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ON THE SOLAR PV MONITORING SYSTEM

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Abstract. ***Solar energy is increasingly becoming commonplace in the society with the ever rising electricity bills and reduction in price in solar equipment. Being an "essentially free" form of energy it is necessary to contribute to developments that support or improve the solar energy sector. This paper presents a way to monitor the voltage, current and power output from a solar panel, with the aim of monitoring and projecting the output from a solar farm.***

Keywords: PV monitoring; solar panel; design

1. INTRODUCTION

Solar energy is energy from the sun and is essentially a "free" form of energy. This means that no one will charge you from harnessing power from the sun. This energy from the sun is harnessed by use of equipment called solar photo-voltaic (PV) cells which have a general name of a solar panel. This harnessed energy is then converted to electrical energy which can be used in homes, industries, hospitals just like normal electricity. To convert the harnessed energy to a level which can be used in the home a couple of devices are required, which we will discuss, but we will start our discussion on what is a solar panel and what it is made of.

A solar panel is basically a device that is used to harness energy from the sun and convert it to electrical energy. It basically consists of a glass outer covering, an array of silicon cells and electrical wires carrying the electrical energy from the silicon cells [1,2].

The production of a solar panel starts with the production of pure silicon which is not pure in its natural state. The raw materials are either silicon dioxide of quartzite gravel or crushed gravel. These are then placed into an electric furnace where a carbon arc is applied to release oxygen, giving carbon dioxide and molten silicon. This molten silicon has 99% purity but cannot be used in the solar cells. Further purification of this silicon is done using the floating zone technique whereby a rod of impure silicon is passed through a heated zone several times in one direction tending to push the impurities to one side of the rod. This silicon is then deemed pure and the impure end of the rod is removed. Silicon boules, which are polycrystalline structures that have the atomic structure of one crystal, are then made using the Czochralski method, from which silicon wafers are made using a circular saw. The silicon is then doped, and this was first done in the Czochralski method where a small amount of boron was introduced, by sealing the silicon wafers back to back and placing them in a furnace where they are heating to slightly below the melting point of silicon, around 1410 °C, in the presence of phosphorous gas. The phosphorous atoms then "burrow" into the silicon which is more porous because it is close to become a liquid. The temperature and time given to the process is carefully controlled to ensure a uniform junction of proper depth. The silicon wafers are then covered with an anti-reflective coating usually titanium dioxide or silicon oxide. The finished solar cells are the sealed into silicon rubber or ethylene vinyl acetate after which they are placed into an aluminum frame that has a glass covering. The solar cells are arranged in series to form a solar module which is also called a solar panel. The finished solar panel is then ready for use according to its ratings in watts and this is determined by the number of silicon cells in the solar panel, generally more solar cells give more wattage [3,4].

For the harnessed electricity to be used in homes, a couple of devices are needed to convert the harnessed electricity, which is in DC, to AC. These components are namely: charge controllers, batteries and inverters.

Charge controllers basically control how the solar panel charges the batteries and prevents the battery from overcharging or over-discharging. They also protect the solar panel from damage by preventing current from flowing back from the batteries to the solar panel [5,6].

Inverters basically do as the name suggests which is to convert DC to AC power. They can be classified into stand-alone inverters and grid-tie inverters.

The objectives of this paper are:
- To monitor the fluctuation of output power of the solar panel at different times of the day.
- To monitor the time of the day there is maximum output power.

2. DESIGN AND IMPLEMENTATION

The design of the solar PV Monitor is based on the MSP430 Microcontroller from Texas Instruments. The design process consists of two stages:

1. Hardware design.
2. Software design.

2.1 Hardware Design

Figure1 below shows the voltage signal conditioning circuit for the solar PV monitor.

The solar panel is connected to a constant load in this case a 100 Ohm resistor rated at 5 Watts. The solar panel electrical characteristics are:

- Maximum power: 10 Watts
- Maximum-power voltage: 17.6 Volts
- Maximum-power current: 0.57 Amps
- Open-circuit voltage: 21.2 Volts
- Short-circuit current: 0.63 Amps

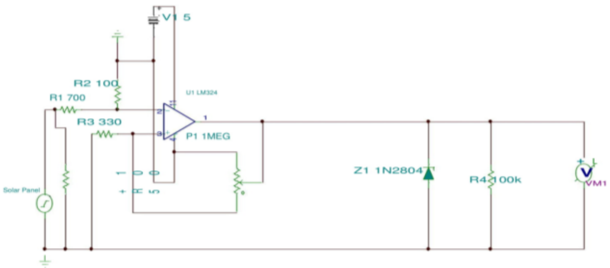

Figure 1. Voltage signal conditioning circuit.

By Ohms Law: $V = I \cdot R$,
V = varying according to sunlight (0–20 V range),
R = 100 Ohms.

