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Development Of A Microcontroller Sun Tracker For Efficient Photovoltaic Electricity Generation

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ABSTRACT: Solar energy is rapidly gaining importance as an alternative source of energy. To make solar energy more viable, the efficiency of the solar panel system must be maximized. A feasible approach to maximize the efficiency of the solar panel system depends on the accurate and effective sunlight tracking mechanism of the system. This paper developed a system that accurately moves and positions the solar panel directly with the sunlight so that maximum sunlight intensity falls on the panel. The system uses a motor to change the position of the solar panel to be in line with the falling light intensity of the sun. The motor is controlled by Atmel 89c51 microcontroller that has the ability to detect the sunlight using photocells. The Liquid Crystal Display (LCD) integrated into the developed system displays the charging voltage of the PV module at every point in time.

INDEX TERMS: Microcontroller, Sunlight, solar cell, luminous intensity, and solar energy electricity generation.

INTRODUCTION

Concerned individuals, scientist's governments, and other agencies nowadays feel uncomfortable about the global warming situation and started researching into other forms of clean energy generation. One of the ways to reduce global warming is to reduce the utilization of electrical energy and change to a natural energy source from wind, water, sunlight, and geothermal heat. For example, this change is achieved by converting sunlight energy from solar panel, wind energy from wind turbines or that of water from water turbines into electrical energy. The conversion is feasible through solar panel installations, wind turbine installations, etc. Every solar energy project installation has the solar panel, battery bank, charging control unit, and an inverter. The sun that provides the photon energy required for electricity generation is directly affected by the weather condition each day. Hence, weather condition is the contributing factor that affect the performance of (amount of energy generated by) the solar panel. Electricity is produced directly from photovoltaic (PV) cells. These PV cells are made from material (for example silicon) that when sunshine falls on it, the photons of light excite their electrons and cause them to flow as electric current or electricity [1*; 3*]. Sunlight photons are small particles of light energy which are absorbed when they fall on material of a solar cell or photovoltaic panel. Photovoltaic light energy is used in a number of ways, but primarily to power homes that are connected to the public utility grid [4]. Atoms of material that makes up a photovoltaic cell absorb energy from light wavelengths corresponding to the visible spectrum. The silicon that makes up the solar panel cells is mixed with two different impurities that produce positive and negative charges (moving electrons or current) in the form of electricity [5*; 8*]. The change of light intensity falling on a solar cell changes all the parameters, including the open circuit voltage, short circuit current, the field factor, panel efficiency, and impact on the entire series and shunt resistances, that is, the increase or decrease of the light intensity has a proportional effect on the amount of power output from the panel [6]. The solar cell is a semiconductor material that converts visible light into direct current for usable electricity [*7*]. Through the use of solar arrays, a series of solar cells are electrically connected to generate a DC voltage that can be used on a load and an increase of solar arrays results in higher output of usable electricity [*6*].

2. METHODOLOGY AND DESIGN

In order to achieve the set objective of sun movement tracker, a physical prototype model is developed using locally sourced materials, which comprise the microcontroller circuit that provides the logic function that determines when to accurately tilt the PV cell to the direction of the sun and the mechanical unit that takes control instruction from the log control circuit and carry out the required task. The to achieve the prototype also covers the software aspect. The step by step procedure adopted in this paper to develop the microcontroller sun tracker is highlighted as follows:

1. Design Specification
2. Input Interface Design
3. Process Flow Chart
4. Output Interface Design
5. Integrating the Sub units to form a Module

2.1 Design Specification

The project was designed to fulfill the following three conditions for efficient output delivery:

1. Input voltage 12V.
2. Input current 6A.
3. Maximum angle of rotation of 240 degrees.

2.2 Input Interface Design

The input interface of this work is the sensor made of Light Dependent Resistor (LDR), two of which were used. The configuration of each sensor is as shown in Figure 1. The LDR is a variable resistor, whose resistance decreases (vary) with the increase in light intensity. The varying resistance is converted into varying voltage that the microcontroller can measure. The LDR and the resistor act as a potential divider to the input of the comparator as shown in Figure 1. The supply voltage, V_{cc} is 5V and connected to port 1 of pin 4 and 6 of the microcontroller. This arrangement makes the LDR resistance varies according to the light intensity.

The current through the resistors is given by:

$I = V_{cc}/(R_1 + R_2)$ (1)

From Ohm's law, at the positive pin of the comparator:

$V_o = I \times R_1$ (2)

The comparators output voltage can be determined by substituting equation (1) into equation (2):

$V_o = V_{cc} \times R_1/(R_1 + R_2)$ (3)

where, V_o is the output voltage of the comparator and R_2 is the LDR resistor value, R_1 is the resistor in series with the LDR resistor.

