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IOT Based Modern Solar Street Light System

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Abstract

This paper demonstrates a prototype for a smart street-lighting system, in which a number of DC street lights are powered by a photovoltaic (PV) source. A battery is added to store the excess energy of the solar panel, which can later be retrieved at night time, or whenever the sunlight is being obstructed by clouds or other forms of shading. A charge controller is used to protect the battery from overcharging and to control the overall system operation. Furthermore, the system is expanded to include a motion sensing circuit, and a dust- cleaning circuit. The overall result is a smart and efficient street lighting system, which can be implemented as a standalone off-grid system, or connected to the rest of the grid as part of a bigger system.

Keywords - Solar energy, smart systems, Photovoltaics.

1. Introduction

In the past few years, the Smart Grid has gained a lot of popularity, mainly due to the fact that it promises a more intelligent, efficient, and reliable use of the power resources, while also providing a better quality of service to the customers. The advances in the technology of renewable energy sources have also contributed to the increased dependence on renewable energy, as opposed to the conventional fossil-based sources. In this paper, we demonstrate an idea for using renewable energy sources; namely, solar energy, to power a street lighting system, which could alleviate a lot of stress on the conventional power grid, and take us a step further in the process of moving towards a more intelligent power grid. We suggest powering street lights completely using solar energy by connecting the lights to photovoltaic (PV) panels, which are accompanied by a set of batteries and a charge controller in order to store energy at day time, and provide it back for lighting the streets during night-time.

Energy conservation at night is also essential when there is no movement on the streets; thus, our system is expanded to include a motion-sensing circuit to activate the use of street lights only when the lighting is necessary. An additional feature is added to the PV panel, which is a dust cleaning circuit, whose purpose is to clean the PV panel from dust whenever it accumulates on top of it. This helps keep the efficiency of the panel at reasonable levels, and prevents it from decreasing due to accumulated dust.

We performed both hardware and software design, where the hardware part included several circuits, such as the motion sensing circuit, the dust cleaning circuit, and the main circuit that connects the street light and the PV panel, while the software portion of the design focused on developing the control algorithm, which puts together all the hardware parts, and controls the operation of the different circuits in the system.

The software used to run this system was the Mat lab/Simulink, which was used for controlling the system operation, as well as monitoring it and verifying its conditions. To ensure proper system operation, several important parameters were monitored including the solar irradiation, the open circuit voltage, the short circuit current, the input and output power to the PV panel, in addition to the status of the dust cleaning device and the motion sensor, all of which were monitored and recorded periodically once every second.

While for this project all the monitoring and control was performed off-grid, the ideas presented can also be used if the street lighting system was connected to the grid. The overall goal of this project is to develop a prototype for an intelligent street lighting system, which would minimize (or in this case completely eliminate) the use of electricity coming from the grid, and retrieve all the required energy from solar panels attached to it. It is also important to develop ways to improve the operation of the system, so we added the features of motion sensing, and dust cleaning, which would reduce the losses due to unnecessary lighting, and would increase the overall system efficiency by periodically reducing the amount of dust covering the solar panel. The rest of the paper is organized as follows. Section II presents a summary of related literature. Section III describes the main circuit and the motion sensing circuit used in the system, and explains their operation. Section IV presents the dust cleaning circuit and details its operation. The details of the MATLAB/Simulink code are presented in Section V, which also explains the operation of the system in general. Section VI outlines the results of the project. Section VII provides an analysis of the system efficiency, and Section VIII concludes the paper.

2. Review of Related Literature

A number of studies were presented in the literature that targeted various aspects of smart street lighting systems. In this section, we summarize the ones that were more relevant to our work. In [1], the authors suggest using LED DC street lights rather than traditional AC street lights; due to their higher efficiency, longer lifetime, lower maintenance costs, and the fact that they are mercury–free, making them environment-friendly. Similar to the LED lamps are the high intensity discharge lamps (HID) that could also be implemented. HID lamps acquire high luminous efficacy and good color rendition, along with their relatively long lifetime [2]. In another study, the authors showed that if the street lighting systems in the city were upgraded to LED, a 64% energy saving is achieved, and 33192 tons of equivalent carbon dioxide are avoided without even applying the renewable energy sources [3]. The work in [4] relates the street lighting system to the overall power grid through the concepts of load demand and renewable power generation.

