Design of a Solar Energy System with Smart Controller Capable of Weather Prediction and Acting as a Virtual Power Plant (VPP)

Tennessee State University

Department of Electrical and Computer Engineering

Students: Cameron Fagan, Richard Wiencek

Project Advisor: Dr. Sagnika Ghosh

Sponsors: EPRI GridEd

Acknowledgement:

This report is to acknowledge EPRI GridEd for allowing the opportunity to implement this project and acknowledge Dr. Sagnika Ghosh for advising the team with weekly check-ups to ensure that this project can be completed successfully. Also, the opportunity to showcase the design to such a positive electrical and computer engineering related field of work to be completed and demonstrated.

Abstract:

The purpose of this project is to improve the quality of modern-day systems that utilize and distribute Solar Energy by means of implementing technology advancements which include access to smart devices to provide a convenient way of generating and monitoring Solar Energy. This is achieved by improving the efficiency of collecting solar energy by designing a Solar Tracking system to collect the most amount of energy throughout the day from the sun, during morning, mid-day, and afternoon. An Energy Regulating system will also be designed to efficiently output a constant voltage from the input of the Solar Panel that will be used to store the energy into a rechargeable battery that will be monitored from a smart controller to manage the charging and discharging of the battery that will also present battery information, that includes battery percentage, charge and discharge time, input/output power, and energy onto a smart device. This monitoring system will also collect weather information to help the user plan for days when collecting Solar Energy is scarce. This will be used to observe how collecting weather information can improve the quality of Energy Monitoring systems. Finally, the system will also have an Inverter to convert the DC power from the input to AC power to work with electronic devices that are designed for AC electricity.

Introduction:

When it comes to engineering design, it is important to consider the environmental impacts that the system design will have, and in this modern society one industry can help or damage the environment, generating power. There are multiple ways on how power is generated, from generating power from burning fossil fuels to generating power from the sun through solar panels. Generating power from burning fossil fuels can be destructive to the environment and is classified as a nonrenewable resource, which means the use of this resource is limited. Whereas, generating power from solar panels is clean and environmentally friendly, according to the U.S. Energy Information Administration, “Solar energy systems/power plants do not produce air pollution or greenhouse gases. Using solar energy can have a positive, indirect effect on the environment when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment” [1]. So, utilizing solar power will be needed to reduce emissions and supply clean, sustainable energy to consumers that will last until the sun dies out. According to the U.S. Energy Information Administration, about 12% of the energy generated is from renewable sources and

11% of it is from solar [2]. By the year 2030, the percentage of energy generated from solar is expected to increase to 13% of all the energy generated [3]. Which means it will be more than all the renewable energy generated today. This shows that switching to solar will be a very good decision to generate energy.

Background:

A Solar Tracking System is a system that follows the path of the sun its solar energy that comes from where the sun is positioned in the sky. By doing this, more generated solar power can be used throughout the course of a day. The solar tracker is connected to solar panels in most cases. The key is to make sure the solar panel generates the most electricity for use. To do that the solar panel has to be perpendicular to the light of the panel. Which is why the solar tracker is needed to make the necessary rotation of the panel that goes along axes typically altitude and azimuth to constantly be in the path of the sun [4]. It's predicted that 25 percent more solar energy will be collected from solar energy than the use of solar tracker compared to fixed solar panels. A particularly important thing to mention is that the solar tracker needs to stay in focus or center collectors that will not work well if it's not in the path of the sun directly. When adjusting the optics or speculum near the presents of the given focal point. In the design the single axis mount in the rotating axis is in the path of the mount [4]. As the design tracks down the sun, there will be a single rotation that goes from east to west. Typically, the sun goes at 15° per hour since the rotation of the Earth rotates 360° in 24 hours. Solar trackers are a staple to the solar industry [4]. In the winter season shorter days will happen that show the sun coming up from the south of east and sets south of west and the noon angle is the lowest point. Summer would be the most efficient time as the days are longer and the sun rises north of east and sets north of west. When it's noon the peak angle for the sun on the equinox is 90 degrees, that is the latitude. For the summer solstice is displaced at 23.38° or more but at winter solstice is 23.38 less than that value [4].

