AC 2009-354: A SUN-TRACKING SOLAR-POWER SYSTEM

Liping Guo, Northern Illinois University

Liping Guo received the B. E. degree in Automatic Control from Beijing Institute of Technology, Beijing, China in 1997, the M. S. and Ph. D. degrees in Electrical & Computer Engineering from Auburn University, AL, USA in 2001 and 2006 respectively.

She is currently an Assistant Professor in the Electrical Engineering Technology Program in the Department of Technology at the Northern Illinois University. Her research interests are mainly in the area of power electronics, renewable energy, embedded systems and control. Dr. Guo is a member of the ASEE, IEEE and a member of the honor society of Phi Kappa Phi.

Paul Curtis, Northern Illinois University

Andrew Barendregt, Northern Illinois University

Anthony Surillo , Northern Illinois University

Design and Implementation of A Sun Tracking Solar Power System

ABSTRACT

A senior design project is an integral part of the undergraduate engineering technology degree program requirements at a four-year engineering technology institution. All students are required to complete a two-semester long (4 credit hours) senior design project. Three electrical engineering technology undergraduate students formed a senior design project team to design and implement a sun tracking solar power system. A majority of solar panels in use today are stationary and therefore do not output the maximum amount of power that they can actually produce. This paper describes the senior design project that utilizes solar power to its full potential by tracking the sun throughout the day. The solar tracker follows the sun from east to west during the day. More energy is collected by controlling the solar panel to follow the sun like a sunflower. The solar tracking system is a mechatronic system that integrates electrical and mechanical systems, and computer hardware and software. The main components in the solar tracking system are standard photovoltaic solar panels (PV), a deep cycle rechargeable battery, battery charger, stepper motor, signal conditioning circuits and a BasicX-24p microcontroller.

INTRODUCTION

Solar energy conversion is one of the most addressed topics in the field of renewable energy. Solar radiation is usually converted into two forms of energy: thermal and electrical energy. The solar electricity has applications in many systems such as rural electricity, water pumping and satellite communications.

The efficiency of the photovoltaic (PV) system depends on the climate conditions of solar radiation, ambient temperature and wind speed, matching of the system with the load and appropriate placement of the solar panels. A majority of solar panels in use today are stationary and therefore do not consistently output the maximum amount of power that they can actually produce. A solar tracker will track the sun throughout the day and adjust the angle of the solar panel to make the sun normal to the solar panels at all times. The orientation of the solar panels may increase the efficiency of the conversion system from 20% up to 50%. [1-3]. The sun tracking solar power system is a mechatronic system that integrates electrical and mechanical systems, and computer hardware and software.

SYSTEM GENERAL DESCRIPTION

The initial requirements for this project were as follows:

- 5 watt to 10 watt solar panel
- Design structure to support 15 lbs
- Design enclosure to protect electrical equipment
- Use microcontroller to control and monitor the system

- Electrical and mechanical design to rotate the solar panel
- Algorithm to implement the tracking and control concept
- Portable system

The main components in the solar tracking system are standard photovoltaic solar panels (PV), a deep cycle rechargeable battery, battery charger, stepper motor, signal conditioning circuits and a BasicX-24p microcontroller. The block diagram of the system is shown in Figure 1. Three solar panels are used, two low voltage panels for system readings and one main solar panel to power the system. The main solar panel is rated at the voltage of 12 V and current of 0.59 A. The main solar panel provides all the power for the system and charges the battery. The other two small solar panels work as angle detectors. They are mounted on two 45 degree wedges to detect the exact angle in which the main solar panel must face to gain maximum power output. When the sun is perfectly normal, the voltages on both cells are equal, and solar panel stays in its position. However, if the main solar panel is not normal to the sun, the sun angles on the two small solar panels are different [4-6]. The microcontroller gives an output to the stepper motor based on the difference of voltages to rotate the main solar panel to be normal to the sun. The stand of the solar panel is made of plexiglass.

