AC 2009-732: A SOLAR-POWERED ART PROJECT PROVIDES A REMOTE GREEN ENERGY LABORATORY FOR ENGINEERING TECHNOLOGY STUDENTS

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A Solar-Powered Art Project Provides a Remote Green Energy Laboratory for Engineering Technology Students

Abstract

An outdoor campus art project required some technology to help create a more meaningful experience for its beholders. The canvas for the artwork is a bus stop shelter structure that is no longer used by the local transit authority. The required technology is a custom solar- powered audio system. The glass walls of the bus stop shelter are covered with translucent vinyl overlays containing candid photographs of campus students and faculty. The audio system plays recorded sound bite excerpts from interviews with students, faculty, and distinguished campus guests. The theme of the artwork experience is “Knowledge is Power” and is intended to provide campus visitors with a glimpse into some of the activities of the college. The custom audio system was designed, built and installed by faculty, staff, and students in the engineering technology department. When the system was designed, the opportunity was taken to include the required electronics to monitor and record the health and status of the solar panel and battery power system. The data obtained from the system is used to help engineering technology students understand the characteristics and performance of solar energy systems. The system contains all of the typical components of large solar power systems. The south-facing side of the structure contains a small stationary (non-sun-tracking) solar panel. The sound system enclosure contains a sealed lead-acid (SLA) battery. The charging of the battery is controlled by electronics on a custom circuit board within the sound system. This circuit board also contains a microcontroller to control operation of the embedded MP3 player and amplifier. Another on-board microcontroller performs the power system measurements, stores the data in non-volatile memory and transfers the data to an external computer via the serial port when queried. By analyzing the voltage and current measurements for the solar panel and battery as well as the battery temperature, engineering technology students can see how the system functions for various combinations of sunlight, battery state of charge, temperature, and power demand from the load. The students gain appreciation for how proper power management is crucial in “Green” energy systems. This paper presents the system design constraints, features, problems and modifications. Typical raw data as well as student-analyzed data is also presented. The ways in which the system is used in the engineering technology curriculum is also provided.

Motivation / Overview

The authors were approached by the campus art director for assistance with developing an interactive and informative work of art. The work was to incorporate audio clips from recorded interviews with students and faculty together with enlarged candid photographs displayed across the sides of a bus shelter structure. The bus shelter was no longer being used by the transportation authority, however, the structure was not to be modified in any way that could not easily be restored to the original configuration. The major design constraints were as follows:

1. No AC power available at the bus shelter location.
2. Project life of one to two years.
3. Deliver approximately three minutes of audio content.
4. Simple user operation: Just one pushbutton.
5. Tamper-resistant housing and mounting.
6. No modifications of the bus shelter structure.

Constraint 1 required that the system be self-powered. Battery power was the logical first choice. The second and third constraints dictated that the batteries would probably need to be replaced or replenished during the useable life of the system. The bus shelter is located in an area with sufficient sunshine therefore a rechargeable battery with a small solar panel charger was selected as the power source. Outdoor solar-powered applications are commonly used. [1]

To deliver the audio content, an inexpensive portable MP3 player and amplifier/speaker system were chosen. The MP3 player was modified to allow it to be controlled via custom electronics that simplified the user interface to just one pushbutton mounted on the front of the system enclosure. Users simply press one button to commence the playing of the recorded information. Upon completion, the system resets and powers down while waiting for the next press of the button.

Figure 1. Bus Shelter Art Project

The entire audio system is contained within one aluminum enclosure secured with tamper-resistant hardware. The solar panel is mounted to the back of the enclosure which is mounted against a south-facing window of the bus shelter. The system enclosure is fastened to the bus shelter structure via existing holes and support members. Figure 1 shows a photograph of the completed bus shelter project. The solar array can be seen peeking through the blue area just above the lion's head.

The theme of the bus shelter art experience is, "Knowledge is Power." In keeping with this theme, the opportunity was taken to make use of the bus shelter audio system as a teaching tool. When the custom electronics were designed, the capability to periodically measure and store parameters of the solar panel and battery status was included. This data could then be downloaded for use in engineering technology classes to help demonstrate the operation of equipment powered by solar energy and rechargeable batteries. Incorporating real-world solar power projects into engineering curriculum has been presented by others. [2,3,4]

System Design and Construction

Figure 2 shows a block diagram of the bus shelter custom audio system. The solar panel is constructed of thin-film amorphous silicon and produces an operating voltage of 7.2V at 100mA. The battery is a 6V, 1.2Ah sealed lead acid deep-discharge battery. The amplifier and speakers are very inexpensive consumer electronic devices typically used with an MP3 player to listen to music without using headphones.