An Energy Regulator is an electronic device that is designed to take an input with a varying voltage level and output a specific constant voltage level, and this is necessary for this project, because the input from a solar energy source might vary the voltage level under certain conditions, and when working with sensitive electronics like microcontrollers, or energy storage devices, it is important to have a constant voltage level powering those devices, so they don't break. One type is a Switching Regulator. This is a type of voltage regulator that uses a switching element to transform the input DC signal into a pulsed voltage, which is then smoothed using capacitors, inductors, and other elements. One example is a Buck-Boost converter which is an electronic device that can step-up or step-down the input voltage to a constant value at the output, and in this system will be used to charge a rechargeable battery to store the energy from the Solar Panel efficiently to ensure the user has power for times when it is difficult to generate power from solar.

When working with Solar Energy it is important to know that energy can only be generated when the sun is out, which is why an energy storage device is required to meet the energy requirements of a user to reliably utilize electronic devices during times when collecting Solar Energy is difficult. Before using an energy storage device, or a rechargeable battery, a Battery

Monitoring system will be required to ensure that the battery is charging properly and efficiently by monitoring the input/output voltage and current values to determine the time to charge/discharge, percentage of charge, power and energy being used. Another thing to consider when utilizing Solar Energy with an energy storage device is the weather, because it can help determine how much power can be supplied by considering future weather conditions. This will be done by utilizing a smart controller with the Energy Monitoring system that can also be used to collect weather information in the Monitoring system to plan for days when collecting Solar Energy is scarce. This will be done by utilizing OpenWeatherMap.org which is an online service that can provide weather data via API for any geographical location [5].

An Inverter is a power electronic device which converts a DC input into an AC output which can then be used to step up the voltage easily utilizing a transformer. One type of Inverter that can be used to power on AC electronic devices is a Square-Wave Inverter. This type of Inverter will be constructed by using an electronic circuit known as an H-Bridge circuit, which consists of four switches that will be controlled by a microcontroller to generate the Square-Wave signal. This signal will then be amplified utilizing a transformer to power on electronic devices that are designed for AC electricity.

Design Objectives:

As part of this project, we intend to build a prototype for a solar energy system capable of optimizing energy usage. An integral part of this system is the smart controller. The smart controller predicts energy generated by solar panels taking into consideration weather patterns and recommends energy utilization based on the user's energy demand patterns.

As shown in Fig. 1, the solar energy system will have an energy storage system that will provide power during times when the solar panels cannot meet the energy demands, it will have a solar tracking system with the solar panel(s) that will attempt to maximize the amount of energy that can be generated and will have an inverter to supply power to electronic devices. The smart weather predicator controller (ESP32) will be able to make estimations of the power generated and the power stored in energy storage devices and calculate the amount of power required for the loads by predicting the weather. All of this will be monitored by a smart energy management system that will give estimations on the amount of power depending on weather conditions, in Tennessee.

The solar tracker shown in Fig. 2 used a laser cutter wood for the body frame of the design. The parts used in this design were an SG-90 motor, an Arduino Uno for the microcontroller, and four photoresistors. The SG-90 motor helps move the design in different directions so that it can stay in the same path as the light source beaming down on the solar tracker four photoresistors. The functionality of the design ran on the program for the Arduino Uno microcontroller and the Arduino software.

The Energy Regulator utilizes an Arduino Nano microcontroller to control the functionality of the Buck-Boost Converter to take an input voltage with a varying range of about 8 to 16 V and output a constant 13 to 14 V which can be used efficiently to charge a 12 V Lead-

Acid Battery with a capacity of 12 Ah.

The design will use one Ina219 Breakout Board, one Relay module, one TC4420 MOSFET Driver IC, one N-Channel MOSFET, one 10 kΩ Resistor, two 22 kΩ Resistors, two 4.7 kΩ Resistors, one 100 µH Inductor, one 100 µF Capacitor, one Diode, and one LM741 OPAMP, for the feedback system.