A picture of the solar tracking power system is shown in Figure 2. The picture shows the enclosure that houses the electrical components, the main solar panel and two small solar panels which present an angle of 45^{o} with the surface of the main solar panel. Components including the solar panels and charge controller, the rechargeable battery, microcontroller, stepper motor and drive will be explained. A solar tracker has single axis. The solar tracker follows the sun throughout the day, facing east in the morning and west in the afternoon. Manual elevation is adjusted based on seasons throughout the year.

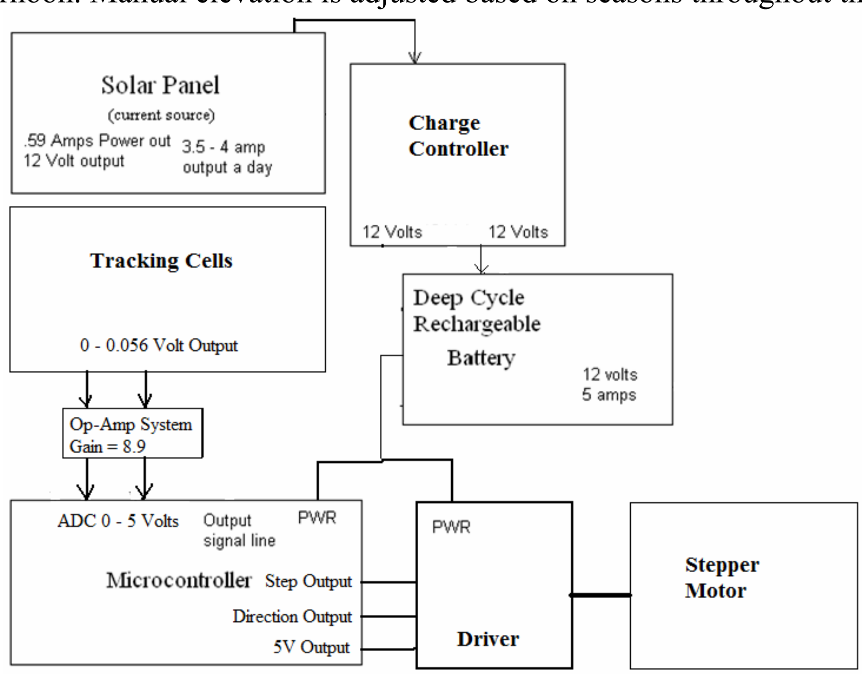

Figure 1. Block Diagram of Solar Tracking Power System

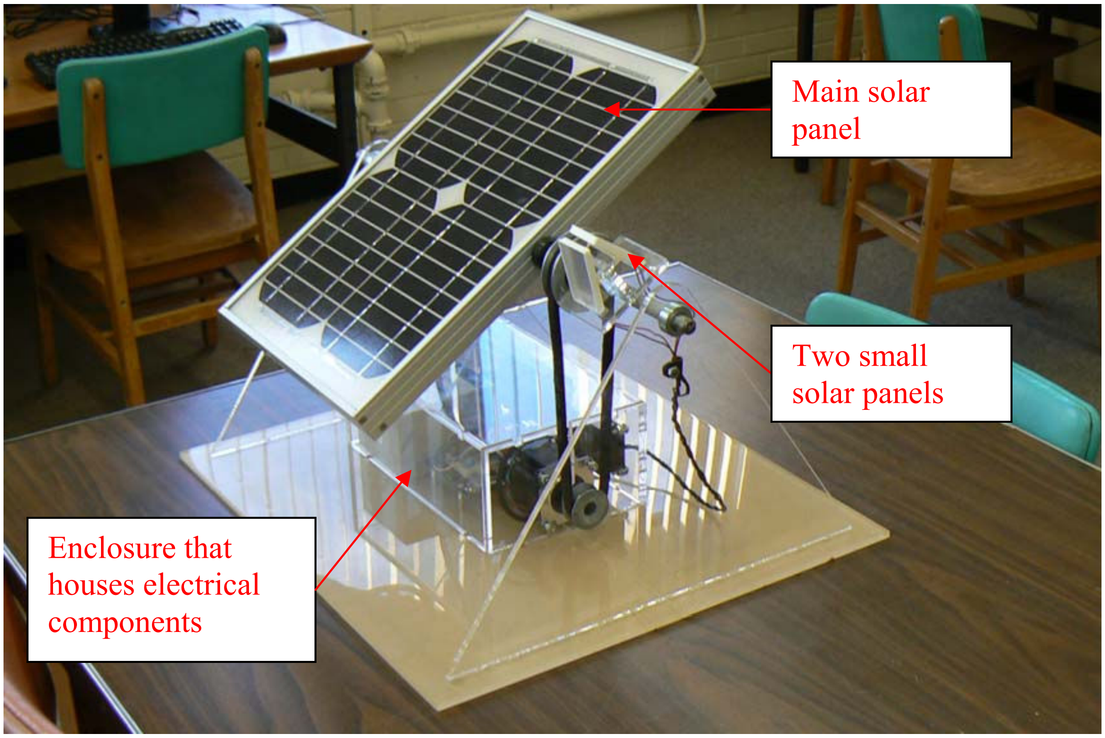

Figure 2. Solar Tracking Power System

SOLAR PANEL AND CHARGE CONTROLLER

Solar panels are made of many photovoltaic (PV) cells connected in series or parallel. The PV cell is a large area p-n diode with the junction positioned close to the top surface [4]. When the cell is illuminated, electron-hole pairs are generated by the interaction of the incident photons with the atoms of the cell. The electric field created by the cell junction causes the photon-generated electron-hole pairs to separate. The electrons drift into the n-region of the cell and the holes drift into the p-region [7].

Main advantages of photovoltaic power are: (1) short lead time to design, (2) highly modular, (3) static structure, no moving parts, hence, no noise, (4) high power capability per unit of weight, (5) longer life with little maintenance due to no moving parts, (6) highly mobile and portable because of light weight [4].

Currently solar power is extensively used in stand-alone power systems. The conversion efficiency of PV cells is defined as the ratio between the electrical power output and the solar power impinging the cell. The efficiency of the PV cells generally is less than 30%. This means that when a cell is illuminated, it will generally convert less than 30% of the irradiance into electricity. The continuing effort to produce more efficient and low cost PV cells results in different types of PV technologies [4]. Major types of PV cells are single-crystalline silicon, polycrystalline, semicrystalline, thin films and amorphous silicon.