The results obtained from a 132W LED system are compared with typical results of HID lamps of similar power levels. Developing new technologies to further control and mange street lighting systems was the subject of many research efforts in the literature. In one such study, communications topologies to control the street lighting systems are presented through developing a street lamp system utilizing the general packet radio service (GPRS), power line carrier, or the global system for Mobile communications (GSM) transmissions as presented in [5]. Other studies such as the ones in [6] and [7] focus on intelligent street lighting systems. They include the design of a wireless data network-based street lighting system capable of controlling and monitoring a system that contains a number of street lights using the ZigBee protocol. In another study, research was conducted in Egypt to design a maximum power point tracker (MPPT) for the street lighting system, which can possibly solve the Egyptian peak point crisis of load demand if the system is widely installed, thus handling a commendable portion of the country's demand [8].

The effect of dust on PV panels was thoroughly studied in [9], where efficiency degradation of the PV panel due to dust deposition was verified. Samples of dust ranging from (0 to 1.963 mg/cm^2) were deposited on the glass covering of the PV panel. The results show a degradation of short circuit current from 0-49%, respectively. Dust is a major concern to PV panels' efficiency; thus many solutions emerged to get rid of it.

One innovative solution is to apply an Electro dynamic screen across the PV panel, as depicted in [10]. The electrodes of the screen are activated by high voltage, low frequency (5-10 Hz) pulses. Accumulated dust particles are charged electro statically and repelled by electrostatic forces, causing the deposited dust to be dispersed. Street lighting in Jordan consumes 2% of the total electric energy consumption every year. In this paper it is suggested powering the street lights completely using solar energy by connecting the lights to Photovoltaic (PV) panels, which are accompanied by a set of batteries with a charge controller in order to store energy at day time, and provide it back for lighting the streets during night-time. Energy conservation at night is also essential when there is no movement on the streets, thus in this design a motion sensing circuit is used to only activate street lights when the lighting is necessary. Further features are added to the PV panel, including a dust cleaning circuit, which cleans the PV panel from dust whenever it accumulates on top of it, which keeps the efficiency of the panel at reasonable levels, and prevents it from decreasing.

3. The Main Circuit, and the Motion Sensing Circuit

The main circuit of this system is shown in Fig. 1. During daytime, the PV panel provides energy to charge the battery, and during nighttime, the battery provides power to the main load; i.e., the street light. The charge controller is necessary to prevent the battery from overcharging during the day time, and control the interaction between the circuit elements. The motion sensing circuit is also an important part of this system, as it contributed directly to reducing the power consumption in the main circuit.

Depending on the amount of traffic on the street, there could be times where no vehicles are passing by especially during late night or early morning hours, when traffic is usually minimal. During these times, there is usually no need for street lights to be on, as there is no use for them, which is why a motion sensor circuit would provide lots of savings in power. The motion sensing circuit consists mainly of a Passive Infrared (PIR) motion sensor, and a relay module. As shown in Fig. 2, whenever a motion occurs, the PIR sensor triggers the relay module to connect the charge controller with the street light. Details of the operation of the PIR sensor can be found in [11]. If it is night time, the light will be turned ON. Note that the PV panel and the battery are connected to the charge controller, which controls the operation of the main circuit by charging the battery during day time, and controlling the light operation during night time.

4. Dust Cleaning Circuit

The other important circuit in our design is the dust cleaning circuit. Dust accumulated for six months decreases the efficiency of the PV panel by 70% of its original value [12], so it is important to develop a solution that would reduce the impact of this highly important issue. Moreover, it has been found that fine dust particulates significantly deteriorate the efficiency of the PV panel more than their coarser peers [13]. The dust cleaning circuit has been divided into a number of stages: the short circuit current stage, the output voltage stage, the input power stage, and the blower stage. From the first two stages the output power of the PV panel can be calculated in Simulink, and then compared with the input power. The input power is taken from a pyranometer signal. If the two quantities did not match and the pyranometer is reading full-sun or near full sun reading, then a triggering signal will be sent to the blower to activate it. Figure 3 shows how to obtain the value of the short circuit current of an operating system, which is then sent to the main control board; the Arduino MEGA 2560 Board.

The Arduino board is an open source microcontroller programmable board, which can be easily programmed via Mat lab, and was chosen in this project for its ease of use, and versatility. Mat lab initiates a triggering signal once every 10 minutes for a period of 1 second during which the short circuit current reading is sent to the Arduino board. During the shortening of the PV panel, the charge controller forces the battery to short as well, which can cause a problem. This, however, can be resolved by using the same signal to force an open-circuit across the battery's terminals while the PV panel is shorted, as shown in Fig 4.

