Hybrid, Semi-Passive Solar Harvesting System

Austin Etzel
Michigan Technological University
ajetzel@mtu.edu

Dustin Long
Michigan Technological University
dmlong@mtu.edu

Joe Mayrose
Michigan Technological University
jwmayros@mtu.edu

Aleksandr Sergeyev
Michigan Technological University
avsergue@mtu.edu

Abstract

There are various solar systems installed around the globe. Some systems are designed to track the sun, and others are fixed panel systems. The stationary systems lose potential power since most of the time they are not perpendicular to the sun. This purpose of this project is to investigate the viability, at high latitude (>40°), of having a solar system track the sun throughout the day. By adjusting the angle of the panels, the solar panels capture power that would typically be unattainable through a fixed panel system. This project uses a set of actively controlled solar panels and a set of stationary panels to compare power collected on any given day. The power generated from these panels is fed into a charge controller, which charges a set of deep cycle batteries. Voltage readings are taken to allow for accurate comparison between the fixed and tracking solar panels. By comparing the data between the two sets of panels, a net power increase of up to 30% is achieved.

Introduction

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants, and artificial photosynthesis. To capture solar energy, a solar tracker can be used. This is a device that orients a payload toward the Sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, lenses, or the mirrors of a heliostat. For flat-panel photovoltaic systems, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generating capacity. In standard photovoltaic applications, it was predicted in 2008-2009 that trackers could be used in at least 85% of commercial installations.

In 2017, the US Energy Information Administration announced that more than half of the utility-scale photovoltaic systems track the sun throughout the day (Today, 2017). A significant amount of research has been conducted on the feasibility of utilizing solar tracking systems and their advantages (Mousazadeh, Keyhani, Javadi, Mobli, Abrinia, & Sharifi, 2009; Chong & Wong, 2009; Abdallah & Nijmeh, 2004; Al-Mohamad, 2004; Eskiçirak, Akyol, & Karakaya, 2014). The systems that require manual adjustments of solar panels have significant disadvantages due to lower efficiency and manual labor involvement. The goal of this project is to establish if an open-loop, single axis, active tracking system is viable in high latitude (>40º) locations. Directly comparing the power generation from a fixed and tracking panel system can determine the effectiveness of the system.

Project Rationale

As the efficiency of solar panels rises, it becomes more and more advantageous to implement solar tracking systems in residential and small commercial applications. These tracking systems should provide an increase in power by spending more time perpendicular to the sun.

There are two main categories of tracking systems, open-loop and closed-loop. Open-loop systems rely on known coordinates for both solar azimuth and elevation. These systems operate based on solar positioning and can be accurate down to thousandths of a degree. Also, since no sensor feedback is required, the system is less complex. Closed-loop systems use different forms of light sensors to keep the array perpendicular to the sun (Safan, Shaaban, & El-Sebah, 2017; Reddy, Chakraborti, & Das, 2016). These systems are more sensitive to partial shading or covering with snow or dust due to the high voltage levels provided by the perpendicular panels. Another type of closed-loop system uses the panels themselves as light sensors (Sharma, Vaidya, & Jamuna, 2107). This system has similar problems as other closed-loop systems, with the added disadvantage of limiting panel connections. Another disadvantage of closed-loop systems is the hunting time. For a one-axis tracker, the array continues to move until the power has gone down and then moves back into the maximum power position. Dual-axis trackers frequently update the position based on the readings from light sensors; anytime this happens, the control system must take a minimum of three readings before settling on a point. In both cases, excess power is consumed by running the motors and controllers more often. This is especially true in the dual-axis tracking system (Bahrami, Okoye, & Atikol, 2016).

Figure 1. Photograph of fixed and tracking system setup.

System Overview

This project focuses on the use of a hybrid tracking panel array. This type of system uses an open-loop system to automatically track along the solar azimuth and a manual adjustment for the altitude of the panels. At northern latitudes, the azimuth of the sun changes much more than the altitude throughout the day. Due to this, active tracking along the altitude would increase the complexity of the system with no significant gain in performance.