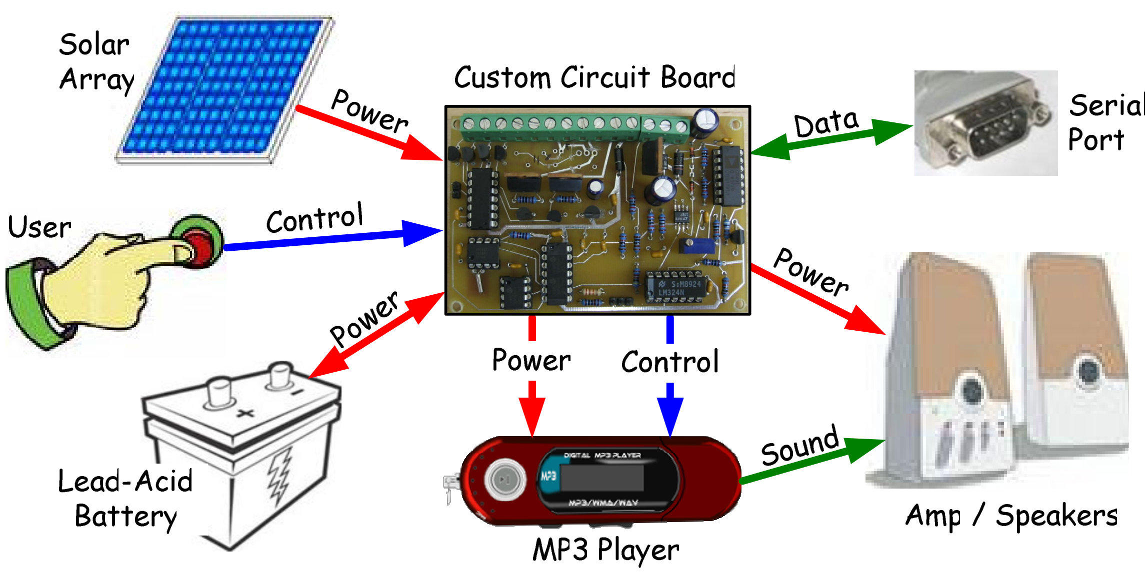


Figure 2. System Block Diagram

The MP3 player is an inexpensive device that also serves as a flash memory stick. The message content is easily stored on this device via USB connection. The MP3 player was modified to make connections to its internal circuitry such that the custom circuit board microcontroller could emulate the pressing of buttons such as PLAY, SKIP, STOP, etc., in order to produce the desired operation.

The custom circuit board contains the electronics necessary to control the charging of the battery, control the MP3 player operation and power, control power to the amplifier, perform data acquisition and storage, and provide external computer communication. A single pushbutton mounted on the front of the enclosure, initiates the MP3 playing sequence. Stored data is downloaded to an external computer via the RS232 style serial port. Figure 3 shows a block diagram of the custom circuit board circuitry.