$V_o = 5 \times 10/(10+5)$

$= 3.33V$

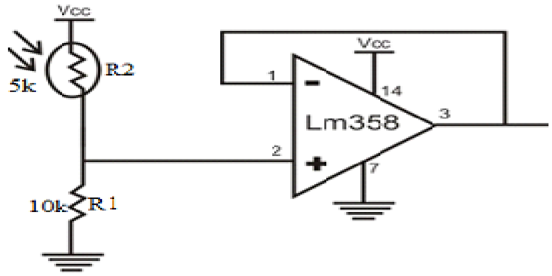

Figure 1 Input Interface Design [6].

The LDR is interfaced with a dual single supply LM 358 operational amplifier as shown in Figure1 and the output of the amplifier is connected to the microcontroller port of pin what? One of the sensors acts as a pilot or tracker that always looks for the direction of the sun's highest intensity to position the panel. The second sensor acts as omnidirectional sensor, which detects the presence of sun light at all times.

2.3 Process Flow Chart

The process control flowchart shows the flow sequence that determines when the solar panel tray should rotate and in which direction. Other sequences not presented on Table 1 are not valid in the design. The following logic table is used in the development of the flow chart.

Table 1: Logic Table of Sensor

Pilot Sensor	**Omni Sensor**	**Action**
0	0	Resting Position
0	1	Tracking Sun
1	0	Stop Tracking

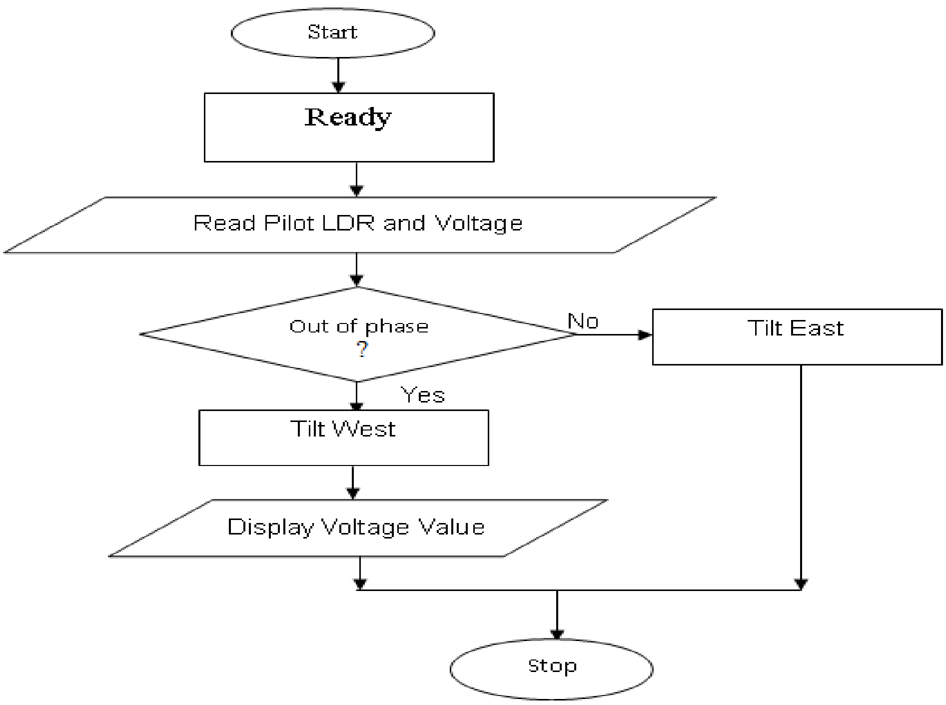

Figure 2: Development Process Flowchart of System

Figure 2 represents the flow sequence of actions to be taken as indicated in Table 1. The flowchart shows the design logic followed in the development of the program that determines the direction of the tracker. At start, microcontroller reads the state of pilot LDR in order to know what action is required taking and an appropriate instruction given. If solar module is out of phase with light intensity, microcontroller commands the motor to tilt the solar module to the West position (assuming that the module was in the East position) and stops once it senses high intensity of light and displays the voltage value of the solar module at that point. If pilot LDR is in phase with the light intensity, microcontroller commands the motor to tilt the solar module to East position, stops it, and displays the charging voltage.