Since solar intensity varies from day to day, a set of stationary panels and a set of tracking panels are used simultaneously, allowing accurate daily comparisons of data. Figure 1 shows a picture of the tracking and fixed systems; the tracking system is on the right and the fixed system on the left. An Arduino MEGA R3 controls the linear actuator to track the sun across the azimuth, and it monitors the voltages of the solar panels. This system uses pre-programmed angles to move the tracking panels throughout the day, changing the solar tracker angle every half an hour. Information such as location of the system and date and time information were used to calculate the required angles for adjustment of the panels (Gronbeck, 2009). The voltage from the panels is fed into a charge controller, which regulates the output to the battery array for effective charging. An inverter is connected to the battery array to allow for an AC output. Grid integration is possible with this system, provided that the inverter outputs a complete sine wave. Less expensive inverters output a modified sine wave that is not as efficient and are not compatible for grid integration.

Figure 2 shows the main components as they are connected in the system. The tracking and fixed solar panels are Renogy RNG-100D 100W models (Renogy, 100W, n.d.). These were chosen for their balance of efficiency and cost. The linear actuator is from Fergelli Automations (Model FA-PO-150-12-8). It has a 150lb lift capacity and an 8-inch stroke with Bournes potentiometer feedback. The position feedback is crucial to accurate angle measurements. The Arduino used is a MEGA R3 with an Adafruit assembled data-logging shield (Earl, 2017). The data-logging shield was used both for voltage measurements and for the feedback sensor on the linear actuator. The charge controller is an Outback Solar FlexMax 80A (Outback, 2017) with maximum power point tracking. The MPPT model was chosen for its high efficiency and high mobility due to its pre-wired configuration with a pure sine wave inverter.

The battery storage bank consists of 4 Renogy 100Ah deep cycle gel cells (Renogy, 100Amph, n.d.) , chosen for their ability to withstand 1000 cycles to 50% depth of discharge (DOD), while a similar AGM battery would only withstand 600 cycles to 50% DOD.

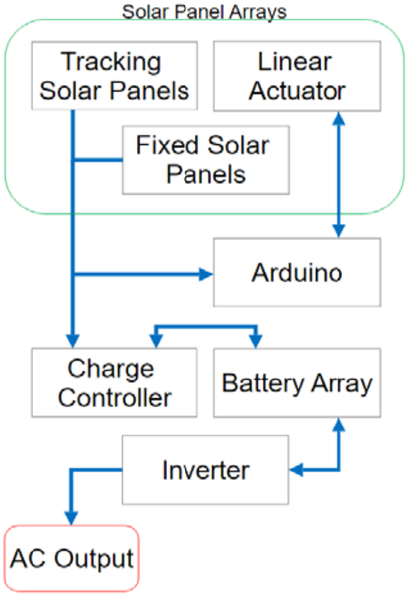

Figure 2. System component flowchart.

Figure 3 shows the full schematic of the system. The six solar panels are connected in series for most efficient power transfer. The voltage of the four fixed panels is measured as well as the full voltage of all six panels. The voltage measurements of the panels are too large for the Arduino to measure directly, so two voltage dividers are implemented to effectively reduce the voltage. The voltages are then calculated in the code using the reduced voltage from the voltage dividers and recorded to the SD card for further study. The Arduino controls a pair of 12V, 30A relays to control the linear actuator. The Arduino also outputs a 5VDC signal that is used on the linear actuator for potentiometer feedback as well as to power the motor control relays.

