Automated Tracking Solar Panels with Batteries

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A Project

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Project Summary

For many, solar panels have been known to generate energy when they face the sun at the proper angle, rendering solar panels useful to only a certain range of hours during the day. By adding efficient motors that can alter the panel angle's direction to the sun, we can extend the generation window that solar can produce energy and store this energy into batteries to be used when solar is no longer generating power. The automated solar tracking system with batteries hopes to build a system in which solar panels move according with the positioning of the sun. It can move in two axes, up and down or left and right. In theory, we will be able to generate more energy throughout the day compared to stationary solar. This energy will be stored in batteries, which will be deployed to a smart grid system in times of backup power. In real world applications, we want to use this project to see if a tracking system is still a viable option to consider for consumers, or if they're better off using stationary solar. We also want to improve the solar with batteries concept and implement it during times of grid blackouts and when electricity is more expensive.

The target audience with this project are individuals in the commercial or industrial sector who have plenty of land to incorporate such systems. At the residential level, solar panels with batteries without tracking capabilities on the solar panels already provide the necessary energy required for that household throughout the day and night, and as such, adding solar tracking capabilities is not required at the residential level for current electricity demands.

In completion of the project, standard electrical engineering practices and knowledge of microcontrollers and semiconductor transistors were utilized to make this project whole and complete. Understanding the logic of the Arduino microcontroller and the demand of the smart grid system in relation to the supply the solar panels and batteries could provide were also essential in designing and planning the logistics of this project.

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Introduction

The implementation of renewable energy as an alternative to fossil fuels has been a topic of discussion among many groups, including politicians, environmentalists, and engineers. Fossil fuels are a finite resource that is limited and will eventually run out. Additionally, fossil fuels used to generate energy contribute to pollution and harmful emissions, leading to climate change and negative health effects over time. Renewable energy, on the other hand, is derived from resources that are not consumed when utilized, such as wind or solar power. Renewable energy can be generated at a higher rate than it is consumed and often produces few to no emissions as a byproduct.

According to the U.S Energy Information Administration, the majority of energy generated in the domestic United States comes from fossil fuels, with only 21.5% generated from renewable energy sources. Of that 21.5%, only 3.4% is attributed to solar energy generation. [3] However, California leads the United States in solar installation and generation and can supply over 27% of the state's electricity demand, enough to power over 10 million homes with over 39,000 MW of solar energy. The state is projected to add over 26,000 MW of generated capacity in the next 5 years, creating over 75,000 jobs related to solar and adding $88 billion to the state's economy. Additionally, the price of solar energy has decreased by 53% over the previous decade. [1]

The objective of the project is to improve the design and functionality of an existing solar tracking system with batteries. The entire system rests on a steel base with wheels, which holds up the solar panels and linear motor actuators. The solar panels are set up on a frame that moves at an optimal angle, facing the sun throughout the day, and energy is stored into batteries to be later applied to an external load. The project also aims to deploy energy to a smart grid to simulate reserve battery storage that can power a utility grid during a blackout or when normal energy generation methods cannot supply energy demands. The main design improvements in this project were replacing individual solar cells with solar panels, replacing the existing battery chemistry utilized, and creating a system that charges and discharges two batteries at different rates. This means that one battery is charged/discharged before the next battery is utilized.

Methods

Previous teams who worked on the automated solar tracking system project had opted to use individual solar cells as their desired type of "solar" used in the project. The individual solar cells were soldered together and placed in a series configuration around the frame, which produced an amplified voltage and relatively consistent current at the output. However, this configuration was not durable over time. The solar cells did not withstand exposure to high heat and physical impacts to the frame, resulting in cracking and poor condition upon inspection of the project in the 2022-2023 school year. This suggests that the individual solar cells were not suitable for use in the project, particularly in areas subject to debris, weather elements, and physical impacts.

As the previous individual solar cells proved to be unsuitable for use due to their fragility and vulnerability to damage, our team decided to source whole pre-built solar panels that were durable and mounted directly to the frame. Because the previous system was in a series configuration, if just one cell was damaged or shaded, energy production would be suspended at the output until the entire system was unshaded again. Repairing the cracked solar cells proved difficult, as the cells were wrapped in silicon material and were delicate to move. Cells that were functional and intact eventually cracked when trying to remove and replace already damaged cells. By changing the solar panel configuration from series to parallel and using whole pre-built solar panels, our team had no issue with the system having no power output when shading occurs.