2.4 Output Interface Design

The output interface consists of a DC motor configuration used in the implementation of the motorized jack that is made of two transistors coupled with relay as shown in Figure 3. The relay enables mechanical switching to activate the motor.

At the base, a pull-up resistor is used to switch the transistor on when the system is powered "ON". The operating mode of the transistor in digital form is that the collector produces logic 1 when the base is not biased. When the base is biased, the output of the collector is logic 0. Now the relay is connected to Vcc on one terminal and the other terminal is controlled by the collector output of the transistor as shown in Figure 3. In this case, the transistor is biased, the collector reads 0, and thus completes the circuit for the relay to switch "ON".

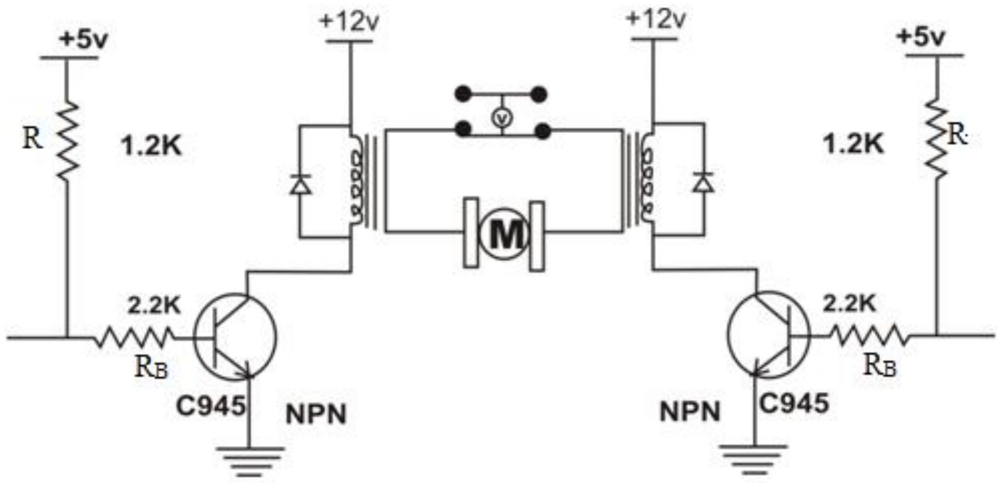

Figure 3. DC Motor Configuration [6]

The value of the base resistor, R_B is calculated as follows:

$$R_B = \frac{V_{cc} - V_{BE}}{I_B} \qquad (4)$$

Q_1= C945
$I_{C\ max}$ = 100mA
$h_{fe\ (min)}$ = 40
$h_{fe\ (max)}$ =500
where, $I_{C\ max}$, $h_{fe\ (min)}$ and $h_{fe\ (max)}$ are determined from the data book.

$$I_E = I_C + I_B \qquad (5)$$

$$h_{fe} = \frac{I_C}{I_B} \qquad (6)$$

$$V_B = V_{CC} - V_{BE} \qquad (7)$$

where, I_E is emitter current, I_C iscollector current, I_B is base current, and $I_E = I_C$, h_{fe} is current ratio transfer.

Assuming that h_{fe} for Q_1 is 40, substituting the values of equation (6) gives base current, I_B as:
$I_B = \frac{100mA}{40}$
= 2.5mA.
When Q_1 is "ON" (saturation point), $V_B = V_{CC}$, but at any point the two are not equal. Hence from equation (7):
$V_B = 5 - 0.7$
= 4.3V.
Substituting the value of V_B (4.3V) into equation (4) yields:
$R_B = \frac{4.3}{2.5mA} = 1720\Omega$
But 2.2kΩ was chosen as the closest resistor value from the data book. Give reasons

2.5 Integrating the Sub Units to form a Single Module

The complete circuit diagram of Figure 4 shows the integration of all the sub units to the microcontroller. The microcontroller ports are used to interface the various sub units. The Analog to Digital Converter (ADC) is interfaced to port 0, the LCD is interfaced to the port 2, the motor unit is interfaced to port 3, and the operational amplifier is connected to port 1 of the microcontroller.

