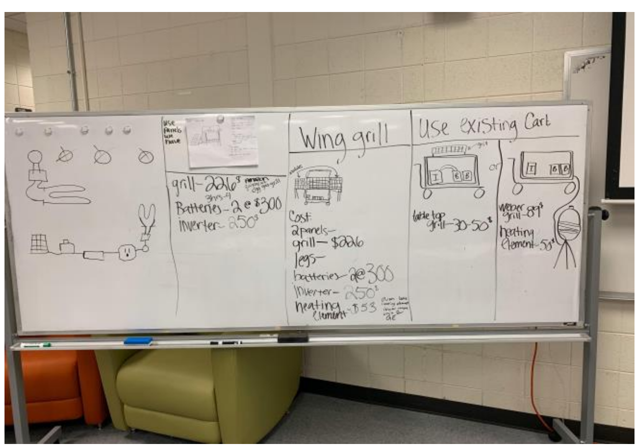

Figure 2: Four final ideas (gas grill w/ separate modules, wing grill, top of box electric, wired free-standing electric)

The first design featured a large gas grill with two small solar modules that would be attached next to the grill like pull out wings (Figure 2- wing grill). This design would use stove top heating elements to convert electricity into heat, and we could store the batteries in the space below the grill where the propane tank would otherwise be stored. We planned on affixing four stove top burners connected to batteries to all four corners of a large gas grill and using the open center space of the grill as a cooking space. This "stove top burner grill" was the premise for most of the designs we initially contemplated. Our two main problems with this design were that the griller or the customer could accidentally block the sun from the side panel mounted modules on the grill, and the heat and grease from cooking the food could adversely affect the expensive solar modules attached so close to the grill. After contemplating how we could keep the modules clear and clean, the group decided that the solar area of the wing-mounted solar modules would be too small to adequately heat the stove top burners.

The next design used the same heating idea, but we decided that the solar modules needed to be more portable in order to ensure we could get the correct tilt angle and azimuth angle for the modules to absorb sunlight at various locations (Figure 2- gas grill with separate modules). Having the modules attached by long wires gives us the ability to grill in a cool shaded area on a hot day, while keeping the modules at a safe distance from the grill. This also allowed the size of the solar modules to be increased compared to the wing-mounted modules and eliminated the two problems we found with the previous design.

Next we had to test the stove top heating elements to see how much power they required in order to produce heat. To do this we first calculated the resistance of each heating element, a small regular stove top burner and a larger "quick heat" burner. The small burner had a higher resistance than the larger burner, so we decided to use the larger one for the test. The larger burner measured 45.5Ω, so to calculate the amperage needed to pass through the burner we used the familiar Ohm's Law relationship,

$$I = \frac{V}{R}$$

In the lab we had four 12V batteries connected in series totaling approximately 48V. Substituting the known values gave us

$$I = \frac{48V}{45.5\Omega}$$

which gave us the amperage of 1.05A. Next we calculated the power that would be converted from the batteries through the burner. Using the equation $P = IV$ we calculated that we should get about 50.6 Watts from the batteries converted into heat in the burner.

We were unsure how hot 50.6W of power dissipation in a stovetop burner would feel, so we were careful while setting up for the test (Figures 3, 4). First, we connected all of the batteries in series using jumper cables from all the student's cars. Then we set the burner far away from the batteries and attached the end of the last jumper cable to the burner. When everyone was ready, we attached it to the series of batteries. We heard a small pop as the circuit was completed, and after some time the burner got moderately warm. From this test we learned two things: we were going to either need more batteries to increase the voltage, or we were going to need to find a different heating solution.

Figure 3: 12V batteries connected in series

Figure 4: Stove top heating element

After the stove top burner test night, we reconvened the following week and opted to work on a different solution. We did not want to add more batteries to the battery bank due to weight concerns, and we did not have a viable alternative heating element. After a group discussion we decided to move to design number 3, using an electric grill (Figure 2- wired free-standing electric grill). In our search for an electric grill, we found several free-standing grills, but no available option was going to be large enough for us to adequately cook enough food for a tailgate crowd. In addition to the grill space not being large enough, no electric grill that we could find had a storage cabinet for the batteries.

