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Design and Implementation of an Electronic Pyranometer

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Abstract: *Due to the difficulties encounter during the course of a project tilted "solar (energy) radiation study and distributed generation plan of photovoltaic in Bida: Taking Pati Shaba Kolo as a case study" (A Tertiary Education Trust Fund sponsored project 2016/2017, The Federal Polytechnic Bida, Niger State) in purchasing a pyranomter or rather getting one from any of the institutions in Nigeria led to the design and implementation of an electronic pyranomter to save cost and promote innovative ideas to solve empirical problems. The pyraometer was designed with a solar panel that charges the battery through a charge controller and the battery powers the electronic pyranometer circuit. The electronic pyranometer circuit was designed using a solar radiation equation Rs which was programmed into to an Atmega328p microcontroller with J (latitude) been inputted manually according to location and the maximum/minimum solar temperature measured through DHT11; a temperature and humidity sensor, and all parameters are inputted into the Rs formula to calculate the average solar radiation at a particular time. In the design, an SD CARD module was used to keep the record of solar radiation calculated by the microcontroller in a text format with a real time clock module (RTC module) that interface with microcontroller through Inter Integrated Circuit (IIC or I^2C); It was used to keep track of the days use in the determination of the solar radiation and the temperature sampling rate. A liquid crystal display (LCD) was used to provide the visual display of all the necessary information required by the user. The pyranometer was tested and readings were taken and it is recommended that an improvement should be made on the types of senor and packaging.*

Keywords: *Solar Radiation, Pyranometer*

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I. Introduction

The Sun is a nuclear reactor. Its energy is emitted as radiation mainly due the solar surface temperature according the Plack`s Law. The electromagnetic spectrum of the sun light includes wavelengths coming from the infrared to the ultraviolet. This spectral range of electromagnetic is called Solar Radiation [1].

Solar radiation is important to mankind, for heating, electricity generation, water pumping for irrigation and crop drying in Agriculture. It determines the rate of photosynthesis in plants and strongly regulates the amount of evaporation from rivers and streams. It warms our planet and gives us our everyday wind and weather [2].

There are mainly three types of devices to measure solar radiation over the Earth´s surface: Pyranometers (direct and diffuse solar irradiance), Pyrheliometers (direct solar irradiance) and Albedometers (reflected solar irradiance) [1].

Pyranometer is an instrument use for measuring solar radiation on a horizontal surface. Pyranometers are widely used in meteorology, climatelogy, agriculture, solar energy studies and building physics. The constructed pyranometer can be used in any installation where reliable measurement of solar irradiance is necessary, especially in those places (like institutions) where cost may be a deciding factor in the choice of a meter [3].

This paper presents the design and implementation of an electronic pyranometer for measuring solar radiation (MJ/m²/day). The constructed pyranometer possesses similar characteristics to those of standard pyranometers. The rest of the paper is prearranged thus: Section 2 presents the Literature review, section 3 presents system description, section 4 covers Design and implementation and in section 5, conclusion and recommendations were made.

II. Literature Review

The author of [4] developed an instrument used for the measurement of solar radiation called a reliable model pyranometer (RMP001). The sensor element used is a silicon diode, mounted on a plastic base, covered with a Teflon diffuser. The whole unit is placed on a base with a level control to ensure horizontality. The reliable model pyranometer (RMP001) was then calibrated against a reference high quality pyranometer, Kipp and Zonen CMP 3 whose calibration was trusted (14.71± 0.36 $\mu V^{-1}\ Wm^{-2}$). In [2], a digital solar radiation measuring instrument was designed, constructed and calibrated. It incorporates a small rectangular silicon photocell as the sensor. On exposure to solar radiation, electromotive force which is proportional to radiation intensity is developed within the circuit. The device correlates voltage developed with available solar intensity. A standard solarimeter was therefore used to calibrate the device to translate the unit of its reading from Volt to Watt per square meter.

[1] Did a novel design for a Low-Cost Sensor (Pyranometer) to measure Solar Irradiance in the North of Chile. The main characteristic of this sensor was the low-cost of all its components. The design of the sensor was based on using the PT202C phototransistor. This device is its better sensitiveness to solar irradiance, allowing an excellent response of the sensor in a range from approximately 300 to 1200 nm.

Design, construction and characterization of a multiple sensors solar radiation detector for ISES 2009 was done by [5], the objective of the research work is to evaluate the use of a weighted combination of photodiodes measurements with a rotating shadow band for monitoring simultaneously diffuse and beam solar radiation and thus be able to estimate global radiation as well.

In this work, an electronic pyranometer was designed using the solar radiation equation Rs which is programmed into to a microcontroller with J (latitude) been inputted manually according to location and the maximum/minimum solar temperature measured through the sensor and all are inputted into the Rs formula to calculate the average solar radiation at a particular time.