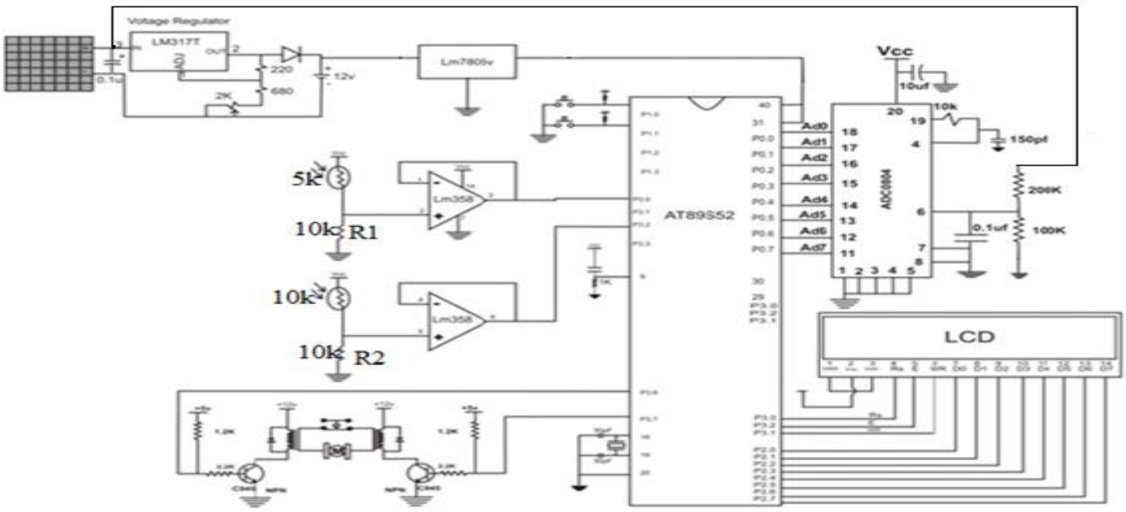

Figure 4: System Complete Circuit Diagram [1

RESULTS AND DISCUSSION

This section covers the results obtained after testing the prototype that was produced. Each result obtained from the test was adequately discussed. Such discussion brought about an complete summary of contributions achieved from this work.

Testing and Result

The developed system was completed and the control program downloaded into the microcontroller. The system was then installed and tested. While tracing the sun, the values of the LDR of both fixed panel and tracking panel at various instances were read through the ADC. The programs on the microcontroller converted the values back to voltage value and were hence displayed on the LCD.

The values both tracking panel and fixed panels were obtained at different hours from 6:30am to 6:30pm in the month of July, 2018 and recorded accordingly as shown in Table 2. The month of July, 2018 was chosen because this is the month when average cloud and sun conditions were observed in Kaduna.

Table 2 shows the voltage increase that was recorded by the panel that was tracking the sun when compared to those of the panel (static flat panel) that was not tracking the sun movement. It was observed that at that point when both panels were at the same inclination to the sun, their respective voltages were the same. It happened at midday when the sun is directly overhead.

Time of the day in July, 2018	**Readings of Voltage**	
	Static Flat Panel	**Tracking Panel**
06:30Hrs	0.196	1.477
07:30Hrs	0.249	2.104
08:30Hrs	0.225	3.411
09:30Hrs	0.723	3.783
10:30Hrs	2.011	3.900
11:30Hrs	3.910	4.657
12:30Hrs	4.888	4.990
13:30Hrs	3.803	4.990
14:30Hrs	3.456	4.985
15:30Hrs	3.930	4.892
16:30Hrs	1.544	4.694
17:30Hrs	0.980	2.456
18:30Hrs	0.718	0.968

Table 2: Results of voltage obtained in July, 2018

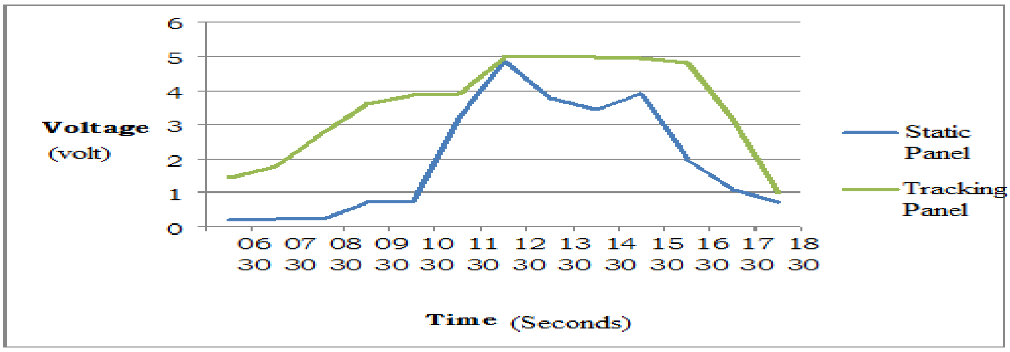

Figure 5: Voltage versus Time Results for Both Panels

The graphical representation of voltages of both panels against the time of the day is shown in Figure 5. From the graph, it is observed that solar intensity increases as the sun rises with the increase of the time of the day to its maximum intensity at 12 pm and then starts to decrease as the sun begins to fall toward evening hours. Some fluctuations are noticed in the graphs which were as a result of cloudy sky and abnormal atmospheric conditions at some instances during the day.