For all of these reasons, we came to the conclusion that we should use an electric grill with a separate storage enclosure for the batteries and associated electric devices (Figure 5). We decided to use a previously constructed plywood box that had been built by the group several years ago to hold the batteries, charge controller and inverter, and we found an electric grill to sit on top of the box (Figure 2- top of box electric grill). The wooden box would then be placed on a wagon for easy transportation to tailgating and other events. Then, the PV modules could still be separate and portable, and we would construct another carrying wagon for them. With the plan finalized, we moved on to pricing the components and ensuring all the specs were correct.

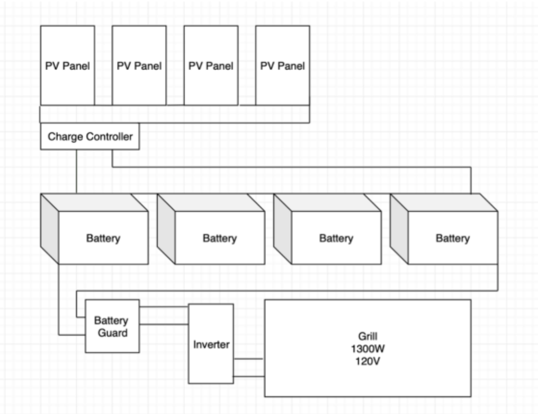

Figure 5: Base design

The final aspect of the design process was to create our own custom-fit solar module transportation unit in a second wagon. We came up with the idea to cut notches into plywood pieces to create “fingers” that would support the individual modules and keep them separated during transportation. The pieces of plywood would be held in place by shelf support brackets. Then, to ensure the stability of the modules we would secure 2×4’s around the perimeter of the plywood. The end 2×4 was designed with a wing nut to be able to open and close the back end to remove and replace the modules for use. Pipe insulation sleeves would be used to cushion the solar modules against the wood pieces (Figure 6).

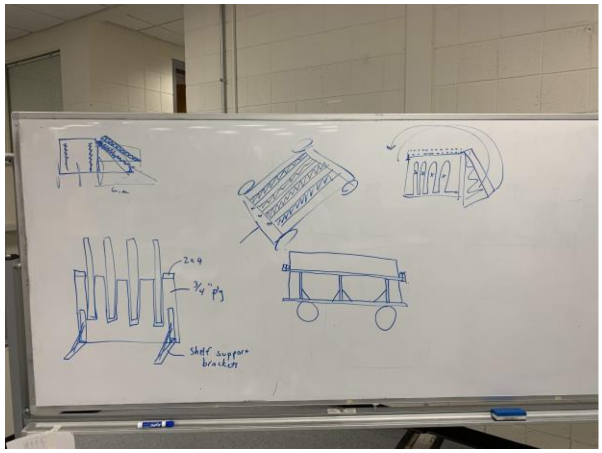

Figure 6: Solar Module Transport Cart Design

Materials and budget

When choosing materials for our grill, we sourced our own materials and took the advice of local and regional experts. The Horticulture Center at Illinois State University has a combined solar and wind system for their outdoor shed and storage area. When on a previous tour of the system, students and faculty noted the use of an OutBack Power charge controller and inverter (Figure 7). Since they were located in an outside system throughout the year, we knew that they would be reliable enough to withstand the conditions our system would be exposed to when in use.


Figure 7: Horticulture off-grid combined solar/wind system

The budget was flexible during the planning process because we were tasked with first putting together a proposal for the university's Student Sustainability Committee. The proposal included funds for the inverter, charge controller, batteries, battery low-voltage guard, transportation wagons, a system monitoring device (Mate3s), storage for PV modules, racking for the modules, and the electric grill. The Sustainability Fund also asks for a 10% contingency amount added at the end of the budget, bringing the total for the project to $6,635.92. The SunPower photovoltaic solar modules were donated by a local company supporting the project and the club, so they were not included in the budget, but they were added to the presentation to show outside support for the project.