In this project a 12V, 10W industrial grade solar panel is used as the main solar panel. The module uses high quality multi-crystalline solar cells. The output voltage of the solar panel ranges from 12 V to 16.8 V. The output current is rated at 0.59 A. Depending on the light conditions, the solar panel outputs 2.5 Ah to 4 Ah a day. It measures 16.4 x 10.6 x 1.0 inches and weighs 4 pounds. Due to its small dimension and light weight, it can be moved very easily. Furthermore, it is waterproof and easy to install.

The solar panel’s terminals are connected to a SunSaver 6 solar controller shown in Figure 3. The function of the charge controller is to prevent the battery from overcharge and discharge. The solar panel itself will continue to charge the battery even when the battery has already been fully charged. The solar charge controller is rated at 12V and 6.5A. When the battery reaches a certain voltage, the charge controller will cut off voltage to ensure there is no overcharge. When the battery is under a certain voltage, the charge controller will start to charge the battery. This ensures that the battery voltage will not fall below the final discharge voltage level. Otherwise the battery may be severely damaged. In addition, the charge controller also provides a regulated output voltage.

Two small solar panels are used as photo sensors to detect the angle of the main solar panel with respect to the sun [8, 9]. The small solar panels are rated at 0.5V and 200mA. The two small solar panels are placed 45^o from the main solar panel. When the angle of sun and irradiance change, the output voltage of the small solar panels will change. When the sun is perpendicular to the solar panel, it generates the maximum amount of voltage. On the other hand, when the angle between sunlight and solar panel is not normal, the output voltage of the solar panel decreases. The voltage difference of the two small solar panels is assessed and used to rotate the main solar panel accordingly. For example, if the sensor on the right side has a higher voltage than the sensor on the left side, then the stepper motor will turn the PV cell to the right until both voltages are equal. When voltages from the two small solar cells are equal, it means the position of the main solar panel is perpendicular to the sunlight.