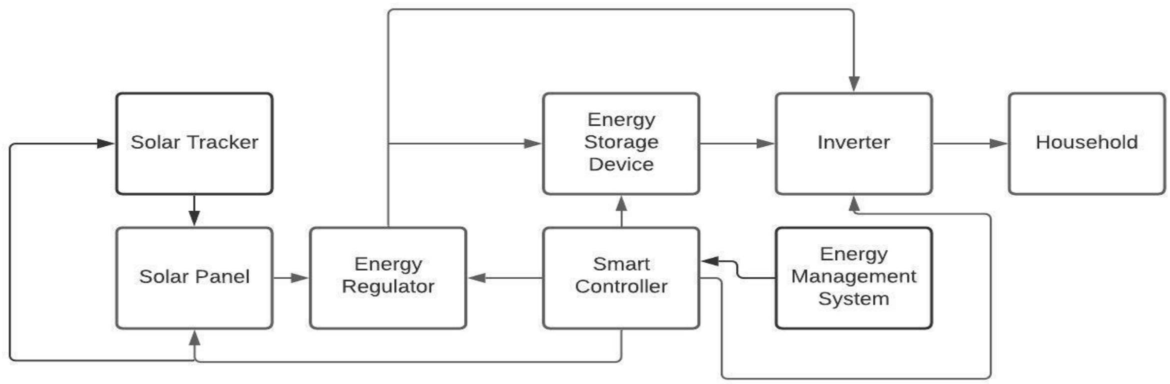

Figure 1. Functional Block Diagram

The Monitoring System will utilize an ESP32 microcontroller that will act as the smart controller using two Ina219 voltage/current sensors that will monitor the charging and discharging of the 12 V Lead-Acid Battery by doing the calculations for the percentage of charge, input/output voltage and current, charge/discharge time, and energy which will be presented on a smart device utilizing an open-source software known as Blynk which allows a smart controller like the ESP32 microcontroller to connect to a smart device like a computer to present data or notifications on an easy-to-use application. The monitoring system will also be collecting weather information from OpenWeatherMap.org that will help the user and the system plan for days when collecting solar energy will be scarce based on the state of the battery, and the power being used.

The inverter will utilize an Arduino nano microcontroller to control two P-Channel MOSFETs, and two N-Channel MOSFETs that will turn them off and on using two TC4420 MOSFET Driver ICs, and four 10 kΩ Resistors. The MOSFETs will be configured in an H-Bridge circuit which will convert the 12 V DC from the source to a 12 V AC signal that will be amplified to 120 V AC using a transformer. The Inverter will be used to output power to loads that will be supplied from the solar power source and battery.