The inverter, charge controller, batteries and Mate3s were all ordered from OutBack Power. The battery guard and the grill were ordered from Amazon. All of the construction materials for the stands and the solar module transportation case were purchased from a local hardware store. The two transportation wagons were purchased from Tractor Supply Co. An itemized budget is shown below. Note that the prices for custom storage and racking for the modules were estimates:

- PV Modules: ………………….………….... $0 (donated by Legacy Solar)
- Inverter:…………………….…………….…….$1,609.38
- Charge Controller: ……………………...….. $340.63
- Batteries: …………………...……..…...... $1,713.64
- Mate3s…………………………….…...…..... $371.88
- Battery Guard: …………………………….... $152.15
- Electric Grill: …………………………...….. $679.99
- Wall Charger:……………...…..…….............. $400
- Wagons:…………………………….………… $319.98
- Custom Storage: $60.00
- Racking:.. $185.00
- Shipping: $200

The electric grill is what guided us to determine the specifications for the rest of the materials. It is a 1300W, 120VAC Kenyon B70090 Frontier All Seasons Portable Stainless-Steel Electric Grill (Figure 8). We chose this grill in particular because it could sit on top of our pre-existing wooden box that would house the batteries, charge controller, inverter, and Mate3s. With the voltage and wattage known, we were able to determine the battery size needed by specifying the number of hours of operation per event. Taking into account our original goal of cooking at a tailgate, we decided 4 hours of operation per event would suffice.

Figure 8: Kenyon Grill

We emailed the closest OutBack distributor, GreenTech, and asked them for their recommendations on the inverter given the 1300W 120V output required to operate the grill. The inverter purchased is the VFX3648M from the FXR series supplied by OutBack Power (Figure 9). With a rated power capacity of 3600W, the VFX3648M inverter is oversized, but this was done to allow for the possibility of future system expansion. The nominal input voltage for the VFX3648M inverter is 48V DC. Given this, we knew that we would need four 12V batteries connected in series to reach the 48V DC needed for the inverter.

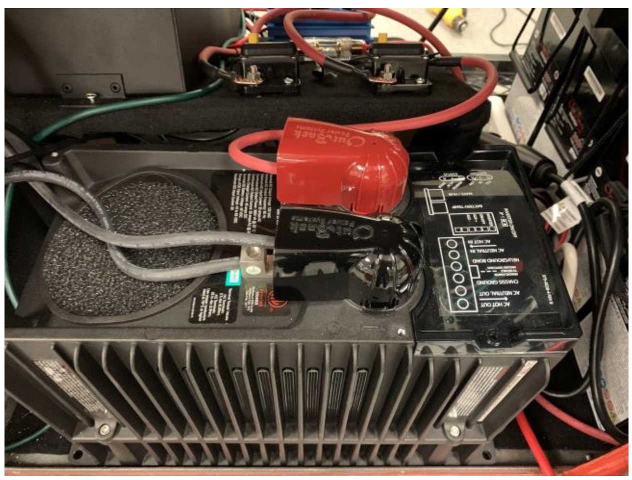

Figure 9: OutBack Inverter

After settling on a DC system voltage of 48V, we were able to calculate the amp hour requirement for the batteries. First, we needed to calculate the amperage for the AC and DC side of the inverter. Since a typical inverter runs from 95-98% efficiency [5], we assumed a very conservative 90% efficiency for the inverter along with other losses and we calculated 30.1 amps DC would be needed from the batteries by using the equation:

$$Amperage\ [A] = \frac{\frac{1300W}{48V}}{0.9}$$

Using that number, we multiplied the amperage by 4 hours of operation time and found that 120.4 Amp hours (Ah) of battery storage would be needed for the system. However, since we knew that the life of batteries is drastically shortened if the batteries are completely depleted, we initially aimed for approximately twice that amount to minimize the depth of discharge and ensure that the batteries have a long life ahead of them. We found a model of battery with 204 Ah and felt that would adequately meet the demands of the system. Using the 120.4 Ah needed for the system and dividing it by the 204 Ah capacity of the batteries, we found that the batteries would have a 59% depth of discharge (D.O.D.). From there we could simply take 100% minus the D.O.D to get the 41% as the minimum state of charge (S.O.C.) during the system's operation based on our assumed operating parameters. We recognize that the batteries are sized rather conservatively, but this will allow for a long battery lifetime and potential future expansion of the system. Each battery weighs about 130lbs, which means that the system includes a total of about 520lbs of batteries.

Figure 10: Batteries in storage box

The solar panels that were donated by a third party are four high-quality 320W E-series SunPower solar modules with specifications shown in (Figure 11). Their dimensions are about 5 ft. by 3 ft., which is large enough to draw attention from passing tailgaters (Figure 12). The solar modules were the first thing we were able to pick up, so with the solar modules secured we turned our attention to the charge controller. The FLEXmax 60 from the FLEXmax Series was recommended to us by GreenTech (Figure 13). Once we had all components ordered, we began planning the custom transportation for the modules on the second transportation wagon.