Figure 3. Solar Charger Controller

RECHARGEABLE BATTERY

Lead-acid batteries are commonly used in solar power systems. A lead acid battery is composed of several single cells connected in series. Each cell produces approximately 2.1 V. A 6-volt battery has three single cells. When fully charged, it produces an output voltage of 6.3 V. A 12-volt battery has six single cells and produces an output voltage of 12.6 V when fully charged. The lead-acid battery has various versions. Shallow cycle rechargeable batteries are used in automobiles where a short burst of energy is drawn from the battery [4]. Deep cycle rechargeable batteries are designed to provide a constant voltage over a long period of time. They are suitable for repeated full charge and discharge cycles. A deep-cycle rechargeable battery is used for energy storage in this project. The DC output voltage is 12 V and the maximum charging current is 1.25 A. The internal resistance of the battery is 30 mΩ. The operating temperature is 4 ° to 140 °F.

MECHANICAL DESIGN

The design of the mechanical system must meet the following criteria

- Ability to support 15 pounds at two contact points
- Ability to keep electronic components safe in good to mild weather conditions
- System to be easily portable
- Ability to easily access components within the enclosure
- Stay within the budget

The base of the system is designed to be 18” x 20” in order to house all the electrical components and have enough room for the risers to properly fit. The top view of the system is shown in Figure 4. The side view of the system is shown in Figure 5. The red outline is the main solar panel. The purple is the belt that connects the stepper motor to the axel. The green is the gears. The gear at the stepper motor has an outer diameter of 1.5” and the gear on the top has an outer diameter of 2.5” giving a gear ratio of 1.67 to 1. This reduces loading torque on the motor while properly stepping the system. The yellow box is the location of the small solar panels.