The previous project teams utilized lead-acid batteries in their system, as they were much cheaper than lithium-ion batteries and easier to implement at the time. However, lithium iron phosphate (LiFePO4) batteries are now considered a better alternative to lead-acid batteries. LiFePO4 batteries have reduced in price through the years and are comparable to lead-acid batteries in terms of capacity. They are also lighter in weight and can be placed in any orientation, while lead-acid batteries are heavier and can only be placed upright due to the liquids contained within the battery enclosure. LiFePO4 batteries require little to no maintenance, while lead-acid batteries need to have their liquids properly maintained over time. The composition of LiFePO4 batteries makes it easier to recycle and reuse them at the end of their lifespan after being recharged for 3000-5000 cycles, while lead-acid batteries are not easily disposed of or recycled and typically only last for up to 1000 charging cycles.

The previous teams had several different methods for switching between charging and discharging the batteries. The initial team used MOSFET transistors but had difficulty managing the high voltage and current being run through them. The next team used relays but had trouble accurately measuring the correct voltage when a load or charge was applied to the batteries. They also encountered difficulty with a buck converter they used to step down the voltage, as this was the voltage they could only read from the batteries and not the true battery voltage. The current team decided to implement single pole, double throw (SPDT) relays alongside a dedicated charge controller. The relay was rated for 12V/30A, which exceeded the system's specifications. By using a dedicated charge controller, the team was able to check the battery voltage via a voltage divider circuit and an Arduino microcontroller. The voltage slightly changes when the battery is charging and discharging, so the offset was coded into the Arduino program to ensure accurate battery percentages no matter what state the battery is in.

Results

The solar panels installed by our team were significantly more durable compared to the previously used individual solar cells. The solar panels were given a rating of IP67, indicating their significant resistance to dust and water, while the junction boxes were rated IP65. With a rated output capacity of 200W, the solar panels represent a 25% increase in energy generation compared to the individual solar cells. The enhanced durability and increased energy output of the solar panels make them well-equipped to withstand weather elements and provide reliable, efficient energy generation.