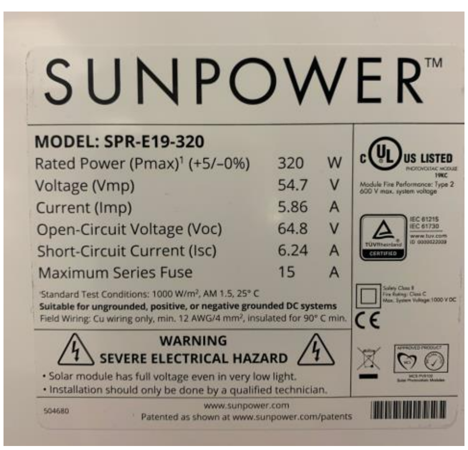

Figure 11: SunPower Solar Module Specs

Figure 12: SunPower modules (right) compared to our old classroom demonstration modules (left)

Figure 13: OutBack FLEXmax60 Charge Controller

Using the weight for the batteries and estimations for the weight of the other components that would be needed for the system, we decided to order two 1300lb capacity transportation wagons (Figure 14). Using the dimensions of the previously constructed wooden box and the solar modules donated to us by the local company, we found two wagons at Tractor Supply Co. that would meet the size and weight requirement to transport the equipment. In the first wagon, we decided to use the wooden box to hold the batteries, inverter, charge controller, battery guard, fuses, AC power strip, and Mate3s. Then, on top of the box we secured the grill using small brackets. With everything positioned in the box on the first wagon, we were able to design the other wagon to hold the solar modules. Since they are large and very fragile, we had to design and construct our own way to transport them separately from the rest of the system. We purchased two sheets of plywood, four 2×4's, three 1×2's, 12 shelf brackets, twelve sections of ¾" pipe insulation, and various wood screws, nuts, and bolts for assembly from a local hardware store.


Figure 14: Garden Wagons

Assembly and construction

The first things to be assembled were the wagons that would be used for transporting the grill and PV modules. The first cart was planned to hold the wooden box with the grill, batteries, inverter, charge controller, battery guard, fuses and Mate3s. By repurposing the wooden box from a previous project, it saved time and material costs. It already had a window on the side, designed to educate people on how the system is wired. The second wagon would be used for custom module transportation and storage.

The wooden box is 4ft × 2ft × 2ft and fits in the garden wagon with 9 inches to spare. Prior to ordering all of the different components, the students measured the spacing in the box to make sure that all components would fit inside. Once the box was placed on the first wagon and the other elements arrived, it was time to load the components.

The first things that were loaded into the box were the four batteries (Figure 15). These were placed all on one end of the box where the terminal connections were towards the opening of the box for easy access. After the batteries were in place, we then needed to decide how the inverter and charge controller were going to be arranged in the box so that it was easy to access but also visibly appealing for people to view. We used a small stand to place the charge controller, a fuse, two circuit breakers and the battery low-voltage guard. The inverter, the final component to fit in the box, fit perfectly behind the stand (Figure 16).

Figure 15: Loading batteries into wooden box

Figure 16: Component layout

Next, we sketched the wiring diagram that would lay out how each component would be wired together as well as identify where circuit protection measures would be installed (Figure 17). To start this process, we referenced the manuals for the inverter and charge controller to see how the components are designed to be wired together. This task was simplified because all of the major components were produced by the same manufacturer, OutBack Power. The first part of the diagram was made by connecting the batteries in series. Then, the positive wire from the batteries is connected to an 80A fuse that goes into the input terminal of the battery low-voltage guard. From the battery guard the positive wire goes through an 80A circuit breaker and then to the positive battery input terminal of the charge controller. The wire from the battery guard output terminal goes through an 80A circuit breaker and then connects to the inverter DC positive input terminal.

We then proceeded to make the wire connections from the 6-gauge wires to the devices based on the schematic. We cut and stripped the wires to the size that would best fit the limited space inside the wooden box. Once we had the main connections made, we made the ground connections for all of the components. The system does not have an earthen ground because the solar grill is portable, so we decided to have a floating ground connected to the negative DC bus. The negative DC bus is a piece of aluminum angle that is attached to the inside of the wooden box.