Figure 2. Solar Tracking System

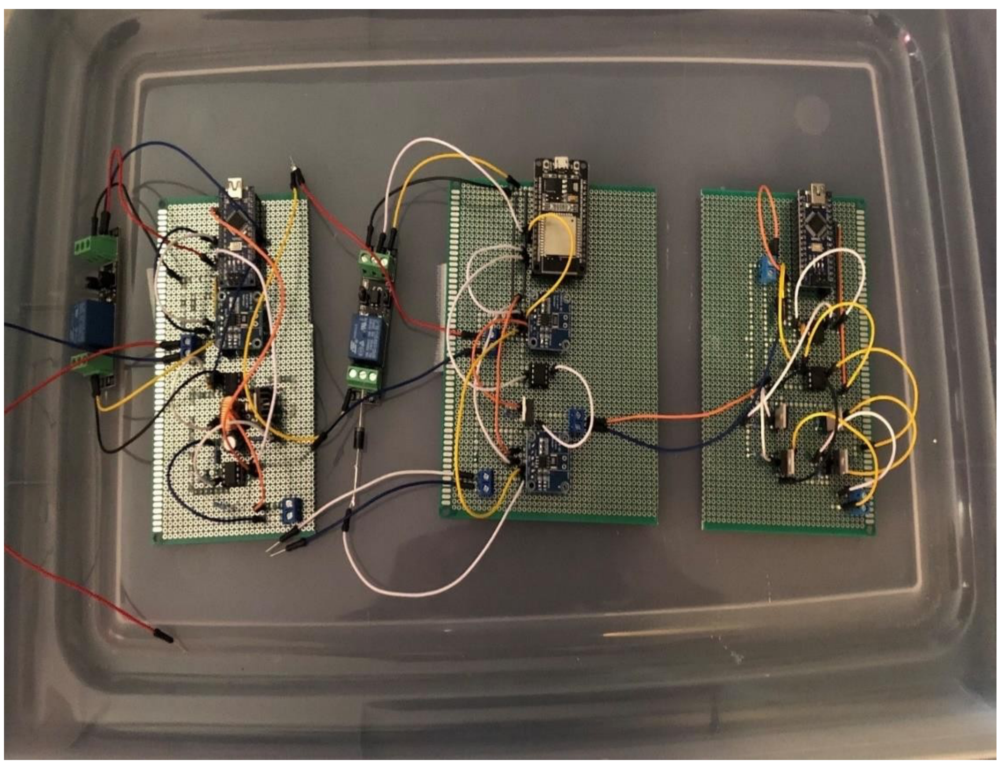

Figure 3. Energy Regulator, Battery Monitoring System, and Inverter Design

These designs will be used together to supply power to loads that are designed for 120 V AC. Figure 4 below shows the results from battery monitoring system using Blynk to see the results on a smart device.