3.2 Analysis

The maximum sunlight occurs at around midday, with these values extending between 12 noon hours and 2 pm when the sun is very hot. In the morning and late evening, intensity of sunlight diminishes and the values obtained are less than those obtained during the day. The tracking system is on during the day and is switched off at sunset to save energy.

For the panel equipped with the tracking system, the values of the LDRs are expected to be close because whenever they are in different positions there is an error generated that enables its movement to adjust the panel inclination in direct contact with the sun. The motion of the panel is stopped when the values are the same, meaning the LDRs receive the same intensity of sunlight. For the fixed panel, the values vary because the panel is at a fixed position and most times the LDRs are not facing the sun at the same inclination. The graphs also show that at a particular point (midday) when both panels are facing the sun at the same time and at the same inclination, the voltages of both panels are the same.

The tracking system's solar panel has increased power output than the fixed panel system as the day progresses because the power generated by its panel is dependent on the intensity of light and the system's panel is adjustable so that it is always in direct contact with the sun. The more the light intensity the more the power that is generated by the solar panel. Since the panels of the tracking system is always in direct contact with the sun, its power is bound to be more than the fixed panel system that may be out of phase with the sun it moves from its rise to its fall in the evening. Therefore, the developed sun tracking system collects maximum energy than a fixed panel system at any time of the day because its panels are always in direct contact with maximum sun light intensity. This is the reason why it is an efficiency tracking system for solar energy collection.

4. RELIABILITY ASSESSMENT OF THE DEVICE

The method adopted in assessing the reliability of the sun tracking system is stress failure rates of components (parts) used in the design of the device. The method is based on obtaining the failure rate of each component from the standard tables of failure rates. The weighing factors for environment, operating stress, and temperature are determined and then the overall failure rate is computed using the following relationship:

$$\boldsymbol{\lambda_{oi} = n_i \lambda_i W_E W_T W_R} (\%/\mathbf{10^3}\text{hr}) \quad (8)$$

where:

λ_{oi} *is overallfailurerate.*

n_i is number of the component used.

λ_i *is* failure rate of individual component.

W_E is enviromental weighing factor.

W_R is operating stress weighing factor.

W_T is temperature weighing factor.

The reliability is then calculated using the relation

$$\boldsymbol{R = e^{-\lambda t}} \quad (9)$$

where, $\lambda = \Sigma\lambda_{oi}$ and t is time of operation of the device.

Table 3 gives the components used in this work, their number, their failure rates, their weighing factors, and the overall failure rate of the device.

Component	Number used ni	Failure rate $\lambda(\%/10^3hr)$	Weighing factors due to:			Overall failure Rate
			Environment W_E	Temperature W_T	Rating W_R	$\lambda_{oi} = ni\lambda iW_EW_TW_R(\%/10^3hr)$
Integrated circuit (IC)	4	0.02	2.0	1.5	1.5	0.18
Capacitors	1	0.2	2.0	1.5	3.0	12.6
Electrolytic Ceramic	5	0.01	2.0	1.5	3.0	0.36
Resistors (gen. purp)	11	0.01	2.0	1.5	1.5	0.765
Transistor	2	0.08	2.0	1.5	2.0	3.84
Soldered	1	0.001	2.0	1.5	2.0	0.006
Motor	1					
						$\lambda = \Sigma\lambda oi$ = 17.811

Table 3.1. Components and Their Failure Rates.

The overall failure rate is 17.811%/10^3hr. The reliability of the device that operates for one year
(t = 24 x 365
=8760hr) is calculated from equation (9) as follows:

$$R = e^{-(0.17811x10^{-3}x8760)} = 0.61 or 61\%$$

RECOMMENDATION

For maximum power used for charging solar batteries to be attained, there is need to install solar panels equipped with a solar tracker in order to make the best use of the energy the sun produces. This will enable users save cost of installing many solar panels facing different positions to gain more energy for a single purpose.

CONCLUSION

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At the end of this project, microcontroller based solar tracker using Atmel AT89S51 was actualized. The system was able to track the position of the sun where maximum intensity could be found. The system was also able to measure and display the current battery level.

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