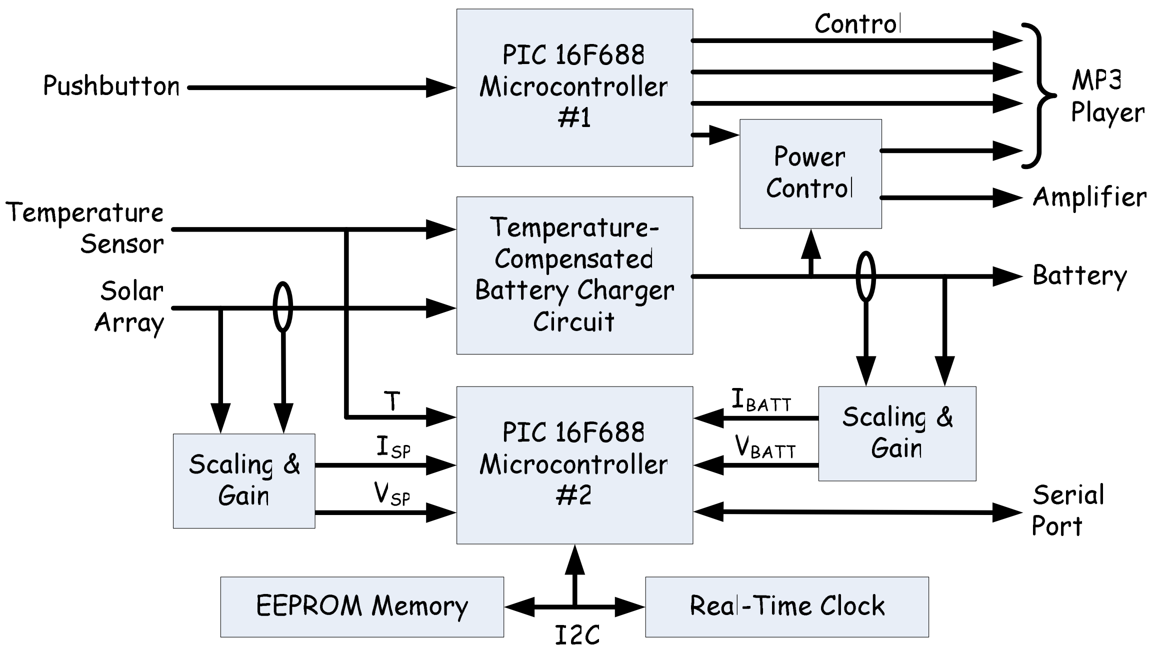


Figure 3. Custom Circuit Board Block Diagram

As shown in Figure 3, the custom circuit board contains two microcontrollers. One microcontroller is dedicated to controlling the MP3 player operation by emulating the sequence of MP3 player button presses to control its state of operation. Recall that the user simply presses one button mounted on the front of the system enclosure. The microcontroller then carries out the proper button presses to play the recorded sound. This device also controls the MOSFET switches that provide battery power to the MP3 player and amplifier.

The second microcontroller is dedicated to data acquisition and storage as well as communication with an external computer for downloading the stored data. Using information from the real-time clock, the microcontroller wakes up every three minutes to measure the temperature sensor voltage, solar panel voltage and current, and battery voltage and current. This data is stored in the EEPROM device together with a timestamp before the microcontroller returns to sleep mode. There is sufficient memory to store about two weeks of data. When an external computer is connected via the serial port, the microcontroller downloads all of the data stored in the EEPROM.

Charging of the sealed lead-acid battery from the solar panel output is controlled by analog circuitry also on the custom circuit board. To help extend the life of the battery, a temperature-compensated charging scheme is employed.[5] A semiconductor temperature sensor is used to measure the battery temperature. The battery float voltage is regulated in response to the temperature such that the battery voltage decreases as temperature increases.

The solar panel and battery voltages, scaled by voltage divider circuits, are measured by the microcontroller's analog to digital converter. The solar panel current is sampled with a small, ground referenced (low side) series resistor and amplified with an inverting op-amp circuit. The battery current is sampled with a small series resistor referenced to the positive battery terminal (high-side). A high-side current sense amplifier, LT1787 by Linear Technology, is used to scale the resistor voltage and produce a ground-referenced voltage to be measured by the microcontroller's A-D converter. All data is digitized with 10 bits of resolution.

All of the audio system components are packaged in an aluminum enclosure. The solar array is mounted on the back of the enclosure. Figure 4 shows the system without the front cover and installed in the bus shelter structure. The placement of the circuit board, battery, MP3 player, and amplifier/speakers can be seen.

Figure 4. System without cover (left) and installed in the bus shelter (right).

Collected Data

About once per week the data is manually downloaded from the audio system by connecting an external computer directly to the system at the bus shelter site. The stored data is transferred serially from the EEPROM via the microcontroller to the external computer in binary format. The external computer is a handheld HP iPAQ running a custom software application (virtual instrument) written using LabVIEW for Pocket PC. This application converts the received binary data into ASCII characters and saves the entire record in spreadsheet format. Figure 5 shows an excerpt from the spreadsheet data.

Time	Vsp	Isp	Vbatt	Ibatt	Temp
9/19/2008 9:50	397	0	606	503	150
	398	0	606	503	151
	399	0	606	503	151
	401	0	606	504	152
	402	1	606	503	153
	404	2	606	504	154
	407	4	606	503	155
	410	6	606	504	155
	415	9	606	505	156
	416	11	606	505	157
	418	15	606	505	157
	419	19	606	505	158
9/19/2008 10:26	419	23	607	506	159

Figure 5. Sample of raw data in spreadsheet format.

As shown in Figure 5, the raw data from the system for each measured parameter is an integer which represents the 10-bit digitized measured voltage. The minimum integer value of 0 corresponds to a voltage of 0V. A theoretical maximum integer value of 1024 would correspond to a voltage of 5.000V but is not possible in a 10-bit digitization. (The actual maximum possible value is 1023 corresponding to 4.995V.) All values in between these extremes are linearly related, therefore the actual voltage measured can be determined from the following expression:

$$V_{Measure} = 5.000 \times \frac{Integer}{1024} \tag{1}$$

Recall that the measured voltages are scaled to fit within the range of the analog-digital converter. The actual measured quantity can only be determined by knowing the scaling factors that were applied to each parameter. Determining the actual system voltages and currents is the task presented to the electrical engineering technology students.

