Online Publication Date: 19 February 2012
Publisher: Asian Economic and Social Society

Development of a Novel Solar Radiation Measuring Device

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Citation: Samer Alsadi , Tamer Khatib, Sulafa Mallooh (2012): "Development of a Novel Solar Radiation Measuring Device" Journal of Asian Scientific Research , Vol.2, No.2, pp.40-44.

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Abstract

In this paper, a novel solar radiation measuring device is proposed. A solar cell, PIC controller, temperature sensors as well as a memory chip are used. The proposed device measures the solar radiation and the ambient temperature through a specific time period and then the measured data is stored on a memory chip through the PIC controller. After that the stored data can be transferred to a computer in order to be analyzed. However, a calibration of the used solar cell is done first, in order to derive an empirical relation between the solar radiation and the solar cell current. The results show that the developed solar radiation device is accurate as compared to the taken benchmark measuring device. Moreover, the developed device is cost effective as compared to the current commercial solar radiation measuring devices. This device helps in analyzing the solar energy impact in a specific region which helps in optimally sizing solar energy systems.

Keywords: Solar Radiation, Solar Radiation Measuring Device, Solar Radiation Sensor.

Introduction

Solar radiation is the portion of the sun's radiation available at the earth's surface for useful applications, such as exciting electrons in a photovoltaic cell and supplying energy to natural processes like photosynthesis. This energy is free, clean and abundant in most places throughout the year and is important especially at the time of high fossil fuel costs and degradation of the atmosphere by the use of these fossil fuels (Muneer, 2004).

Solar radiation consists of two parts; extraterrestrial solar radiation which is above the atmosphere and global solar radiation which is under the atmosphere. The global solar radiation incident on a horizontal surface may have direct beam and diffuse solar radiation. Diffuse solar radiation is usually measured by pyranometers, solarimeters, or actinography while direct beam solar radiation is measured by a pyrheliometer. These measuring devices are usually installed at selected sites in specific region and it is not feasible to install at many sites due to high cost of these devices. In addition, these measuring devices have tolerance and accuracy and consequently wrong/missing records may be found in the data set (Khatib, 2011,). The measured solar radiation values can be used for developing solar radiation models which describes the mathematical relations between the solar radiation and the meteorological variables such as ambient temperature, humidity and sunshine ratio. These models can be later be used to predict the direct and diffuse solar radiation using historical metrological data at sites where there is no solar energy measuring device installed (Khatib, 2011(1)).

However, the cost of the pyranometers and other solar radiation measuring devices is the in the range of (100-400) USD depending manufacturing company. On the other hand, most of the solar radiation devices come as autonomous sensors whereas they measure the solar radiation without any further process (Khatib, 2011). Meanwhile, data loggers or computers must be connected to these devices in order to store the measured data. According to this, the main objective of this paper is to propose a cost effective solar radiation measuring device. The proposed device measures the solar radiation and ambient temperature and displays them on a LCD screen. Moreover, the device is able to store the measured data on a memory chip for long periods and consequently these data can be transferred to a computer in order to be analyzed.

Calibration of a solar cell for solar radiation measurement

In this paper, a solar cell (4.5 V/ 80 mA) connected to a resistor 100Ω/ 1 Watt is used to measure the solar radiation. This solar cell is supposed to feed the resistor by a certain current and voltage under a certain solar radiation and ambient temperature value. However, the solar cell current can be relatively measured by measuring the resistor terminal voltage as follows,

$$\mathbf{P_{CELL}(t)= P_R\,(t)*\eta_{WIRE}} \qquad (1)$$

Where P_{CELL} is the power generated from the solar cell at a specific solar radiation conditions, P_R is the power dissipated in the resistor and η_{WIRE} is the wire efficiency (the losses). Assuming that the loss is too small, then

$$\mathbf{I_{CELL} = I_R} \qquad (2)$$

This leads to

$$\mathbf{I_{CELL}= V_R* R} \qquad (3)$$

According to equation (3) the solar cell current is linearly proportional with the resistor terminal voltage and consequently the resistor terminal voltage is linearly proportional with the solar radiation. Based on this, the terminal voltage of the resistor which is connected to the solar cell is monitored during a specific number of days. Meanwhile, the solar radiation is measured at the same time using a commercial pyranometer. After that the recorded solar radiation verses the resistor terminal voltage are used to established a relation between the resistor terminal voltage (solar cell current) and the solar radiation. Figure 1 shows the liner regression that suggested to fit the recorded data. From the figure the relation between the resistor terminal voltage (solar cell current) and the solar radiation is liner and can be described as follows

$$\mathbf{G(t)= 227.6V_R(t)- 69.62} \qquad (4)$$

Where G is the solar radiation and V_R is the resistor terminal voltage.