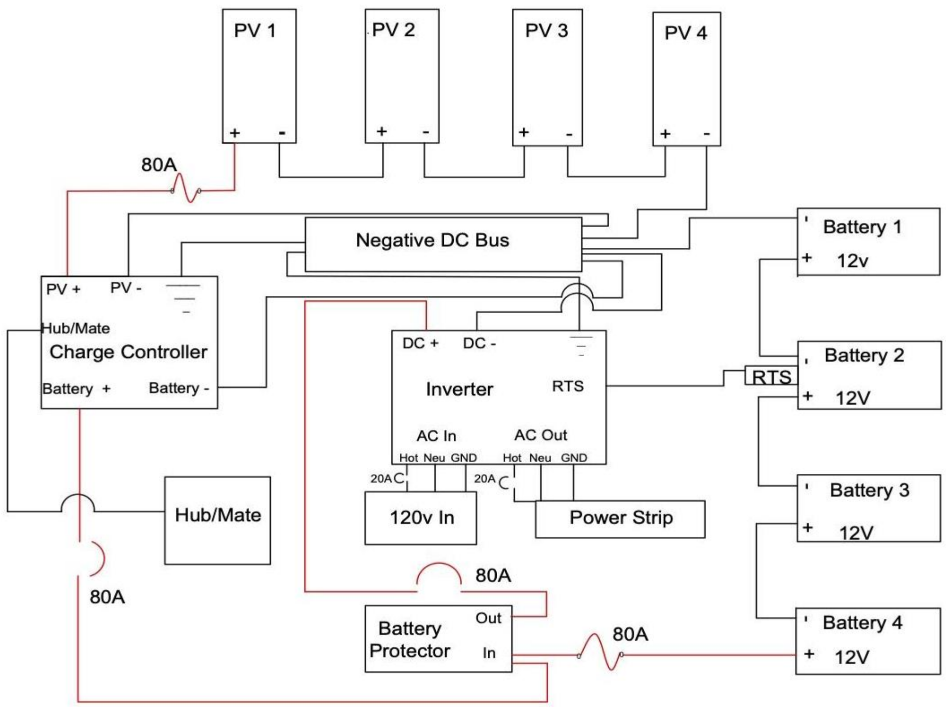

Figure 17: The wiring schematic

Later we added more safety measures such as fuses and circuit breakers to make sure that it would be as safe as possible while in operation. The fuse and circuit breaker sizes were based on manufacturer recommendations and expected system loads. Once the connections were made, it was time to secure the electric grill to the top of the wooden box. This was done by using brackets and placing them to the exact measurements of the grill and then setting the grill inside those brackets for safe transport. The grill would not be attached directly to the top of the box but sitting inside those brackets, the main reason for this is in case in the future there was a need to replace the grill, clean it, or repair it then we could do so easily.

After the grill was placed on top and the connections made inside the wooden box the last part that needed to be assembled was the wagon that was going to hold the four solar modules (Figure 18). To start construction on this project we needed to start by cutting the plywood down to the measurements of the wagon. The first measurements that were made were the base of the wagon (32 ½” x 61”). Then, we needed to cut three identical panels from the plywood with four slots for each PV module. We covered the edges of the plywood with ¾” foam pipe insulation to ensure the safety of the modules. This vertical piece of plywood holds the panels sitting on their sides and 6 inches above the floor of the wagon. Then once those were cut, they were painted red to match the other box. The next step was to secure the three vertical plywood structures by using 3 large shelf support brackets for each of the plywood structures that would help support the weight of the PV modules. Once those were secured, then the 2x4’s were cut and secured on top of the vertical plywood structures to add rigidity. In order to be able to get the PV modules out for use there is another smaller piece of 2x4 that was placed with a wing nut and bolt on the end of the wagon that can be removed. This ensures that the modules are as secure as possible while being transported but also easily accessible for use at the tailgating location.

Figure 18: Solar module transport wagon

The last thing to be constructed for the project were the stands for the solar modules. Using basic trigonometry, we found the length of the legs by using the equinox azimuth angle of the sun for the spring and fall in Central Illinois, the two times we assumed the grill would be most used. We attached 1” aluminum legs to the back of the panels to ensure the proper tilt angle for the modules (Figure 19).