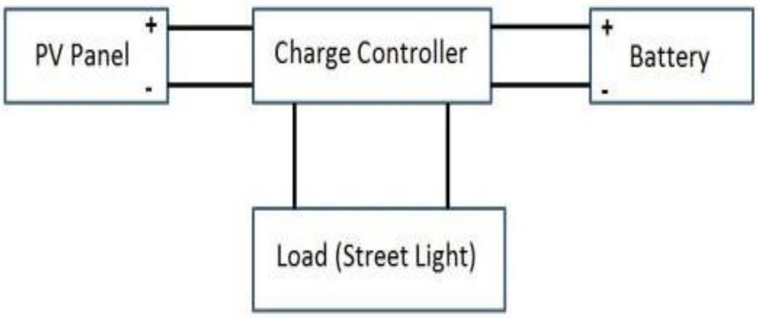

Figure 1 Charge controller combination with the load, PV panel, and battery

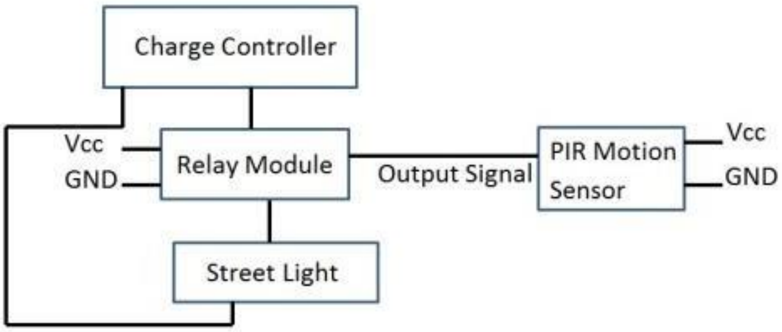

Figure 2 Motion sensor control design of the street- light

The instantaneous output voltage of the PV panel is entered into the Mat lab program using a voltage divider, as shown in Fig. 5. The input power is taken from the pyranometer's reading after multiplying it with the PV panel's efficiency and area. However this signal from the pyranometer needs to be amplified in order to be accepted by the Arduino. The pyranometer amplification stage is shown in Fig. 6. With all the previous quantities determined, Mat lab decides whether or not to trigger the relay (shown in Fig. 7) for a certain period of time in order to blow away the dust. While in this system we used an AC blower, this can be replaced with a DC blower powered from the battery, if the off-grid system is required.

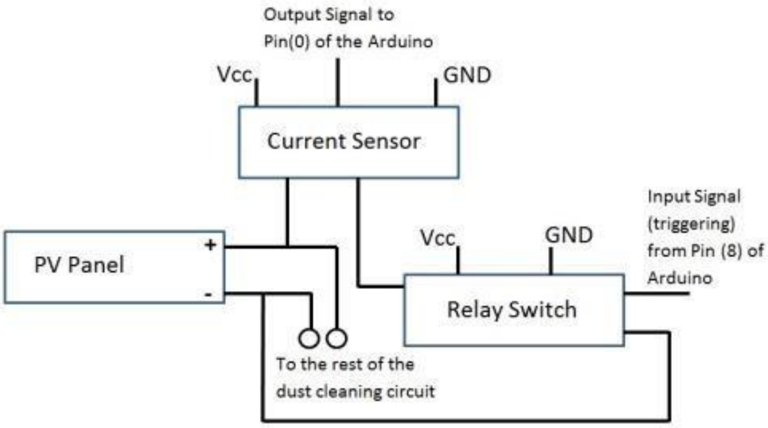

Figure 3 Short-circuit current reading stage of the dust cleaning circuit

5. Simulink Coding

The main brain behind the operation of this system was the Arduino MEGA 2560. The Arduino controls the entire operation of the system including the main circuit, the charge controller, and the dust cleaning circuit.

Programming the Arduino was conducted via block-diagram coding in the Simulink environment, which is part of the Mat lab software [14], as shown in Fig. 10. In this section, we provide a brief description of the operation of this code.

