AC 2012-3256: DESIGN AND IMPLEMENTATION OF A LOW-COST PHOTOVOLTAIC TRAFFIC LIGHT SIGNAL SYSTEM

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Design and Implementation of a Low-Cost Photovoltaic Traffic Light Signal System

Abstract

Power failures in roads and intersections can cause serious difficulties and dangers due to non-availability of electric power for traffic light signals. Application of solar energy has been increased to power-up the traffic light signals all over the world recently. This paper proposes the application of solar energy in powering traffic signal systems for rural areas with no power grid. A photovoltaic system is used to capture the solar energy. Three B.S. students have involved in this educational project. The implemented system is simple, low-cost and free of maintenance. Captured solar energy is saved into a 12 volts lead-acid battery. A circuit including IC regulator is used to control the flow of charge through the battery instead of a dc-dc converter that lower the price of system controller. Timing of the traffic light is carried out via AVR ATMEGA16 microcontroller. Some software tools that have been used in this project are: PROTEUS for simulation of the circuit, Code vision for programming AVR microcontroller, and Microsoft Excel for plotting the captured data. Experimental results for different angles of radiation at different times of the day are also shown in this paper.

Introduction

Solar energy technologies, which harness the sun's energy to generate electrical power, are one of the fastest growing sources of renewable energy on the market today[1]. Engineers and scientists are collaborating to lower the material costs of solar cells, increase their energy conversion efficiency, and create innovative and efficient new products and applications based on photovoltaic (PV) technology around the world.

On the other hand, vehicular travel is increasing throughout the world, particularly in large urban area. Traffic control systems have also increased in installation as a result. However it is still economically difficult to provide traffic control in country and rural areas, primary due to cost of building power infrastructure over long distances. Solar traffic signs have many uses. They can be used in manufacturing facilities, for pedestrian safety, stop and yield signs, vehicle directions, emergency instructions, parking and school zone safety[1].

A solar traffic light system as shown in Fig. 1 composed of the four major components as following: (1) Solar panel that includes solar cells, (2) DC to DC converter to maintain the output voltage at a constant level, (3) Charge controller to control the flow of charge through the battery and charges it when needed, (4) Battery to store electric energy and use it during the absence of sunlight[2].

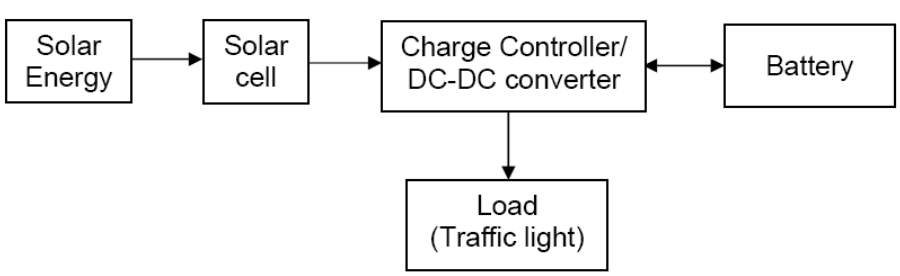

Fig 1. Energy flow in a solar powered system

Photovoltaic Cells

Photovoltaic energy is the conversion of sunlight into electricity through a photovoltaic (PV) cell, commonly called a solar or PV cell. PV cells are constructed out of semi-conducting materials so that when light shines onto the cells a certain amount of the light is absorbed. The energy of the absorbed light knocks the electrons loose from their atoms allowing them to flow through the compound[3].

The photovoltaic cell is the basic part of the building block of a PV system. PV cells can be arranged in a series configuration to form a module to supply electricity at a certain voltage, such as a common 12 volts system. Modules can then be connected in parallel-series configurations to form arrays. When connecting cells or modules in series, they must have the same current rating to produce an additive voltage output, and similarly, modules must have the same voltage rating when connected in parallel to produce larger currents. Fig. 2 shows a sample cell, module, and array.

The following factors are affected on the performance of a solar cell[4]:

- Sunlight and the angle that the sunrays hit the PV cell.
- Climate conditions such as clouds, fog, dust.
- The atmospheric layer's absorption and reflection.
- Temperature of the surroundings.