III. Design And Implementation

The Electronic Pyranometer comprises of the followings: solar panel, a charge controller, battery, DHT11 is a temperature and humidity sensor and the electronic circuit. The project is design to bring practical physics on solar radiation measure close to students as affording one in higher learning appears to be very expensive. More so, the interest in diversifying the sources of generating energy from non renewable to renewable is on the rise and solar power system appears to be more available and easy to access. This is best achieved if the energy radiated can be measured and use to determine the number of solar cells needed for particular project.

Solar Panel, Charge controller and Battery:

The solar panel was included in this work to charge the battery through the charge controller. The panel also serves as a shade to the electronic circuit. The electronic circuit is powered from the battery.

Design of the Electronic Pyranometer Circuit:

Power Supply:

The input power supply to the system ranges from 7V to 12V. This could be from any type of rechargeable battery in the market. In this design the battery is be charged by a solar panel through a charge controller. Figure 1.0 show the power supply circuit.

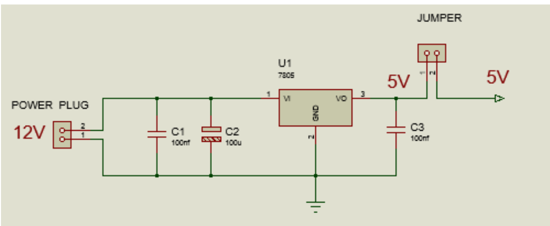

Figure 1.0: Power Supply Circuit

Capacitor C1 and C2 are for filteration and stability of the input supply. U1 is a voltage regulator that step down the input voltage to constant 5V required by the system components. When 7V or 12V is applied to the input, the output can be calculated as follows:

$\text{Vin} = 7\text{V}.$

$\text{Vdrop} = \text{Vin} - \text{Vout}.$

$\text{Vdrop} = 7\text{V} - 5\text{V}$

$\text{Vdrop} = 2\text{V}$

Since the system consume maximum of 327mA, power dissipation from the regulator will be:

$\text{P} = \text{Vdrop} * \text{Load Current}.$

$\text{P} = 2 * 327\text{mA}$

$P = 654mW$ or $p = 0.654w$.
When 12V is the input sypply voltage:
$Vdrop = Vin - Vout.$
$Vdrop = 12V - 5V$
$Vdrop = 7V$
Since the system consume maximum of 327mA, power dissipation from the regulator will be:
$P = Vdrop * Load\ Current.$
$P = 7 * 327mA$
$P = 2289mW$ or $p = 2.289w$.
[6]

The final ceramic capacitor at the output of the voltage regulator is to minimize any unwanted ripple that might come up.

The Jumper is either inserted or remove depending on the condition. The jumper must be remove when ever the system will be connected to PC for reprogramming. Durring the programming the microcontroller board get its supplyy voltage from the PC USB Port and this supply will not flow back to meet the other sypply from the battery since the jumper is remove. After the programming, the jumper must be place back so that sypply voltage from the battery will also power the microcontroller board.

The SD CARD Module:

Figure 2.0 shows the SD CARD Module.

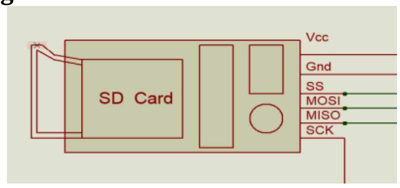

Figure 2.0: The SD CARD Module

The SD CARD module is a complete plug and play module which support the micro SD CARD used by mobile phones. The module uses SPI communication protocole with the microcontroller. In this system, the SD CARD module is use to keep the record of solar radiation calculated by the microcontroller in a text format.

LCD:

Figure 3.0 show the Liquid Crystal Display unit.

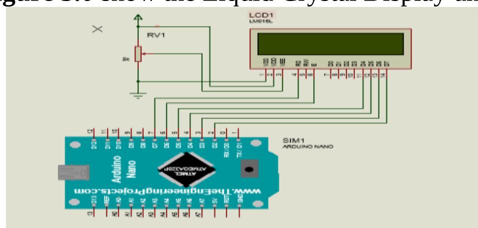

Figure 3.0: LCD Unit

The liquid crystal display(LCD) is a 16 by 2 type, meaning it has 2 raws of which each can accomondate 16 characters. Its provide the visual display of all the necessary information required by the user.

RTC:

The real time clock module (RTC module) is a plug and play module that interface with microcontroller through Inter Integrated Circuit (IIC or I^2C). this module keep track of real time clock and calander. The RTC is shown in figure 4.0.

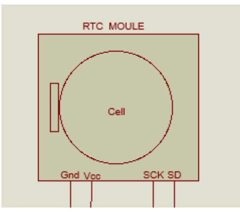

Figure 4.0: Real Time Clock Module

It is use to keep track of the days use in the determination of the solar radiation and the temperature sampling rate.

DHT11:
DHT11 is a temperature and humidity sensor which is capable of sensing temperature up to 55 degree shown in figure 10.0.