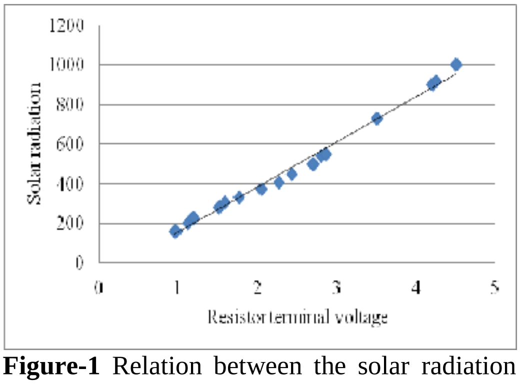

Figure-1 Relation between the solar radiation and a solar cell output current – Tulkarm, Palestine

Proposed device description

Figure 2 shows the proposed device consisting of sensing unit (solar cell and LM35 temperature sensor), PIC 16F877 microcontroller, display unit and storage unit (MMC). The proposed device measures the solar radiation and the ambient temperature for a certain time and displays it on a LCD screen. Moreover, the measured data is stored in a memory chip in order to construct a solar radiation and ambient temperature database for a specific selected location and these data can be transferred to a computer to be analyzed.

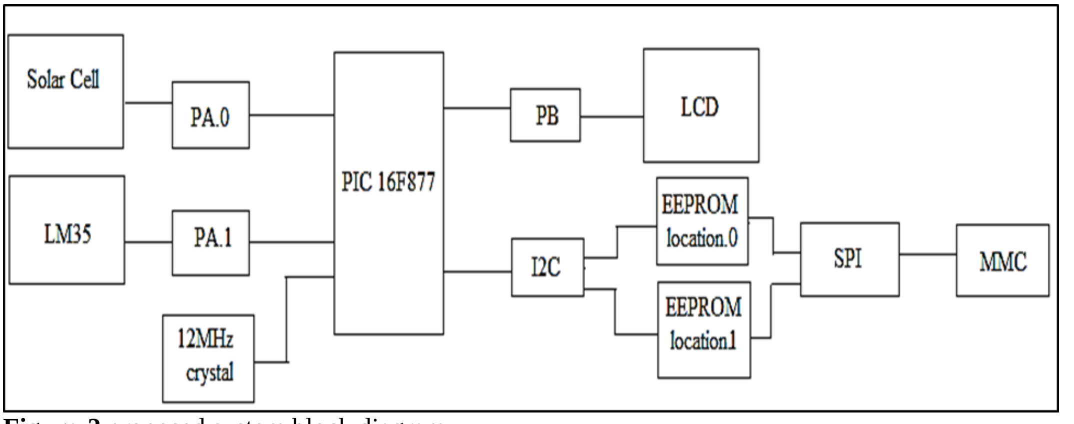

Figure-2 proposed system block diagram

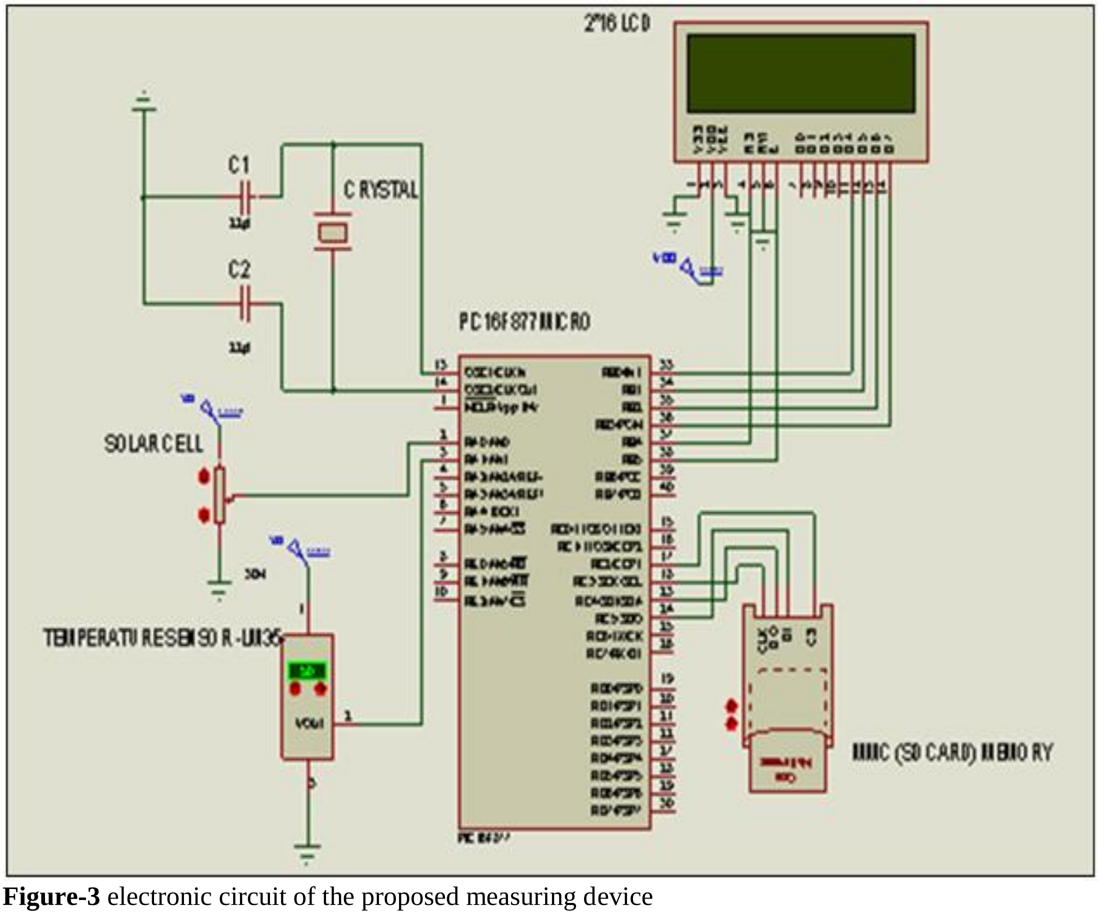

Figure-3 electronic circuit of the proposed measuring device

The first part of the block diagram is the sensing unit. The LM35 temperature sensor is used to measure the ambient temperature. On the other hand the solar cell that described in section 2 is used to measure the solar radiation. However, the LM35 sensors are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration to provide typical accuracies of ±1⁄4°C at room temperature and ±3⁄4°cover a full −55 to +150°C temperature range (Boland, 1995, Kumar, 2011).