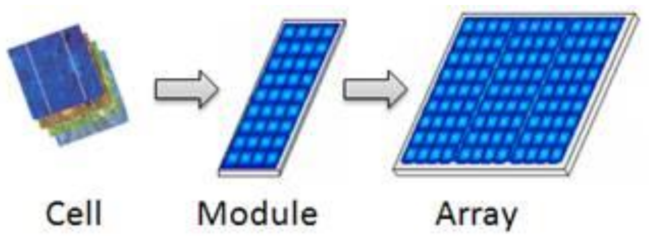

Fig 2. Solar panel configurations

The equivalent circuit of PV cells can be modeled as a current source in parallel with a diode and series and shunt resistances[4,5] as shown in Fig. 3. The output current I is obtained from:

$$I = I_l - I_0\left(e^{\frac{q(V+R_s I)}{nkT}} - 1\right) - \frac{V + R_s I}{R_{SH}} \quad (1)$$

where I_0 is the saturation current of the diode, q is the elementary charge 1.6×10^{-19} Coulombs, k is a constant of value 1.38×10^{-23}J/K, n is the diode ideality factor (typically between 1 and 2), T is the cell temperature in Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias). Parallel shunt resistance (R_{SH}) and series resistance (R_S) are parasitic resistances that model the dissipation of power in solar cells. The I-V curve of an illuminated PV cell has the shape shown in Fig. 4 as the voltage across the measuring load is swept from zero to V_{OC}. It is possible to approximate the series and shunt resistances, R_S and R_{SH}, from the slopes of the I-V curve at V_{OC} and I_{SC}, respectively.

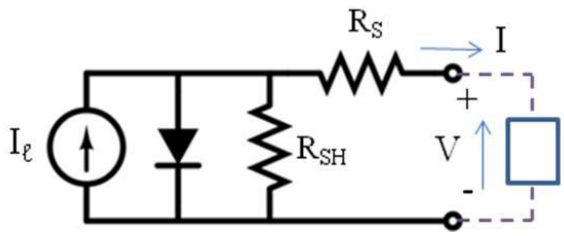

Fig 3. Simplified equivalent circuit model for a photovoltaic cell

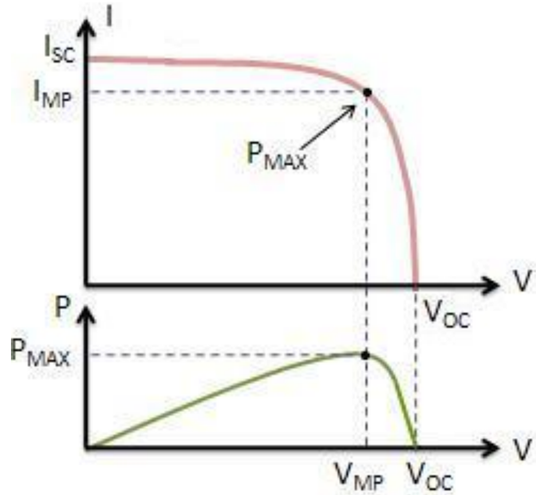

Fig 4. Illuminated I-V sweep curve

The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation $P=IV$. At the I_{SC} and V_{OC} points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as V_{MP} and I_{MP} respectively. The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power (P_T) that would be output at both the open circuit voltage and short circuit current together as follows. FF can also be interpreted graphically as the ratio of the rectangular areas depicted in Fig. 5.

$$FF = \frac{P_{MAX}}{P_T} = \frac{I_{MP} \cdot V_{MP}}{I_{SC} \cdot V_{OC}} \qquad (2)$$

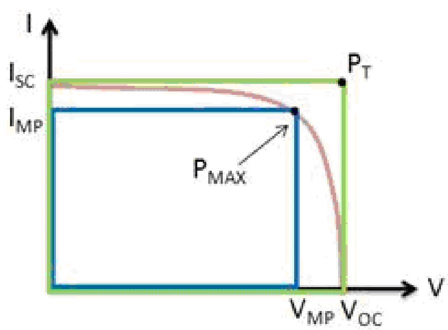

Fig 5. Illuminated I-V sweep curve with rectangular area

There are four different types of solar cells; crystalline silicon, thin film, high efficiency III-V multi-junction, and dye-sensitized solar cells. Thin film family is including Amorphous Silicon, $Cu(InGa)Se_2$, and Cadmium Telluride (CdTe) solar cells. The most feasible technology to be used in the solar traffic light application would be the crystalline silicon solar cells. This is mostly based on the fact that crystalline silicon technology is well established and understood, unlike thin film solar technologies, which are still being researched. Moreover, although thin film silicon solar cells can potentially be cheaper in the future[6], they currently have a market price of around $4.00/Wp[7], which is very close to that of crystalline silicon (~$4.1/Wp).