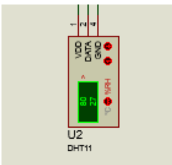

Figure 5.0: DHT11 Sensor

MICROCONTROLLER:

The Microcontroller board is call Arduino Nano board, it is a complete board that connect to PC through USB Port. All the program was written in Arduino IDE send to the microcontroller through USB Port. Figure 6.0 shows a microcontroller board

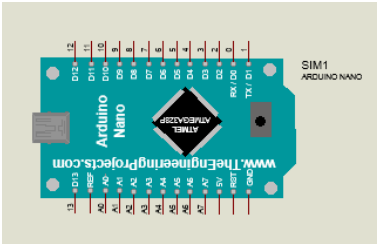

Figure 6.0: Microcontroller Board

The main processor chip on the board is Atmega328p which is the normal microcontroller chip manufacture by Atmel. Followings are some of the parameters of the chip:

Supply voltage 5V
Frequency up to 20MHz but the board has 16MHz.
32KB of programmable memory.
1KB of EEPROM
2KB of internal SRAM
6 channel of 10bit ADC
8 bit Architecture
Uses total 28pins of which 23pins are programmable.

BUTTONS:
Buttons are input device that are use to set date and time in to the device as shown in figure 7.0.

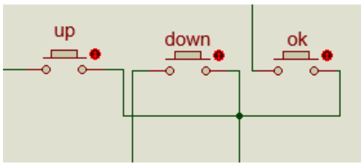

Figure 7.0: Input and Reset Button

The up button is use to form counting up while the down button is for counting down durring settings. The ok button is for accecpting setting. Figure 8.0 shows the complete circuit diagram of the design.

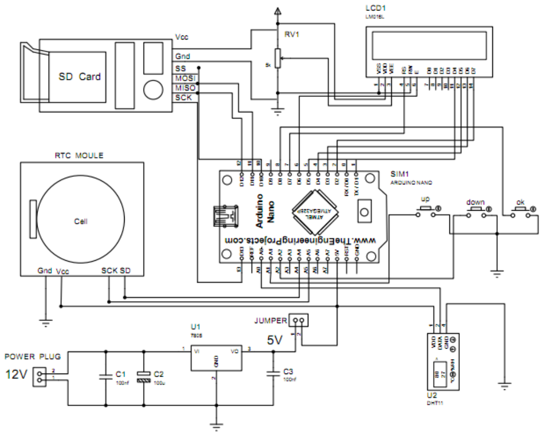

Figure 8.0: Complete Circuit Diagram

IV. System Description And Result

How the Electronic Pyranometer Operates:

As it was explained in the designed circuit, a programme was written on the microcontroller through which the measured temperature difference from the sensor (DHT11temperature and humidity sensor) is input into solar radiation (Rs) equation to calculate the instantaneous Rs. The equation comprises of the date and day of the year (J), the latitude of the location (in decimal degrees) which is manually inputted and Extraterrestrial Radiation (Ra) [MJ m^{-2} day^{-1}]. The equation is as follows:

$$Rs = kRs\left(\sqrt{Tmax - Tmin}\right) Ra \qquad 1$$

Where

Ra extraterrestrial radiation [MJ m^{-2} d^{-1}],
T_{max} maximum air temperature [°C],
T_{min} minimum air temperature [°C],
k_{Rs} adjustment coefficient (0.16 .. 0.19) [$°C^{-0.5}$].

The square root of the temperature difference is closely related to the existing daily solar radiation in a given location.

The extraterrestrial radiation, Ra, for each day of the year and for different latitudes was estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24\ (60)}{\pi} G_{sc}\, d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right]$$

Where
R_a extraterrestrial radiation [MJ m^{-2} day^{-1}],
G_{sc} solar constant = 0.0820 MJ m^{-2} min^{-1},
d_r inverse relative distance Earth-Sun,
ω_s sunset hour angle[rad],
φ latitude [rad],
δ solar declination [rad].

Ra is expressed in the above equation in MJ m^{-2} day^{-1}. The latitude, φ, expressed in radians will be positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

[Radians] = $\pi/180$[decimal degrees] 3

The inverse relative distance Earth-Sun, d_r, and the solar declination, δ, were given as:

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right)$$

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).
The sunset hour angle, ω_s, was given by:

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right]$$

[7]
The above equations when put together generates the solar radiation and the electronic pyranometer has the ability to store data measured including the calculated solar radiation after every minute for the whole year.

Result: The pictorial view of the electronic solar radiation is as shown in figure 9.0A and 9.0B respectively.

Figure 9.0A: A view of the electronic pyranometer display

Figure 9.0B: A view of the solar panel stand

V. Conclusion And Recommendation

Conclusion:

This work has demonstrated the effectiveness and efficiency of using an Electronic designed Pyranometer used in measuring solar radiation instead of the conventional type of Pyranometer used. This electronic type has the ability to store information, it can be used for practical in higher learning institution.

Recommendation:

it is recommended that an improvement should be done on the types of senor and packaging. The senor could not withstand water and also the packaging should be more strong to resist heat from the sun to avoid any damage to the circuit.

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