However, the second part of the block diagram described in figure 2 is the PIC controller. In this paper, PIC16F877 microcontroller has been used due to its advantages, such as Low power consumption and high speed CMOS EEPROM technology. However, the function of the microcontroller unit is to process the electrical signal from sensing unit by converting the measured value to a standard value with a standard unit. In other words, the measured data is converted by an integrated analog to digital converter (ADC) and after converting the data to a standard digital values, it will be displayed and stored.

On the other hand, the function of storage unit is to permanently store data for specific periods in order to be analyzed. In this research MMC – SD card- is used for this application. Secure Digital (SD) memory card is a non-volatile memory card format. The Standard-Capacity (SDSC) card family, commonly called SD, has an official maximum capacity of 2 GB. Finally, a 16x2 LCD unit was used as display unit to show the instantaneous solar radiation and ambient temperature measured values.

Proposed Device Development

Figure 3 shows the electronic circuit of the proposed measuring device. The circuit is consisted of the microcontroller and its deriving circuit, the sensors (solar cell and the LM35), the storage unit and the display unit.

The microcontroller used in this paper, must be operated at 5 V and therefore, a regulated voltage source is recommend in order to avoid damaging the PIC. However, In order to trigger the used controller, a clock circuit that generates oscillations is used. This circuit is consisted of two capacitors, C_1 and C_2 as well as the oscillations generator device (Crystal). Meanwhile, the value of the capacitors is assumed to be 22.27 pico Farad.