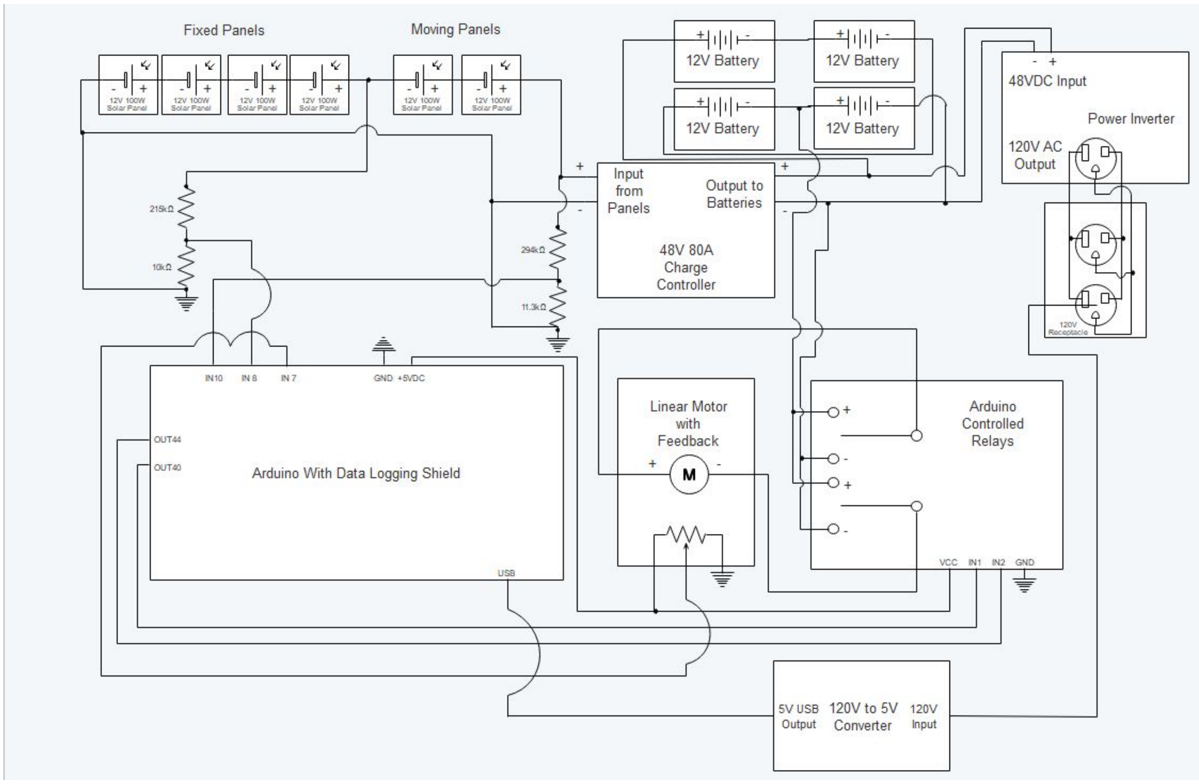

Figure 3. System schematic.

Programming Approach and System Operation Modes

The main approach when writing the code and deciding operation modes was to create the code to be efficient, resulting in the Arduino consuming less power and improving the efficiency of the system as a whole. The code has three basic operation modes: rest, stationary data collection, and data collection with panel movement. The start and stop times of these three modes are based on the sunrise and sunset times for the current month.

Rest mode is set to start at sunset and end at sunrise. These specific times are set by the user at the beginning of each month, since sunset and sunrise are not at constant times throughout the year. When the controller first enters rest mode, it moves the panels to the correct position for the morning sun and then wait until sunrise.

Stationary data collection mode happens at two separate time periods during the day. The reason for a separate data collection mode outside of the panel movement with data collection mode is due to the mechanical limitations of the panel holder, which is discussed later in this paper. This mode operates from sunrise until the data collection with panel movement mode begins. This mode resumes operation at the end of the data collection with panel movement mode and operates until sunset. The stationary data collection mode takes voltage readings every 10 seconds and stores it to an SD card for later analysis. Due to the mechanical limitations of the panel holder, since the code keeps the panels aimed in the general direction of the sun when outside the movement range, there should still be an increased amount of power intake by the panels. This is why there are separate modes for just stationary data collection and data collection with panel movement.