Many types of solar cells are available in the market[8] and the average selling price of solar modules these days is around US$4/W. The chosen solar array is FVG 10 P - FVG 25 M – 50106. The operating specifications of this type solar cell are V_{oc}=21.8V, I_{SC}=1.76A, V=17.1V, P=25W, I= 1.46A and its dimensions are 680×335×23 mm. Fig. 6 shows the schematic of implemented photovoltaic traffic light signal system with real components.

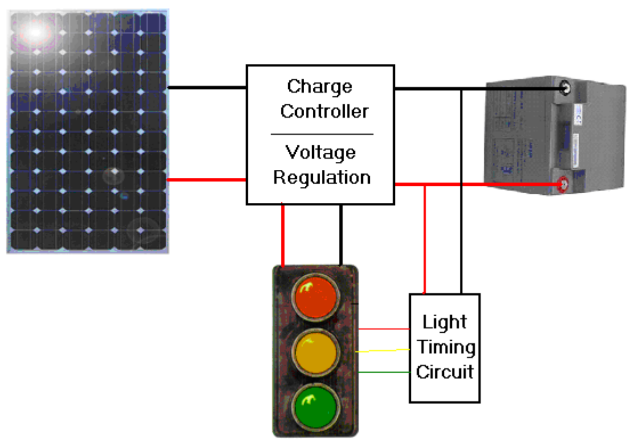

Fig 6. Schematic of implemented PV traffic light signal system

Energy Storage

Stand-alone PV systems require energy storage to compensate for periods without or within sufficient solar irradiation, such as during the night or during cloudy weather. Chemical batteries are the most candidates. The most suitable battery technologies to use in a stand alone photovoltaic system are: lead acid batteries, Lithium-ion batteries, Ni-Cd batteries. Currently, the lead-acid battery is the most common form of energy storage in photovoltaic applications due to its low cost, low rate of self discharge and its ability to work at higher temperatures. Although, it has a low mass/energy ratio, that doesn't affect their performance in solar traffic light application as the battery is stationary[4, 9].

Traffic Light

Nowadays LED bulbs are replacing the old incandescent bulbs. LED's is very efficient, with low energy consumption and a long life span. The most recent technological innovation reached in the traffic industry is using solar traffic light systems[10]. In this paper, we have used LED traffic lights with rating 12 V, 8 W. It always is supplied from the battery.

Charge Controller

A charge controller is used to control the flow of charge through the battery during charging and discharging. A charge controller protects the battery from overcharging and deep discharging in order to protect the battery from damage and also to increase its life span. Fig. 7 shows the employed circuit charge controller[11]. It regulates the power flowing from a photovoltaic panel into a rechargeable battery. It features easy setup with one potentiometer for the float voltage adjustment, an equalize function for periodic overcharging, and automatic temperature compensation for better charging over a range of temperatures. This analog designed circuit is simple, high efficient, and reliable. IC2 is 7805 regulator that supplies IC1. IC1b is a comparator the turns on red and green LED. Red LED indicates the battery is charging and green LED means the battery disconnected from solar module. Comparator IC1a commands to Q3 for charging the battery. The voltage level of charging can be adjusted through VR1 potentiometer. An automatic temperature compensator using NTC, has been designed to have an optimum charging of the battery.

In this paper, no dc-dc converter has been used for voltage regulation. Instead of that, an IC regulator LM317 has been used between solar panel and the battery and traffic light. Fig. 8 shows the employed regulator circuit. It output voltage can be adjusted via R1 and R2.