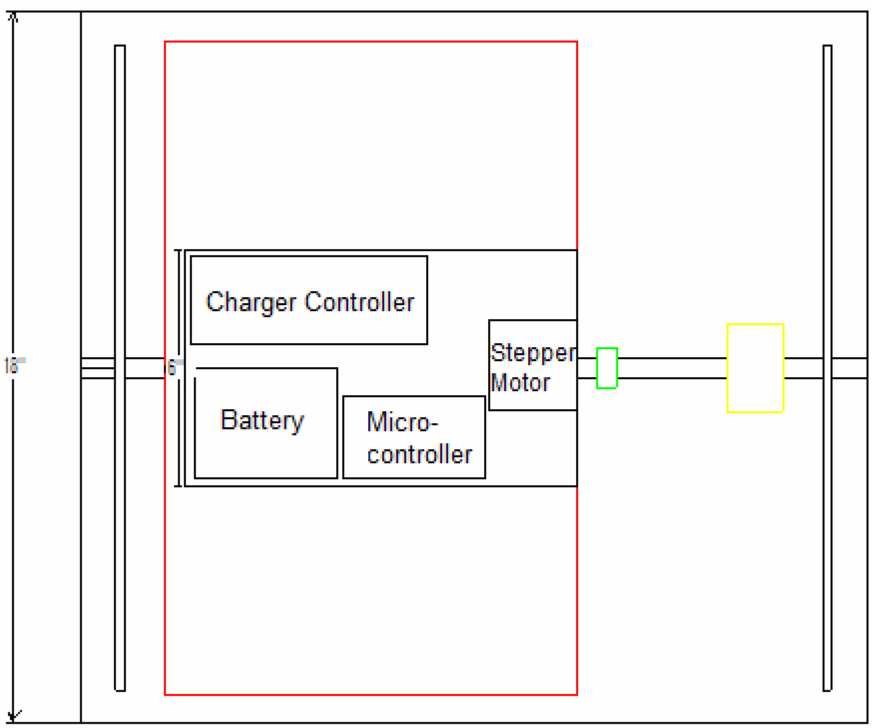

Figure 4. Top View of the Sun Tracking Power System

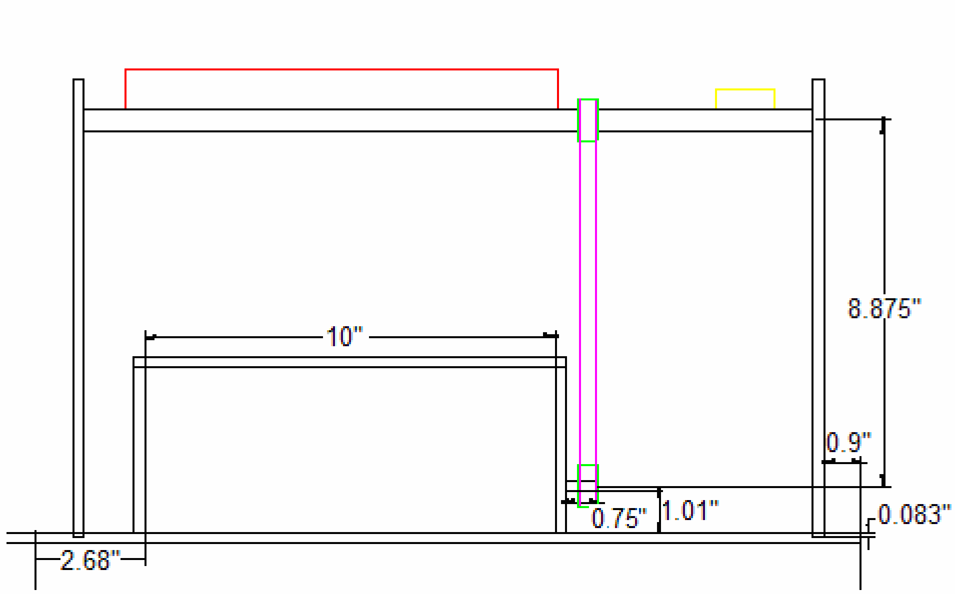

Figure 5. Side View of the Sun Tracking Power System

MOTOR AND DRIVE

A stepper motor is used because motion and position need to be precisely controlled. Stepper motors rotate in discrete steps, each step corresponding to a pulse that is supplied to one of its stator windings. The stepper motor used in this project is a 5704M-10-01 high accuracy bipolar motor from Lin Engineering. The step size is 0.45°. The phase current is 0.9 A/phase. The holding torque is 0.99 N·m. The stepper motor has plenty of holding torque and moving torque to perform its task, and does not drain too much power from the battery.

A microstepping driver R208 from Lin Engineering is used to drive the stepper motor. The drive operates from +12 V to 24 V. Phase current ranges from 0.35 to 2.0 A peak. The step resolution is selectable from full, half, 1/4, and 1/8 microsteps. The step, direction and disable/enable inputs are optically isolated. The driver has low power dissipation and efficient current control. There is thermal shutdown and under-voltage protection. Operating temperature is -20°C to 50°C and humidity range is 0 to 95%.

MICROCONTROLLER

A BasicX-24p is a powerful BASIC programmable microcontroller. It has the following features: (1) 83,000 Basic instructions per second, (2) 32K bytes EEPROM for user program and data storage, (3) 8000+ lines of Basic code, (4) 21 I/O pins, (5) 8 channel 10 bit ADC, (6) built-in 32bit × 32bit floating point math, (7) high speed serial programming interface, (8) 24pin DIP package. The above features make the Basic X-24p microcontroller a very efficient and convenient tool to control the solar tracking power system.

The flowchart of the control algorithm is shown in Figure 6. The microcontroller will read inputs from the two small solar cells every 15 minutes. If the two voltages are equal, no control signal will be generated. If the east facing solar cell has higher voltage than the west facing solar cell, the motor will rotate the main solar panel towards the east. On the other hand, if the west facing solar cell has higher voltage than the east facing solar cell, the motor will rotate the main solar panel towards the west. If the output voltage of both of the small solar cells fall under a certain value (0.9 V in this case), the motor will reset the main solar panel to the starting position. Following is the meaning of each variable in the flowchart.