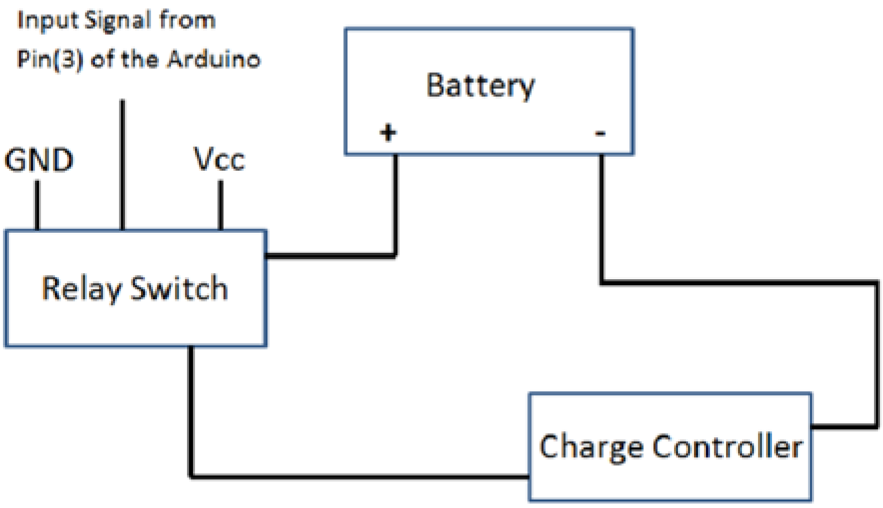

Figure 4 Battery short circuit prevention circuit

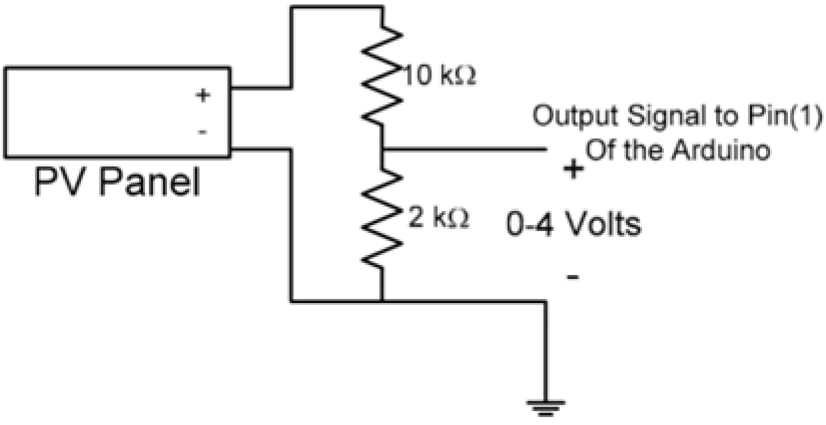

Figure 5 Output voltage reading stage of the dust dealing circuit

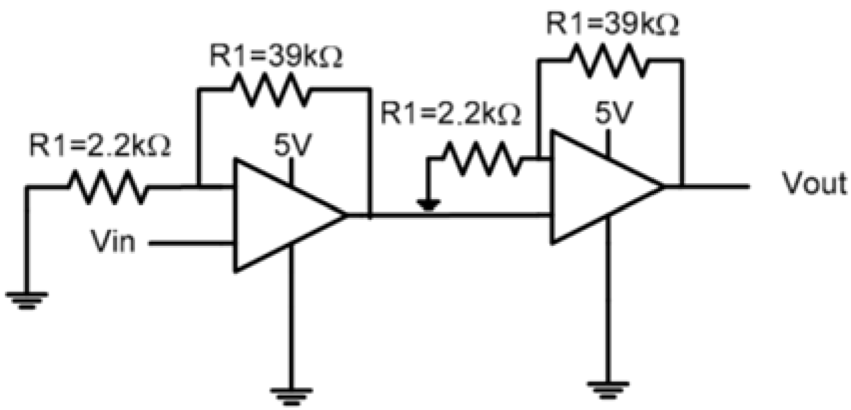

Figure 6 Amplification of the Pyranometer's output voltage

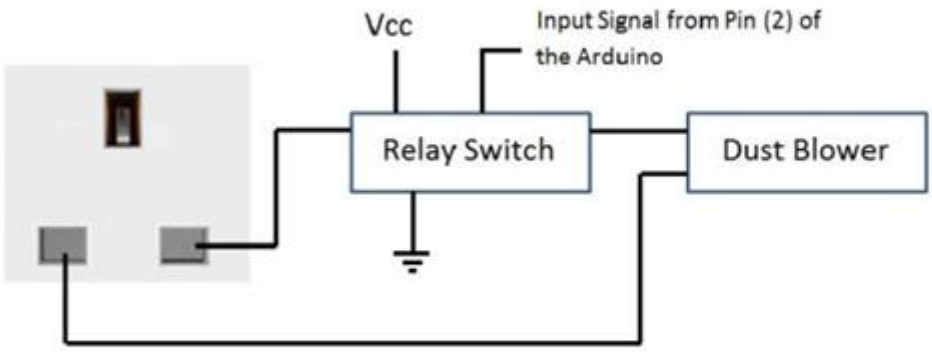

Figure 7 Blower stage of the dust cleaning circuit

Figs. 8 and 9 show the experimental setup as seen in the laboratory environment, with all devices labeled. First of all, energy consumed in the system is calculated by incrementing a counter every time the motion sensor detects movements, and then multiplying the counter by the power rating of the light and by the amount of time during which the light the light is ON; that is, 20 seconds per each signal of the motion sensor, and the resultant consumed energy will be displayed after it has been converted to kWh. This is shown on the bottom right portion of Fig. 10. The first analog input (top left) represents the short circuit current reading, which is converted to Amperes, and saved it in a memory location on the Arduino board. The lower portion represents the output voltage reading, and the conversion process to Volts. Unlike the short-circuit current, which requires shortening the terminals of the panel, and acquiring a reading, there is no need to save the value of the output voltage because the reading is continuous and is displayed in real time.

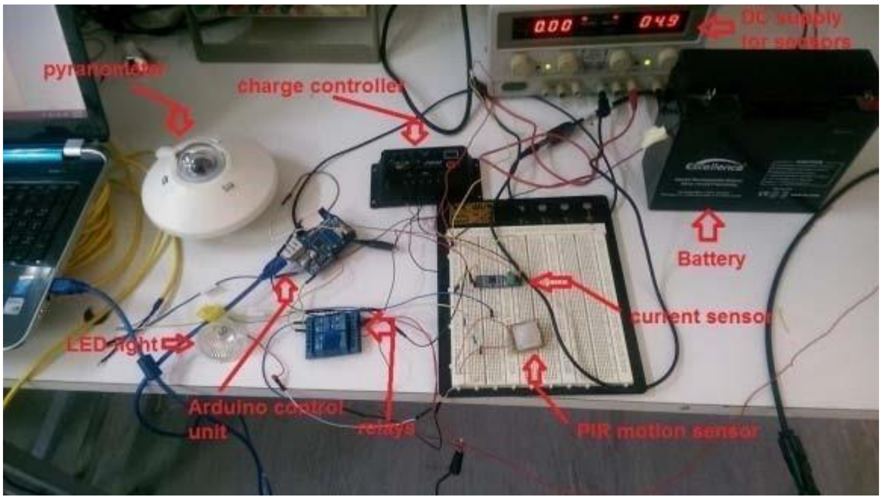

Figure 8 Laboratory Setup

Figure 9 Laboratory Setup Including the Solar Panel

Both values of current and voltage are multiplied to yield the actual maximum power that the PV panel is able to produce. The lower left portion obtains the pyranometer's reading, and converts it into W/m², after multiplying it by the panel's efficiency and area. The resulting value is then compared with the output power previously found. Depending on this comparison operation (shown on the bottom of Fig. 10), and by taking the maximum and minimum derate factors of dust into account, a signal is sent to the relay module responsible for triggering the blower. This signal will be sent if the two previous