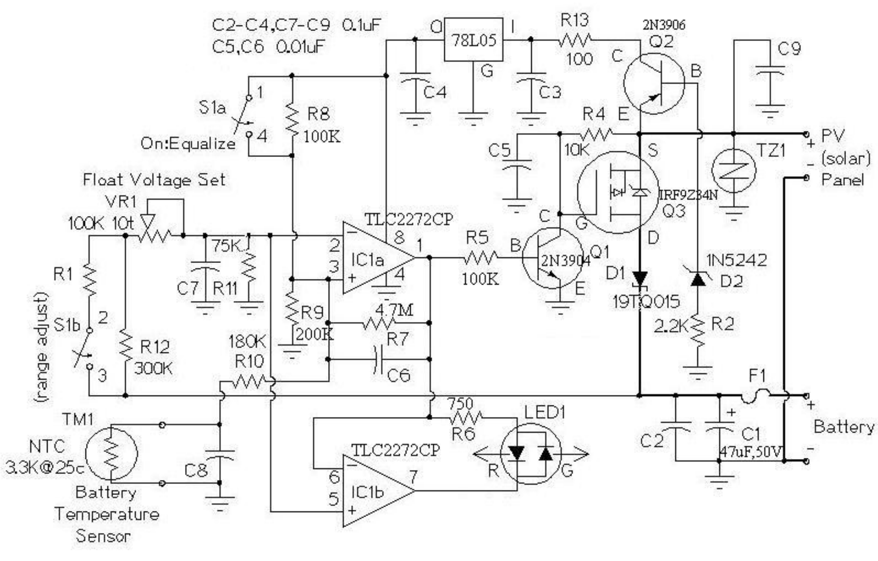

Fig 7. Schematic of implemented PV traffic light signal system

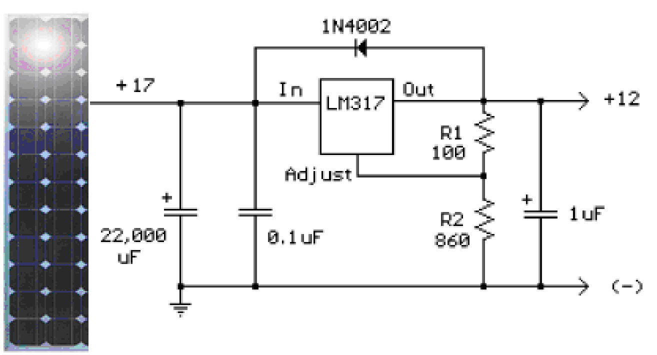

Fig 8. Voltage regulation circuit

Test Results

The proposed PV traffic light system has been implemented and under different conditions tested. All tests were carried out on December 9, 2010 at university of Kashan. Kashan is a city located in the center of Iran. Its geographical coordinates are 36° 13' north, 50° 38' east.

Fig. 9 shows the no-load voltage for a period of time 8:00 till 17:00. The values are for the angles 0 and 45 degrees. The maximum voltage does not only depend on the angle; it also depends on the time of the day, which reflects the position of the sun in the sky. A peak value is given between 10:00 and 10:30. Furthermore, the effect of the day on the voltage output of the panel gives the same angle of radiation. The time of the day has a major effect on the voltage output of the solar panel.

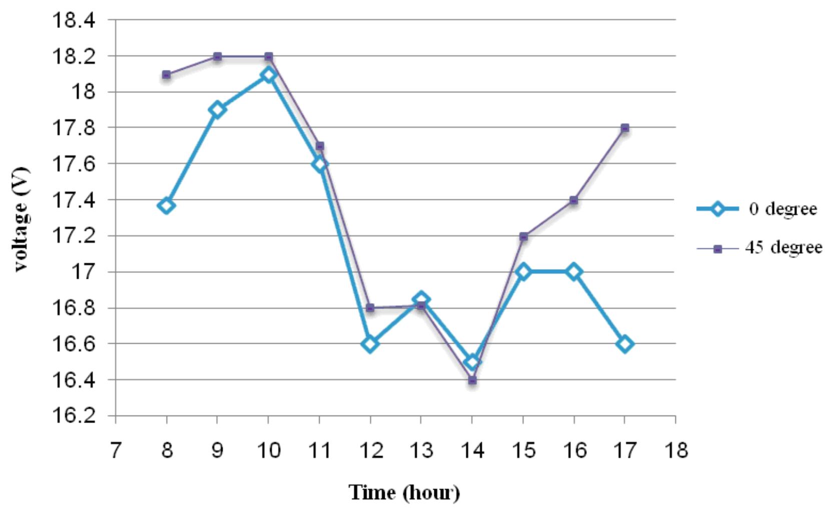

Fig 9. No-load voltage versus time for PV system

In Fig. 10, output voltage of module under load condition is shown. The battery is full-charged and so, the variation of voltage is low. If the battery was discharge the drop-voltage will be more. Fig. 11 shows the solar current vs time for different time of the day on December 9, 2010. Fig. 12 shows the battery voltage vs time that is reducing while the solar radiation decreases at the noon.