Thus:

$$I = 20/100 = 0.2 \text{ Amps} \tag{1}$$

The circuit is designed while ensuring the current is below 4 Amps so as not to damage the microcontroller.

Since I = 0.2 Amps, the power dissipated in the resistor is given by $P = I^2 \cdot R$. Thus:

$$P = (0.2)^2 \cdot 100 = 4 \text{ Watts} \tag{2}$$

A 5 Watts resistor is thus chosen.

The resistors $R1$ and $R2$ form a voltage divider to reduce and divide the voltage by a certain ratio thus attenuating the voltage. In this case the resistors chosen are $R1$ = 700 Ohms and $R2$ = 100 Ohms.

Using the voltage divider formula:

$$V = R2/(R1+R2) = 100/800 = 0.124 \text{ Volt} \tag{3}$$

Thus

$$V_{out} = V_{in} \cdot 0.124 = 20 \cdot 0.124 = 2.48 \text{ Volt} \tag{4}$$

Since the internal reference voltage of the microcontroller is used, the voltage input limit to the analog-to-digital converter (ADC) is 2.5 V. In this case the maximum voltage is 2.48 V.

The Op-Amp used is the LM324 which is configured as a voltage follower and has the following characteristics:

- Short circuited protected outputs.
- True differential input stage.
- Single supply operation: 3.0 V to 32 V.
- Low input bias currents: 100 nA maximum (LM324A).
- Four amplifiers per package.
- Internally compensated.
- Common mode range extends to negative supply.
- Industry standard pin-outs.
- ESD clamps on the inputs increase ruggedness without affecting device operation.

The Zener diode (1N2804) and the resistor (100 K Ohms) form a voltage regulator. The Zener diode outputs a constant voltage when its breakdown voltage is reached. This protects the microcontroller from damage in case the voltage goes beyond a certain value. The Zener diode is connected in its reverse biased mode, that is, the cathode is connected to the positive side of the circuit and the anode to ground. The resistor that is in parallel with the Zener diode is selected so that when the input voltage is at V_{in} (min) and the load current is at I_L (max) that the current through the Zener diode is at least I_Z (min). The maximum power rating of the Zener diode is chosen using this formula to ensure that its maximum power rating is not exceeded:

$$I \text{ (max)} = \text{Power/Zener diode} \tag{5}$$

1) Power supply

The power supply circuit is shown in Figure 2.

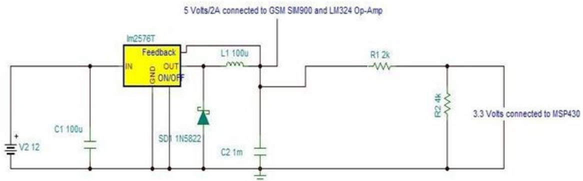

Figure 2. Power supply circuit.

The LM2576T produced a constant output of 5 V with a maximum current limit of 3 Amps. It is connected to a 12 Volts battery. The capacitor $C1$ is used to filter any ripples from the battery source and any AC components that may be riding on the DC. The capacitor $C2$ is used as a by-pass capacitor to filter out any noise and any other high frequency components ensuring that the output is smooth.

2) Microcontroller

The microcontroller used is an MSP430 from Texas Instruments. It incorporates a 16 bit RISC CPU, peripherals, and a flexible clock system that interconnect using a von – Neumann common memory address bus (MAB) and memory data bus (MDB). Figure 3 shows the MSP430 pin diagram while Table 1 gives its pin description.

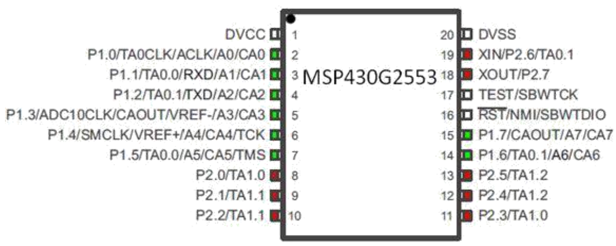

Figure 3. MSP430G2553 pin diagram.

Table 1. MSP430 pin description of used pins

Pin Number and Label		Pin Description	Usage
1	VCC	Input 5 V DC	
2	GND	Ground	
5	RXD SW	Receive Pin for Software UART	Connected to TX Pin on GSM Sim900 Modem
6	TXD SW	TXD Pin for Software UART	Connected to RX Pin on GSM Sim900 Modem

3) GSM SIM900 modem

The global system for mobile phone (GSM) is used to send the data to a server and uses a SIM card to access the internet via the general packet radio service (GPRS) network. Figure 4 shows GSM SIM900 modem, while, Table 2 gives pin description. Pin D0 is used as the receive pin and Pin D1 as the transmit pin for the software Universal Asynchronous Receiver/Transmitter (UART).