power quantities did not match AND the pyranometer was giving a noncloudy reading. The upper right portion of Fig. 10 shows the pulse generator responsible for triggering the relay module that shorts the PV panel for 1 second every 10 minutes (while also open- circuiting the battery at that same second) to obtain the value of the short circuit current.

6. Experimental Results

A number of graphs were obtained when running the system explained above, and in this section we show the results obtained, and we explain them as they relate to the objective of our project. The two cases that were studied represent a sunny day and a cloudy one. Figure 11 shows the solar radiation during 50 minutes of time on a cloudy day. As can be seen in the graph, there is a high amount of intermittency in the power received by the solar panel due to the effect of clouds constantly disrupting the availability of sun rays. Figures 12 and 13 demonstrate the short circuit current and the output voltage of the PV panel, respectively, during fifty minutes of time on cloudy day. Figure 14 shows the irradiance on a sunny day. While there are a few short spikes due to sudden cloud shading, during which the power is significantly reduced, the amount of solar irradiance is relatively stable around 1000 kW/m^2, which is typical for a mostly sunny day.

Figures 15 and 16 illustrate the short circuit current and the open circuit voltage during the same fifty minutes of time on a sunny day. As can be seen from the figures, during cloudy days, the amount of solar energy that we obtain is generally less than in the case of the sunny day. More importantly, however, the large amount of variation that can be seen in the voltage, current, and consequently the power, is mainly due to the constant variation in the amount of solar energy obtained during the cloudy day. These measurements show the proper operation of the system in terms of its ability to monitor the amount of solar irradiance. These values are then compared to the readings of the pyranometer, as explained earlier to help detect whether or not there is dust accumulated on the panel.

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