Student Data Analysis

The electrical engineering technology students were given the assignment of analyzing data obtained from the bus shelter audio system over a period of one day. In prior assignments, the students had analyzed the circuits that provide scaling and gain for each of the measured parameters:

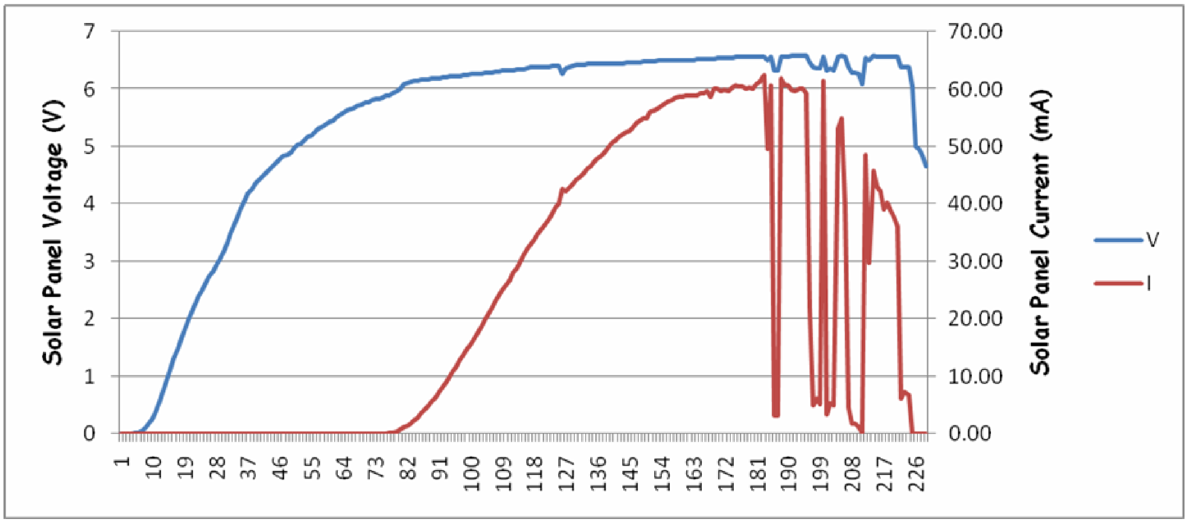
- The actual solar panel voltage is three times greater than the measured voltage.

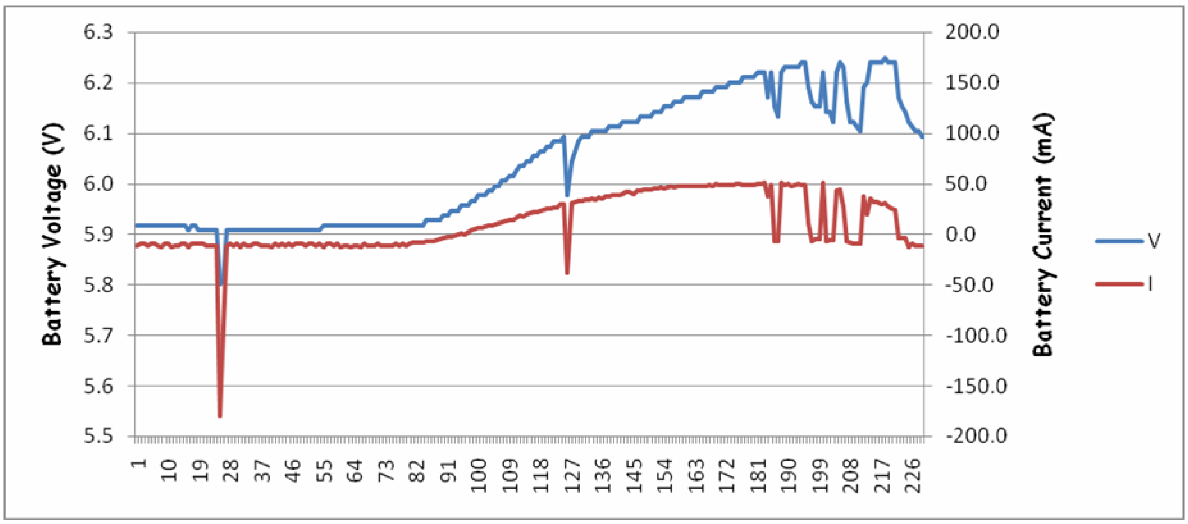
- The actual solar panel current, in Amperes, is 40 times less than the measured voltage, in Volts.
- The actual battery voltage is two times greater than the measured voltage.
- The actual battery current is bidirectional with zero Amperes corresponding to a current sense amplifier output voltage of 2.5V. Current flowing into the battery results in a voltage *greater* than 2.5V while current flowing out of the battery results in a voltage *less* than 2.5V. The sensitivity of the current sense amplifier circuit is 4 V/A.
- The temperature sensor produces an output voltage of 10mV/°F.