V1 = Output voltage of solar Panel 1 facing the east
V2 = Output voltage of solar Panel 2 facing the west
Motor + = Rotate clockwise
Motor - = Rotate counter-clockwise
Reset = Setpoint

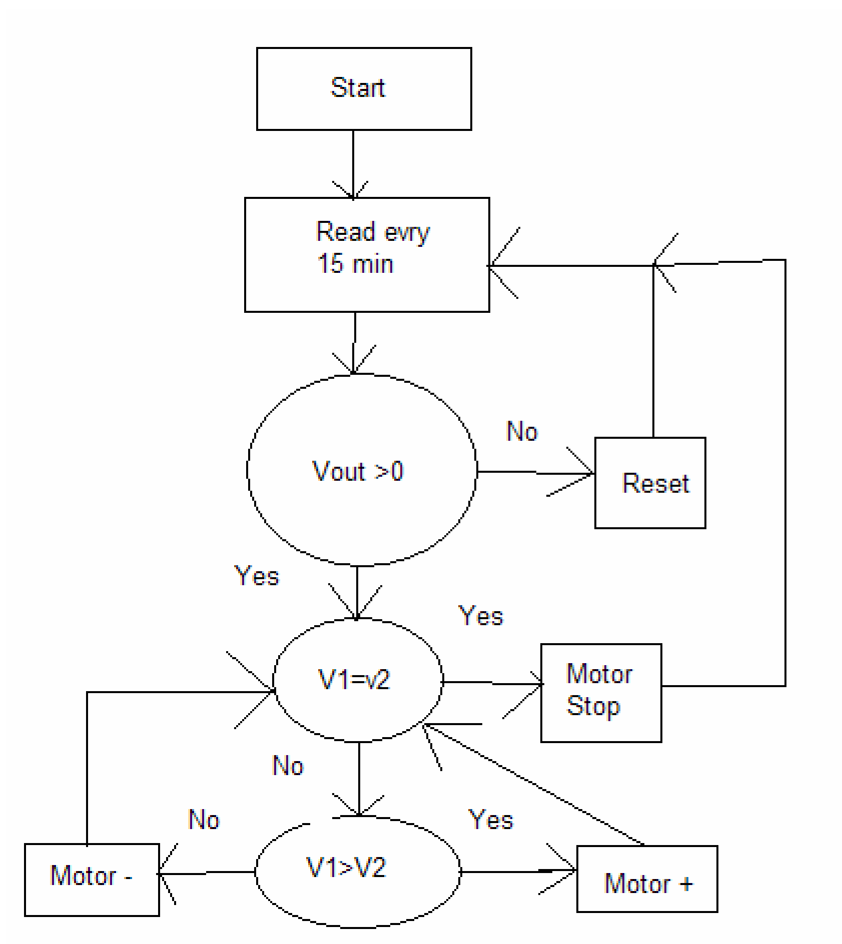

Figure 6. Flowchart of Control Algorithm

SIGNAL CONDITIONING CIRCUIT

The two small solar panels have a voltage rating of 500 mV, while the ADC of microcontroller will accept input voltage from 0 to 5 V. A signal conditioning circuit is designed and built to interface between the small solar panels and the microcontroller. A non-inverting amplifier is built using a single source operational amplifier LM324. The voltage gain of the non-inverting amplifier is designed to be 8.03. A Multisim simulation of the non-inverting amplifier is shown in Figure 7. R1 is 1.421 kΩ and Rf is 10 kΩ.