Figure 4. GSM Sim900 modem.

Table 2. Pin description of GSM SIM900 modem

Pin Number	Description
V In	5 V DC
D1	Receive pin for software UART
D0	Transmit pin for software UART
GND	Ground

2.2 Software Design

The software design is divided into two parts and is implemented as follows:

1. Microcontroller software.
2. Server software.

Microcontroller software. The flow chart of program algorithm is shown in Figure 5.

Server software. *The flow chart of program algorithm is shown in Figure 6.*

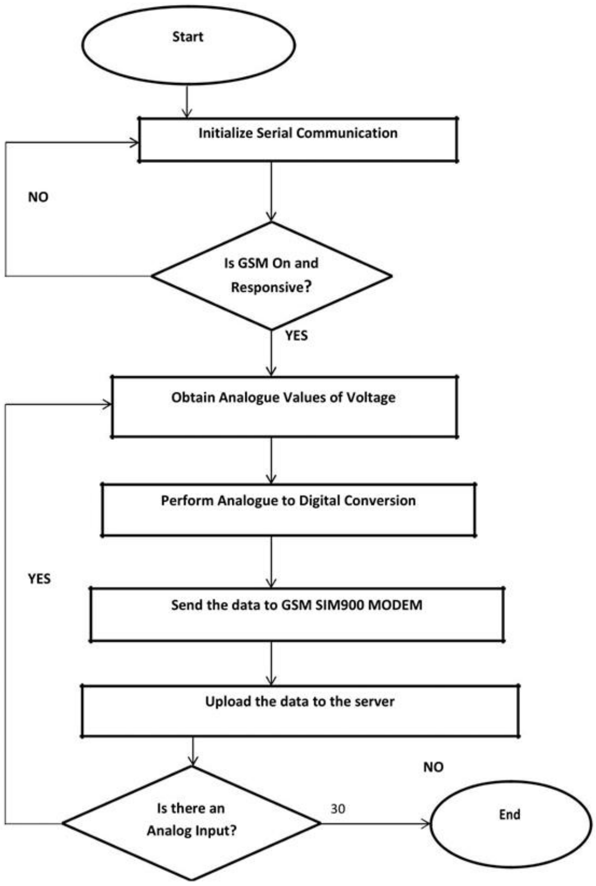

Figure 5. Microcontroller program algorithm.

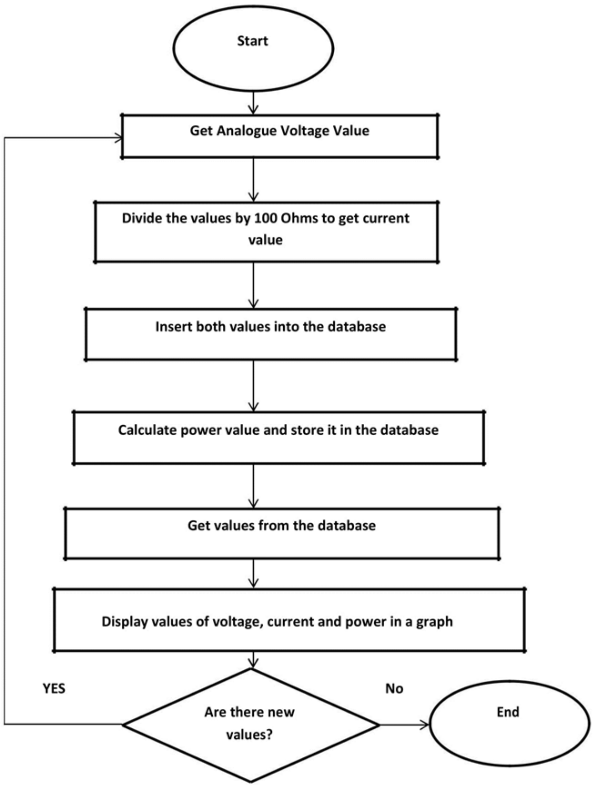

Figure 6. Server program algorithm.

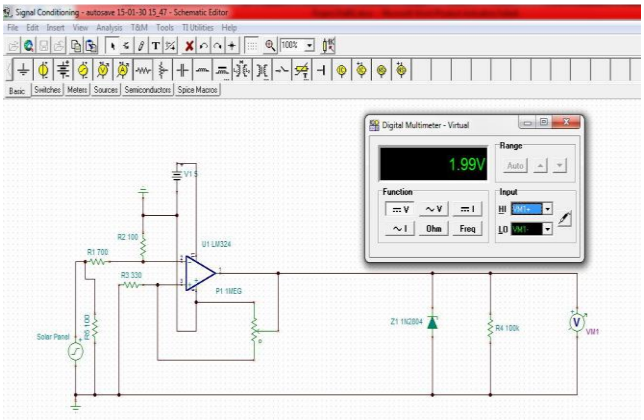

Figure 7. Signal conditioning simulation result.