The solar cell and the temperature sensor are conntedted to Port A which the second and the third pins as Port A is an input port according to the datasheet. Meanwhile, the LCD and the memory chip are connected to an output Ports.

Experiment Results

In order to test and validate the accuracy of the proposed device, an experiment for the device under the condition of Tulkarm city, Palestine is conducted. The proposed device and a commercial pyranometer (LI-200 Pyranometer) are used to measure the solar radiation at the campus of Palestine Technical University-Kadoorie, Tulkram, Palestine for three days. Figure 4 shows the solar radiation measured by the proposed measuring device verses the solar radiation that measured by LI-200 Pyranometer for one of the three days. From the figure the proposed device measured the solar radiation successfully whereas the measured data by the proposed device were close to the one that measured by the LI-200 Pyranometer. However, assuming the LI-200 Pyranometer as a reference, the main absolute percentage error values in measuring the solar radiation is 4.5%.

Table-1 proposed device units cost

Item	Cost (USD)
PIC	8
Solar cell	8
Temperature sensors	5
LCD	4
Memory card	15
others	10
total	50

However, the proposed device exceeds the LI-200 Pyranometer by two advantages; firstly the ability of storing the data on a memory card whereas the LI-200 Pyranometer needs to be connected to a data logger in order to store data. In addition, the cost of the proposed device is 11% of the LI-200 Pyranometer. Table 1 shows the unit cost of the developed device. The capital cost of the proposed device is 50 USD while the LI-200 Pyranometer cost is 450 USD. In addition, the proposed device is even competitive when it is compared to low quality pyranometers whereas the cheapest commercial pyranometer costs is about 100 USD.

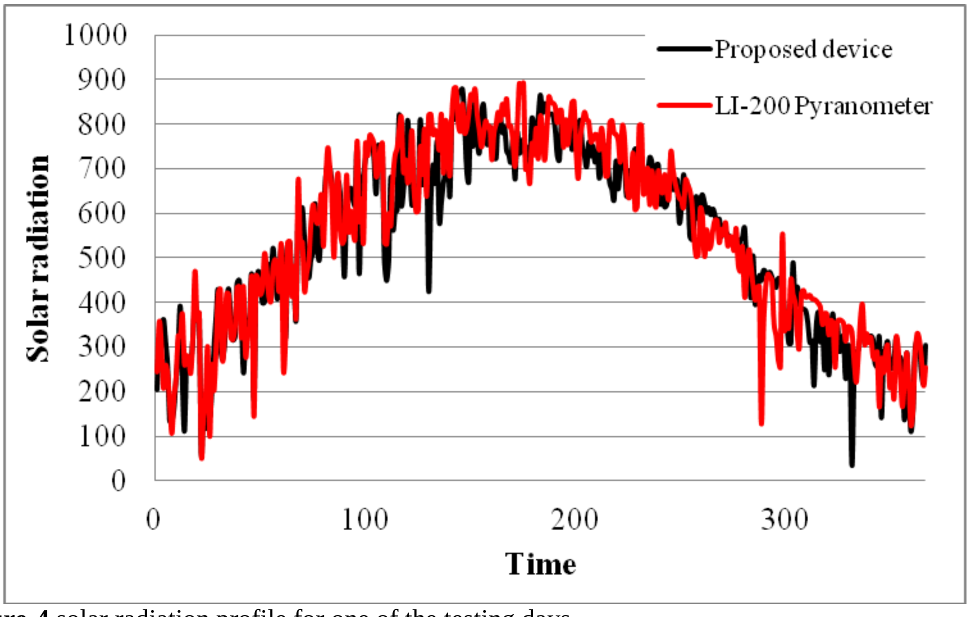

Figure-4 solar radiation profile for one of the testing days

Conclusion

A novel and cost effective solar radiation measuring device is developed in this research. The proposed device measures solar radiation and ambient temperature and display these data on a LCD screen. Moreover, the proposed device is equipped by a memory chip in order to store the measured data. The experiment results showed that the proposed device measured the solar radiation with acceptable accuracy as compared to the benchmark device. Meanwhile, the proposed device cost is 11% of the benchmark device. Such device is helpful is analyzing the solar energy potential in a specific location which important for designing solar energy systems.

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