Time	Vsp (V)	Isp (mA)	Vbatt (V)	Ibatt (mA)	Temp (F)
9/19/2008 9:50	5.815	0.00	5.918	-10.99	73.2
	5.830	0.00	5.918	-10.99	73.7
	5.845	0.00	5.918	-10.99	73.7
	5.874	0.00	5.918	-9.77	74.2
	5.889	0.12	5.918	-10.99	74.7
	5.918	0.24	5.918	-9.77	75.2
	5.962	0.49	5.918	-10.99	75.7
	6.006	0.73	5.918	-9.77	75.7
	6.079	1.10	5.918	-8.54	76.2
	6.094	1.34	5.918	-8.54	76.7
	6.123	1.83	5.918	-8.54	76.7
	6.138	2.32	5.918	-8.54	77.1
9/19/2008 10:26	6.138	2.81	5.928	-7.32	77.6

Figure 6. Data sample after analysis.

Figure 6 shows a sample of actual student analyzed data corresponding to the same interval shown previously in the raw data of Figure 5. Student analyzed data for the full daylight period is plotted in Figure 7. The electrical engineering technology students were asked to determine the time(s) of the maximum solar panel and battery voltage and current as well as the maximum solar panel output power. Figure 7 also shows this tabulated information. The students were also required to write a summary of the events that are detectible in the data. Events such as when the audio system was used, time of sunrise, sunset, cloudy periods, etc. This type of information is easily extracted from the plotted data shown.





1. Find the peak solar panel current (in mA) and time(s)	Max = 62.5mA at 15:20
2. Find the peak battery **charge** current (in mA) and time(s)	Max = 51.27 mA at 15:20, 15:35, 16:11
3. Find the peak battery **discharge** current (in mA) and time(s)	Max = -179.4 mA at 7:26
4. Find the peak solar panel voltage (in Volts) and time(s)	Max = 6.577V at 15:44, 15:47, 15:50, 15:53, 15:56, 16:26, 16:53
5. Find the peak battery voltage (in Volts)	Max = 6.25 at 17:05
6. Find the peak solar panel power (in Watts) and time(s)	Max = 0.41W at 15:20

Figure 7. Student-Analyzed Data

Upgrade / Future Use

The experience gained in the first generation of this project will be used to upgrade and modify the system. Better power management is required to help the system span large periods of cloudy weather. Some of this can be fixed in the microcontroller firmware. A slightly larger solar array and battery has been installed to also help with sustained cloudy periods. The lessons learned will also be applied to other remotely powered applications on campus.

The system is also being enhanced to aid the ability to access the stored data via wireless link. This will eliminate the need to physically connect to the system to download data. This will allow more timely access to the data for use by the students.

Conclusions

This project was the first foray into solar power technology education at our campus in recent history. Although the scale of the project was small, the components are those of much larger systems. Therefore the concepts presented are applicable to many other applications that the students may encounter in their professional experience.

The topic of renewable energy is certainly popular in current literature. Engineering technology students are also very aware of the importance of renewable energy therefore this topic was met with a good level of interest and enthusiasm. The student analysis and reports indicate that they had a good understanding of the system operation.

The lessons learned from the first deployment of this system are also valuable as a teaching tool. Careful site study to determine incident solar flux together with detailed power budget calculations can help to design a more reliable solar-power system; the first time. Students can perform these studies and calculations to help get a better understanding of the parameters involved with this type of remote installation. The proper sizing of system components is critical.

Engineering technology students must also learn to appreciate the need for renewable energy in whatever form is available. Common renewable energy sources include solar and wind energy but students must also learn to be open to using other energy harvesting techniques as required or available. By incorporating this small solar-powered audio system into the ET curriculum, students get to experience some of the benefits and challenges of renewable energy use.

The opportunity to incorporate the art project into engineering technology education was unusual at first but makes perfect sense in retrospect. Opportunities such as this should be seized whenever possible. Knowledge *is* Power.

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