3. RESULTS

3.1 Simulation Results

The result in Figure 7 shows the voltage output of 1.99 Volts at a virtual multimeter for a maximum DC output voltage of 20 Volts from the solar panel. The maximum voltage the ADC can handle is 2.5 V, and this shows that it is below the acceptable range for input to ADC of the microcontroller.

DC transfer characteristic in Figure 8 shows that the input voltage is attenuated and for a maximum input voltage of 20 V from the solar panel, the maximum output from the circuit is 2.48 V which is acceptable for input to the ADC of the microcontroller. The signal is attenuated by a factor of 0.124.

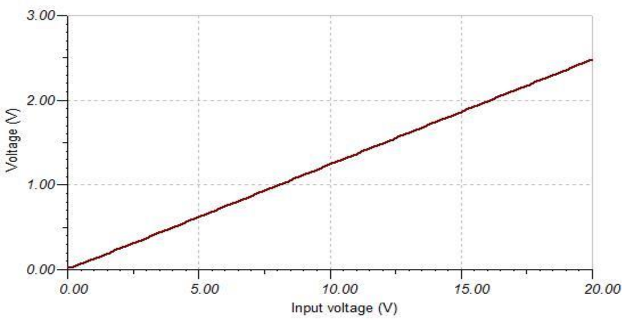

Figure 8. DC transfer characteristic.

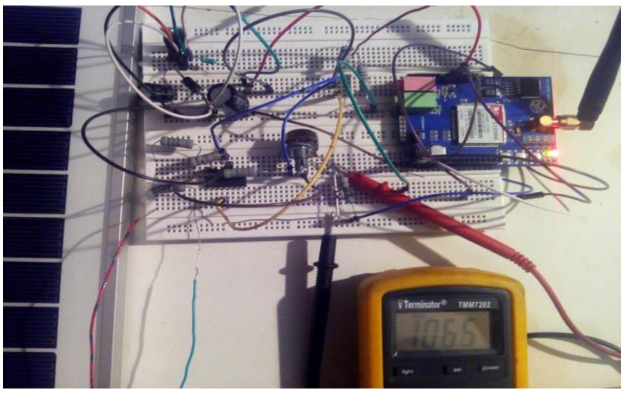

Figure 9. Setup on the breadboard.

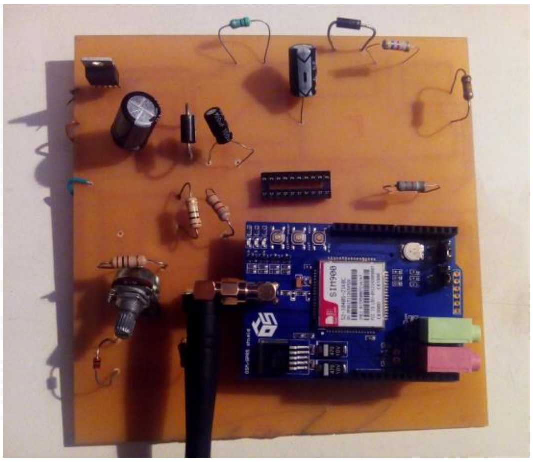

Figure 10. PCB diagram.

3.2 Practical Results

Figure 9 and Fig 10 show the setup on the breadboard and printed circuit board (PCB) respectively. The multimeter in the Figure 9 displays a value of 106.5 mV, which translated to 0.858 Volts from the solar panel, after it is connected to the analogue output values from the signal conditioning circuit. This confirms that the signal is attenuated by a factor of 0.124.

From Figure 11, the solar panel is producing an almost constant voltage of about 7 Volts under low light conditions. The current produced under these conditions is around 0.07 Amps and power is around 0.54 Watts. This shows that the solar panel is very effective even in low light conditions.

Figure 12 shows data collected during the morning hours in a partly cloudy day. The output voltage from the solar panel is about 10 Volts even in cloudy weather. The power output increased to about 1 Watt and current is about 0.1 Amps. This shows that the output voltage from the solar panel increases with an increase in light intensity.

Figure 11. Screenshot 1 of the solar PV monitor database.

Figure 12. Screenshot 2 of solar PV monitor database.

4. CONCLUSION

A microcontroller based solar PV monitor was successfully implemented and was able to record the voltage from the solar panel and perform calculations to determine the values of current and power and store the results in a database. It was observed that the solar panel used was able to produce a substantial amount of voltage under low light conditions and was thus very effective. It also produced an almost constant voltage when illuminated. This system can be used in solar farms to monitor the output and with additional information of feed-in tariffs, can be used to calculate returns for the investor and predict future solar power outputs based on the trends recorded in the database.

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