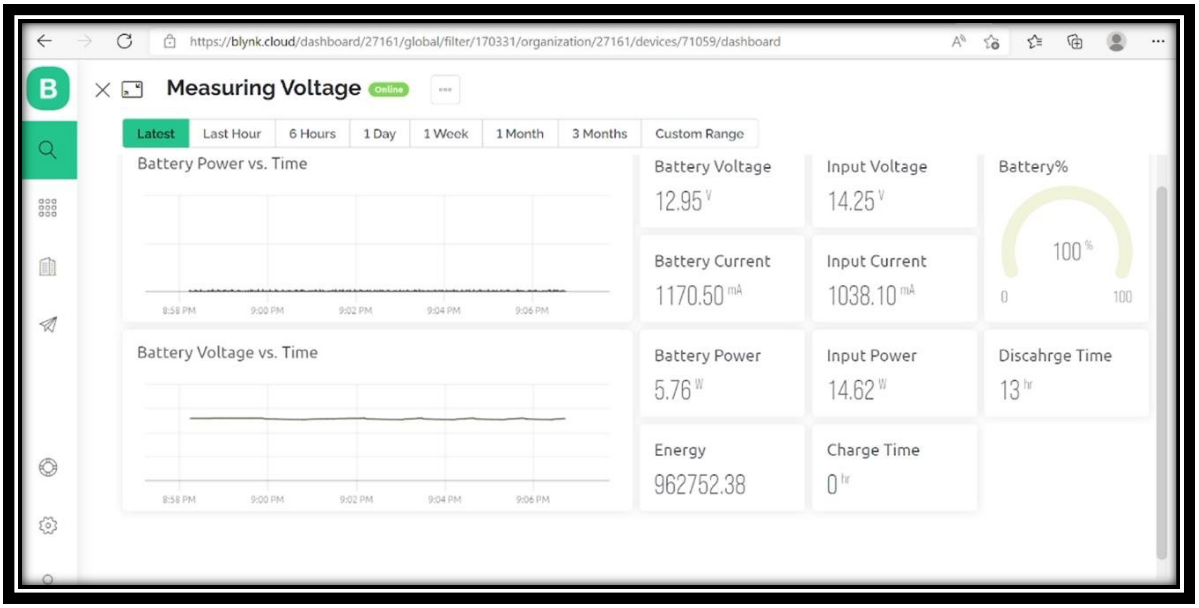

Figure 4. Results from Battery Monitoring System

The results show that the Energy Regulator is charging the 12 V Lead-Acid Battery which is shown to be at 100% with a voltage of 12.95 V, because it is currently charging and will continue to charge until the battery voltage is 13.00 V. The output voltage from the regulator shows that it is charging the battery with a voltage of about 14.25 Volts and a charging current of about 1,038 mA, this value can be used to calculate the time for the battery to be fully charged, which is shown to be 0 hours, because the battery voltage is about to approach 13.00 Volts, but the battery shows that it will last about 13 hours on a full charge while supplying about 1,170 mA. This is because the Monitoring System is connected to the input of the Inverter that is converting the DC power from the battery into AC power that is being used to power on a load rated for 120 V and 3 Watts, but the battery output power is shown to be about 5.76 Watts. The reason why there are about 2.76 Watts of power not being used by the actual load is because the microcontrollers, the sensors, and the electronic devices require power to distribute and monitor the power from the source and battery to the load. The Monitoring system is also collecting weather information from OpenWeatherMap.org that was used with respect with the state of the battery and power being used to notify the user when the weather will cause a decrease in the amount of available power that can be generated to help plan for days when generating power will be scarce.

Conclusion:

This project demonstrated the design of a Solar Energy system with a Solar Tracking system that was designed for a solar panel that allowed tracking of the path of the light beaming down on the dual sensor based solar tracking device to ensure the maximum amount of power being generated. An Energy Regulator was designed to ensure that the output voltage was a constant value of 13 V to 14 V to charge a 12 V Lead-Acid Battery that was being monitored with a Battery Monitoring system that was designed to monitor the input/output voltage and current values to determine the time to charge/discharge, percentage of charge, power and energy being used. The Monitoring system was designed with a smart controller that was capable of weather predictions to notify the user about the available energy, user's consumption, the weather so the system and user can plan to ensure power will always be utilized. Finally, an Inverter was designed to convert the DC power from the sources to AC power that was used to replicate the power that is supplied to consumers.

Recommendations:

The rotation of the dual sensor based solar tracking device shows some hesitation within the design sometimes that creates some problems. Specifically, when figuring out which LDR (Light Dependent Resistors) photoresistor should depend on for power generation. This helps with determining how the dual sensor based solar tracking device should rotate in response to the beaming of the light in use for solar energy. A more stable platform to help with the rotation of the device.

The Energy Regulator can be improved by utilizing a Synchronous Buck-Boost converter that replaces the diode with a MOSFET to decrease the power loss and increase efficiency but would require more controls to be programmed by the microcontroller. For the Monitoring system implementing cybersecurity protocols could help ensure that the values weren't manipulated, considering the monitoring system utilizes a Wi-Fi based microcontroller. For the Inverter, it can be improved by including a feedback system to increase the output voltage when there are voltage drops that occur when adding new loads to the output, and adding flyback diodes to the H-Bridge circuit to protect the MOSFETs from any voltage spikes that would occur when powering off the inverter, because the transformer would discharge all its stored energy into the H-Bridge circuit, when the magnetic fields around the coils start to collapse.

Refernces:

[1] *U.S. Energy Information Administration - EIA - independent statistics and analysis*. Solar energy and the environment - U.S. Energy Information Administration (EIA). (n.d.). Retrieved May 2, 2022, from https://www.eia.gov/energyexplained/solar/solar-energy-and- the-environment.php

[2] *U.S. Energy Information Administration - EIA - independent statistics and analysis*. U.S. energy facts explained - consumption and production - U.S. Energy Information Administration (EIA). (n.d.). Retrieved May 2, 2022, from https://www.eia.gov/energyexplained/us-energy-facts/#:~:text=The%20percentage%20shares%20and%20amounts%20%28in%20quads%29%20of,liquids%29%2031%25%2031.8%20quads%20coal%2014%25%2014.3%20quads

[3] Newman, N. (2017, January 20). *10 energy predictions for 2030*. Nicnewmanoxford.com. Retrieved May 2, 2022, from https://www.nicnewmanoxford.com/10-energy-predictions-2030/

[4] "Solar Tracker Arduino Project." Clean Energy Institute, 29 Sept. 2021, https://www.cei.washington.edu/lesson-plans/solar-tracker-arduino-project/.

[5] OpenWeatherMap.org. (n.d.). *Current weather and forecast*. OpenWeatherMap. Retrieved May 2, 2022, from https://openweathermap.org/