Data collection with panel movement mode operates during the peak hours of solar intensity. This mode operates between three and five hours a day, depending on the time of year. The movement starts between 11:30 and 12 and concludes between 3:30 and 4:30, again, depending on the month. Due to the mechanical limits of the panel holder, the only azimuth angles (Bas, 2011) the system can adjust to are between -30º to 45º from due south. This means that panel adjustment only happens 8 to 10 times a day. While in this mode, the panels move every half an hour to a set angle, depending on the time and the month. As with the stationary data collection mode, this mode takes a data reading every 10 seconds and stores those data to the SD card for future analysis.

Figure 4 shows a flowchart of how the code and microcontroller operate throughout the day. The first part of the flowchart shows the startup procedures of the code, microcontroller, and data-logging shield. During the power-up phase of the microcontroller, the standard initializations of the microcontroller are executed. Next, the data-logging shield is powered on, and the microcontroller verifies it is functioning properly. Finally, the code checks to verify the presence of an SD card. It then creates a new CSV file on the SD card and labels the first line of the CSV file with the appropriate labels for the data being recorded. This part of code is only executed on startup and is then superseded by the loops shown on Figure 3.

Once the initializations have been completed, the code acquires the current time from the data-logging shield, which uses an onboard RTC (real time clock) chip to keep an accurate time. Depending on the time of day, the code goes into one of the three modes of operation as described above. The bottom loop of Figure 3 shows rest mode, which first verifies the panels are at their home position. If they are not at their home position, the microcontroller moves them back to their home position. The code then waits until sunrise to begin data-logging. The top loops of Figure 3 show both stationary data collection mode as well as data collection with panel movement mode. The microcontroller decides which mode to function in based on the time acquired from the data-logging shield (Solmetric, 2008). If the current time is within the preset timeframe for data collection with panel movement mode, the code then checks the time against the preset times for panel angle adjustment. If the current time matches the preset times for readjustment, the microcontroller adjusts the panels to the appropriate angle for the current time. If is not time to move the readjust the panel’s angle, the microcontroller then uses the data-logging shield to record the current data readings of the system. If the current time acquired from the data-logging shield is outside the timeframe for data collection with panel movement mode, the microcontroller then enters stationary data collection mode and only record data.

Cost and Parts List

Table 1 provides a list of each part and their associated cost. This table is provided to aid in the recreation of the design and to allow the data to easily be reproduced.