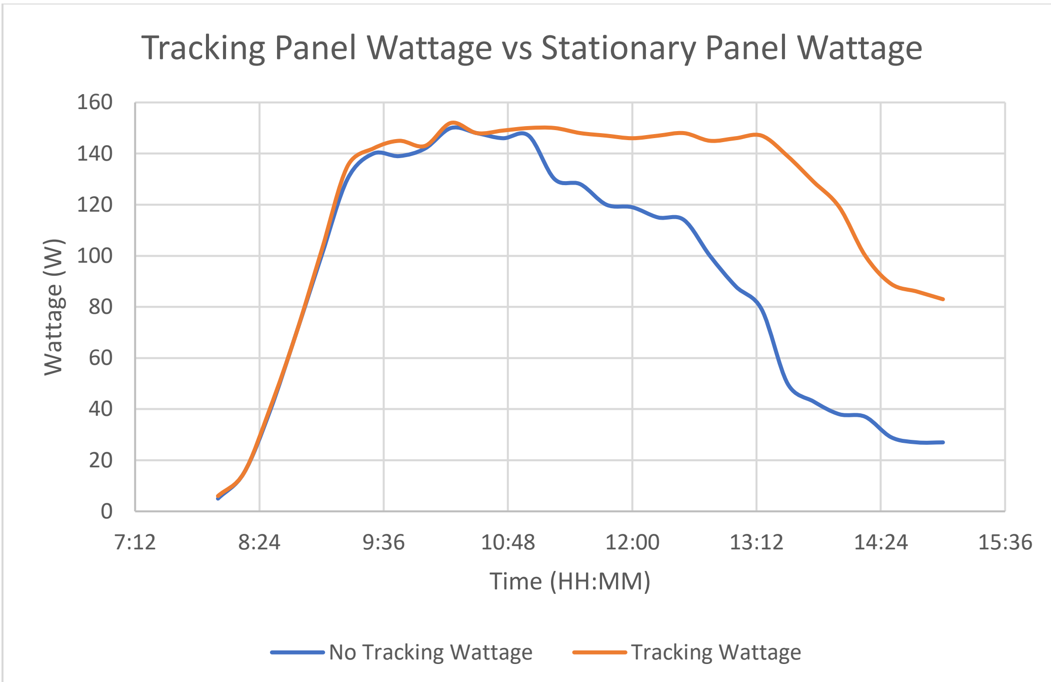

Figure 1: Solar Wattage Output over Time Comparison with and without Tracking

As shown in the figure above, testing the solar panels with the actuators resulted in an increase in energy production throughout the middle of the day compared to when the panels were left at a stationary position. At 1:30 PM, the stationary solar panels reported an output of just 50W, while the tracking solar panels reported an output of 139W. The tracking solar panels were outputting 2.78 times more energy than the stationary solar panels and can sustain more energy generation throughout the day compared to the stationary solar panels.

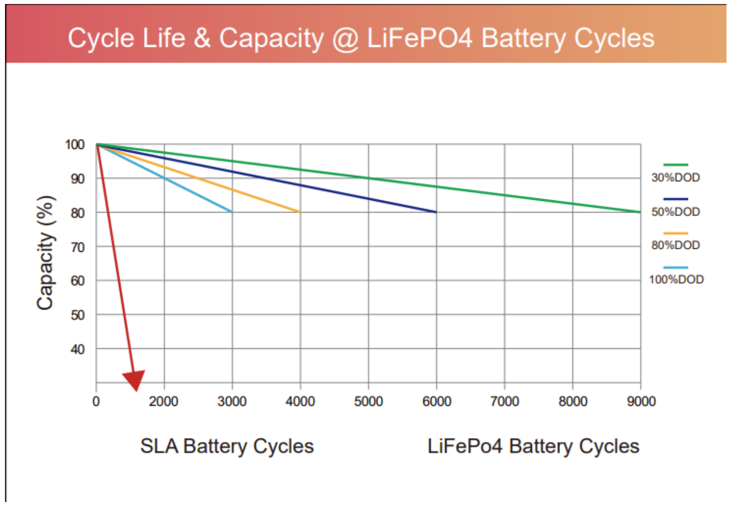

Figure 2: Battery cycles based on depth of discharge of lead acid and lithium iron phosphate batteries

The figure above shows the longevity of LiFePO4 batteries and how many cycles they can charge compared to lead-acid batteries. Most lead-acid batteries only have a 50% depth of discharge (DoD) rate before entering a hazardous state of charge, meaning that only 50% of the battery capacity can be utilized before charging is needed to prevent harmful effects on the lifespan of the battery. Repeatedly going to this SoC rate will shorten the battery's lifespan and can cause potential damage when brought to a low enough SoC rate. In contrast, LiFePO4 batteries can use 100% of their battery capacity and can have longer lifespans if not fully discharged every time they're utilized. For example, a battery that is usually only discharged 30% can last up to 9000 charging cycles and retain 80% of its capacity, while a battery that is usually discharged to 100% can last up to 3000 charging cycles and retain 80% of its capacity. The batteries utilized in the project were two 12V 20AH LiFePO4 batteries, with a combined capacity of about 480Wh. The smart grid the batteries were providing backup power to consumed approximately 120W at max load. With two fully charged batteries, the smart grid could be supplied with about four hours of continuous off-grid main power at max load.

Conclusion

The automated solar tracking panels with battery storage project was significantly improved upon and offers a glimpse into how renewable energy can power the electricity grids of the future. With better solar panels that are more durable and efficient available at a cheaper price, our team was able to implement improved technology and designs into the project. The use of $LiFePO_4$ batteries provides more energy for operation while being safer and more recyclable than lead acid batteries. For future improvements, an automatic control can be implemented to return the solar panels to their resting position in the morning, and changes can be made to the methodology used to acquire the battery's state of charge. This could include the use of the coulomb counting method to obtain an accurate state of charge regardless of the battery's current state. Overall, the project serves as an example of how renewable energy and battery storage can provide a reliable backup source of energy during grid failures and blackouts.

References

[1] “California Solar,” SEIA - Solar Energy Industries Association, https://www.seia.org/state-solar-policy/california-solar (accessed May 9, 2023).

[2] *Cycle Life & Capacity @ LiFePO4 Battery Cycles*.

[3] “U.S. energy information administration (EIA),” Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA), https://www.eia.gov/tools/faqs/faq.php?id=427&t=3 (accessed May 7, 2023).