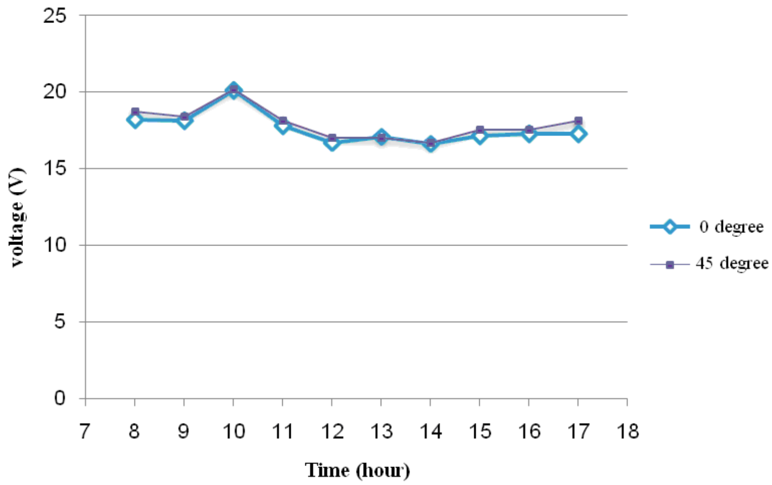

Fig 10. Load voltage versus time for PV system

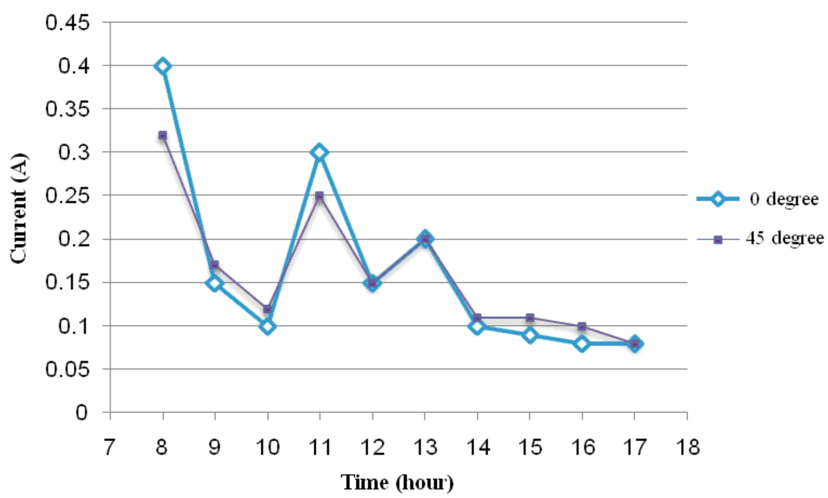

Fig 11. PV module current versus time

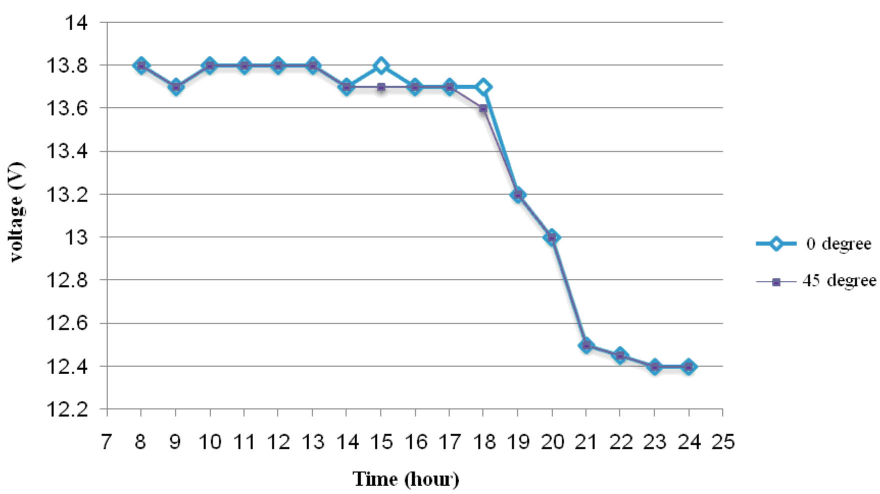

Fig 12. Battery voltage versus time

Conclusion

A low-cost solar traffic light system was presented. The system has four major parts: PV fixed-array, charge controller, lead-acid battery and traffic light. Crystalline silicon solar cells were used in this project because it is the most favorable type for traffic stop light signals, due to its availability in the market, and its higher efficiency. The timing sequence of light signals was managed via an AVR microcontroller. In order to regulate voltage of PV array, IC regulator was employed instead of conventional buck-boost dc-dc converter which reduced the price of the control system. Lead acid battery was employed since these batteries are relatively inexpensive and have a longer lifetime compared to other batteries for energy storage. The LED stop light is energy efficient and has a long life span and low maintenance costs. The experimental results shows that angle of array, time of day and different days of the year are effective to capture the highest power, which were done by three undergraduate students. In order to capture maximum power, movable array that can changes the angle is more effective which can be used for high power applications.

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