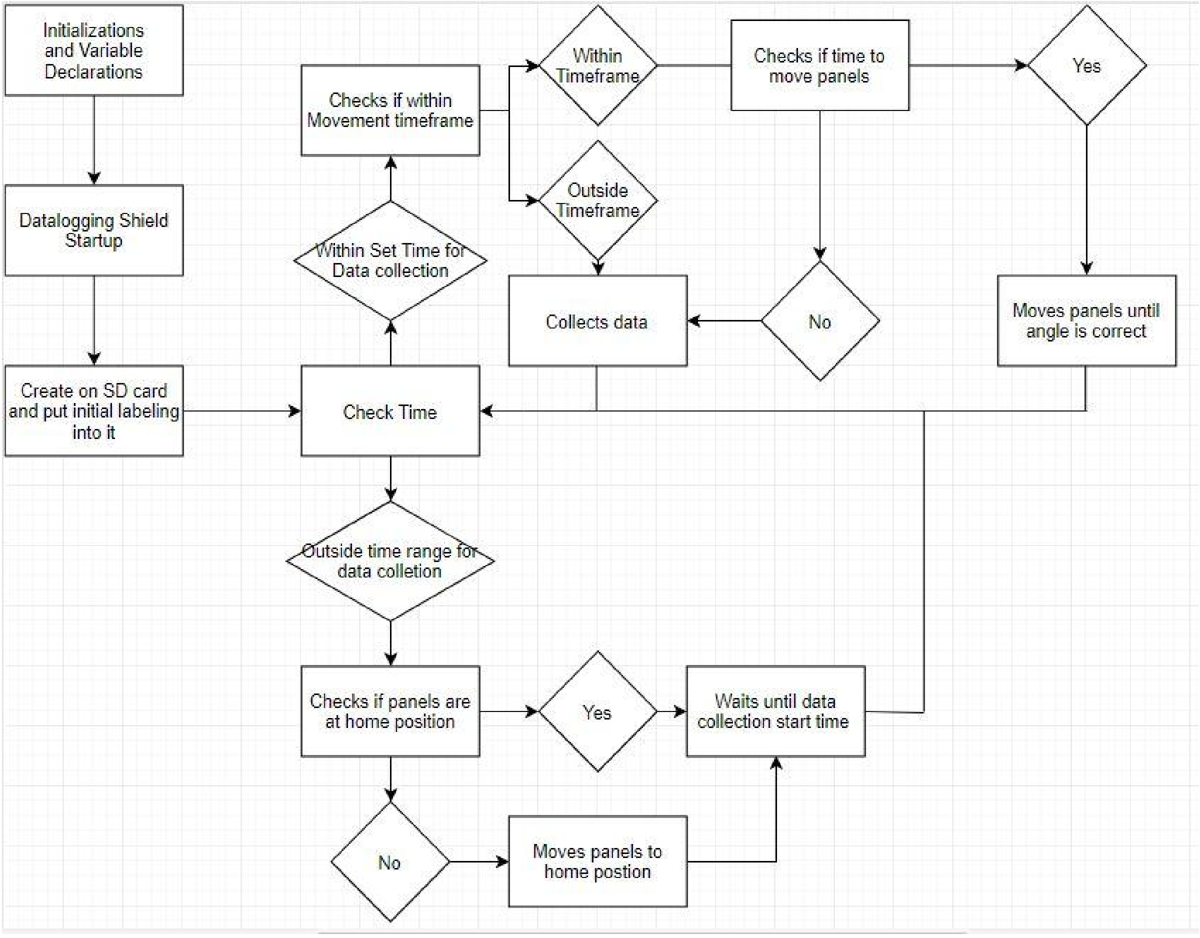

Figure 4. Microcontroller code flowchart.

Table 1. Detailed parts list and their associated cost.

Quantity	Item	Description	Cost per unit	Cost Total
1	Outback Power FP1 VFXR3648A solar kit	3600W 48VDC pre-wired MPPT charge controller and inverter system	$3660.10	$3660.10
2	Solar panel expansion	3 100W Renogy solar panels	$377.97	$755.94
2	Renogy battery	100Ah deep cycle battery	$229.99	$459.98
1	Arduino	Arduino MEGA R3 microcontroller	$44.95	$44.95
1	Data-logging shield	Adafruit Industries data-logging shield board	$12.99	$12.99
1	Relay	x2 12V 30A relay	$8.33	$8.33

1	Linear motor	Firgelli Automations 150lb Capacity 8in stroke with Bournes potentiometer feedback	$138.84	$138.84
2	Battery boxes	Outdoor grade with ventilation	$12.86	$25.72
1	Stationary frame materials	Assorted lumber and hardware	$70	$70
1	Miscellaneous	Connectors, hardware, and wiring	$100	$100
4	⅛" steel tubing	38' of tubing for tracking array frame	$150	$150
1	Waterproof case	Container for all the circuit and delicate instruments	$104	$104
			Total Cost	**$5370.56**

Data Collection and Analysis

Figures 5 shows a sample set of data acquired from the system. This data was collected using the Adafruit data-logger described above. The logger took a measurement every 10 seconds for around 5000 data points per day. The data collection started at 6:00 a.m. local time and lasted until 10:00 p.m. The average net voltage gain for Figure 5 shows that a tracking system is viable in high latitudes. Specifically, 4/27 shows a gain of 26%, 4/28 shows a gain of 21%, and 4/29 shows a gain of 17%.