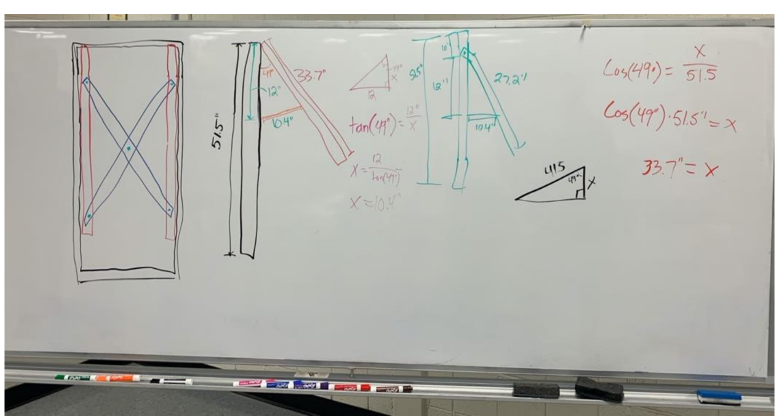

Figure 19: Trigonometry to calculate support leg length

Through the rest of the first half of the 2020 spring semester, the group worked on finalizing the grill construction. In late February, the student organization turned on the grill portion of the system for the first time. Using every precaution, we turned on each component one at a time until finally we switched on the electric grill. The system worked exactly as hoped, and the initial testing session was completed by grilling and eating a pack of hot dogs. Although we have yet to test the battery-charging functionality of the system with the solar modules, the grill portion of the project (including batteries, inverter, grill, and associated circuitry) works perfectly. We spent the rest of the first half of the semester impressing the student organization with our perfectly cooked hot dogs, bratwursts, and grilled cheese sandwiches. Just before the midsemester spring break, the group finished the project by attaching the support legs to the solar modules. Due to the COVID-19 university shutdown, we did not get the chance to come back from spring break to test the project together as a whole system. We look forward to the fall 2020 semester where we can use the Mate3s to monitor and perform more rigorous testing of the completed project.

Alternative uses of the grill

Students in the Renewable Energy Society performed the vast majority of the design and construction of this solar electric grill project. The faculty advisor for the student group participated in every step of the process, but was primarily used for oversight and technical advice. This project provided a rare opportunity for students to propose, design, and construct an innovative, practical, and functional renewable energy system. It is our hope that the project inspires teams of faculty and students from our own university as well as other universities to pursue practical renewable energy demonstration projects of their own.

The main goal for the solar grill is to be used at University sanctioned events, specifically to educate the public on reducing emissions through the “Zero-Waste Tailgate” initiative. While attending the tailgates, we hope to gain recognition for RES and for the associated Sustainable and Renewable Energy major. When the solar grill is not at football games, it will be frequently transported to the main quad of the campus for students to engage with. While waiting for their food, customers will be able to see the solar panels in use and learn how solar energy is converted into electrical energy to heat a grill. This will serve a dual purpose as being a demonstration of renewable energy at work and a fundraiser for the student organization. There is hope that the solar grill will not only inspire students and faculty to look for sustainable alternatives in their everyday lives, but also encourage future students in the organization to think outside the box and find creative sustainable solutions to anything.

References

[1] “Office of Sustainability” *Illinois State University*. [Online]. Available: https://sustainability.illinoisstate.edu/

[2] “Fourth of July no picnic for the nation's environment,” *Oak Ridge National Laboratory*, 03-Jul-2003. [Online]. Available: https://www.ornl.gov/news/fourth-july-no-picnic-nations-environment. [Accessed: 02-Feb-2020].

[3] GoSun, “Grill,” *GoSun*. [Online]. Available: https://www.gosun.co/products/grill. [Accessed: 02-Feb-2020].

[4] “Solar Cooking,” *Solar Cooking - an overview | ScienceDirect Topics*. [Online]. Available: https://www.sciencedirect.com/topics/engineering/solar-cooking. [Accessed: 02-Feb-2020].

[5] “System Loss Diagram,” *Aurora Solar Help Center. Ionin, Victor.* [Online] Available: Ihttps://help.aurorasolar.com/hc/en-us/articles/235994088-System-Loss-Diagram