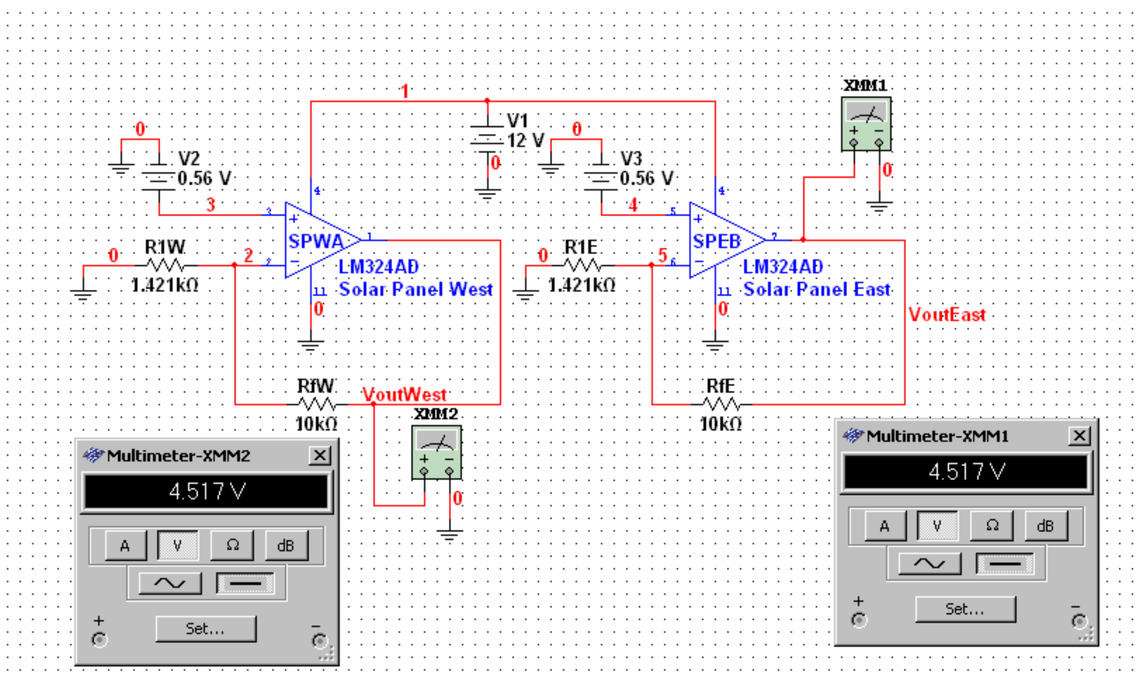

Figure 7. Multisim simulation of signal conditioning circuit

PROJECT EXECUTION

The first semester is mainly focused on the design of the system. Students start from doing literature search and review theories related to the project. Components were selected under the guidance of faculty advisor. A tradeoff between the performance and price was considered. Theoretical analysis and simulation of the system were done next. Mechanical structure of the system was designed using AutoCad.

In the second semester, students construct the sun tracking solar power system. Quite a few designs had to be changed due to price, functionality and compatibility with the rest of the system. Through several iterations the system was constructed and tested. Total cost of the system is about $300. The motor and motor drive are donated by Lin Engineering. The major cost is from the solar panel which cost $114, and the microcontroller starter kit which costs $130.

During the implementation and testing phase of the system, one difficulty comes from the weather in November and December since there were only a few sunny days in DeKalb, IL. This limits the amount of time for students to test the system. In the future, it is better to start the design of the project in fall semester. Implementation and testing should be done in the spring semester so that sufficient time will be available for outdoor testing in April and May.

CONCLUSION

In this paper, a senior design project of one axis solar tracker has been presented. Students need knowledge of circuit theory, power electronics, microcontrollers, electric machines, solar power and mechanical design in order to design and implement the system. A video of the solar tracker will be shown at the ASEE conference presentation to demonstrate the operation of the solar tracker. The broad scope of this project requires the students to investigate and address a wide range of complex issues and expose students to renewable energy technologies. There is no one unique solution to the problem and a compromise has to be made based on total cost vs. reliability. Some of the comments from the team members are "Working on the Solar Tracking System provided our group with a real world experience. Our system started from just an idea which gave us the chance to work through all the challenges that come along with a group project. The best experience that I personally gained from this project was working in a group, managing a budget and utilizing skills gained from NIU and internships.", "The skills that I had gained from this project are programming in basic language, understanding the use of a solar panel to charge a battery, and the understanding of the workings of our tracking system. All in all this project has given me a nice reference for working in teams, solving problems, and an understanding of solar energy." and "My experience from the senior design project is that of hard work and accomplishment.". In the future, more advanced control algorithms such as PID control and fuzzy logic control will be studied and implemented for the sun tracking solar power system.

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