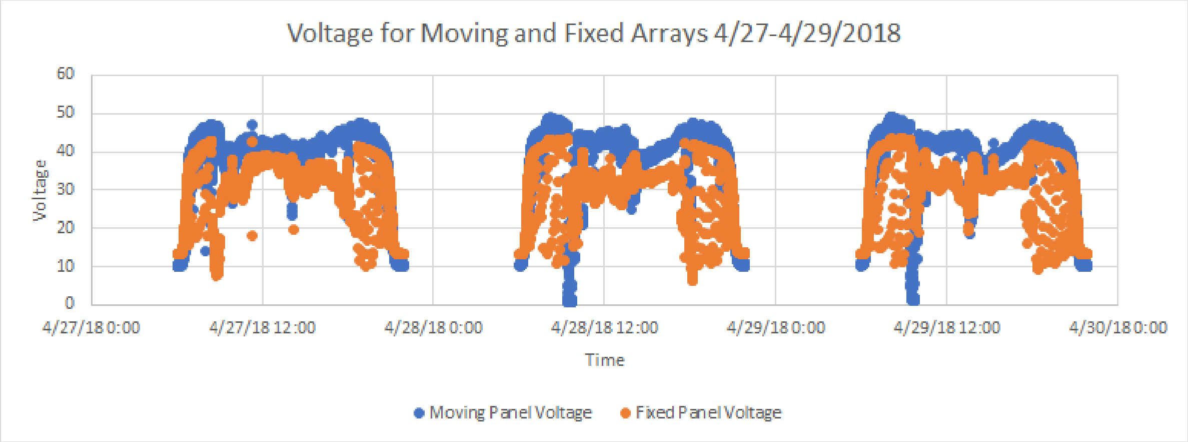

Figure 5. Voltage measurements for 4/27/2018 to 4/29/2018.

Because the panels are all wired in series, the difference in voltage will be proportional to the difference in instantaneous power.

Conclusions and Future Work

Short term data collection and analysis show the tracking system generates roughly 15 to 25% more power than a traditional fixed panel system. Due to limited data, further experimentation and analysis are required to reach a more definite conclusion as to the viability of a hybrid, semi-passive solar harvesting system versus a traditional fixed panel system. However, due to the amount of additional voltage gain and the consistency of the data, shown in Figure 5, it is evident that this system is could be feasible as a power-harvesting system.

Further data collection and analysis are needed to develop a more definite conclusion as to the viability of this system. The system is set up to collect identical sets of data throughout the coming months. To improve the accuracy of future data collection, a few upgrades will need necessary for the current system; namely, connecting the grid-tie compatible inverter to the electrical grid. This would allow for the best for data collection, as it would use all of the energy generated by the solar panels. Data collected during those months will then be used to further support or refute our claim.

Acknowledgments

The authors would like to thank the Michigan Technological University's School of Technology for sponsoring this project and providing the lab space for design and testing. Additional thanks to the School of Technology Machine Shop for their help in construction of the aluminum and steel framing, and to Dave Camps at Blue Terra Energy for his advice and comments on traditional fixed panel solar systems.

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Biographies

AUSTIN ETZEL is currently pursuing an undergraduate degree in Electrical Engineering Technology in the School of Technology at Michigan Tech. Contact Mr. Etzel at ajetzel@mtu.edu.

DUSTIN LONG is currently a student in the Electrical Engineering Technology program in the School of Technology at Michigan Tech. Dustin Long has a minor in data acquisition and industrial controls. Dustin Long works as the desk receptionist for Housing and Residential Life at Michigan Tech. Email Mr. Long at dmlong@mtu.edu.

JOE MAYROSE is currently pursuing an undergraduate degree in Electrical Engineering Technology in the School of Technology at Michigan Tech. Contact Mr. Mayrose at jwmayros@mtu.edu.

ALEKSANDR SERGEYEV is currently a professor in the Electrical Engineering Technology program in the School of Technology at Michigan Tech. Dr. Sergeyev's research interests include industrial control and automation, robotics, high energy laser propagation through the turbulent atmosphere, developing advanced control algorithms for wavefront sensing and mitigating effects of the turbulent atmosphere, digital inline holography, digital signal processing, and laser spectroscopy. Dr. Sergeyev is a member of ASEE, IEEE, SPIE, IAJC, PICMET, ATMAE, and is actively involved in promoting engineering education. Dr. Sergeyev may be reached at avsergue@mtu.edu.