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Development of a Single-Axis Sun Seeker using Three Sensors

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ORIGINAL ARTICLE

Abstract: The output power generated by the solar photovoltaic panel is directly proportional to the amount of solar energy it receives. Therefore, for maximum efficiency, a solar photovoltaic panel must be perpendicular to the sun. As a result of this, a tracking device is required to ensure that solar panels are always directly perpendicular to the direct component of the sun. Such a tracking device is referred to as a sun seeker. This research work describes the development of a single-axis sun seeker using three sensors. Light-dependent resistors are used as sensors. The light intensity received by two of the sensors is compared by two comparators and an appropriate signal is sent to the driving mechanism which moves the solar panel tray until the right and left sensors receive an equal amount of light intensity. The middle sensor was designed to activate the speed control unit of the system when it senses the required light intensity. The whole system runs on a 12V rechargeable battery. A battery charger circuit with automatic cut-off was incorporated to the design to keep the battery topped-up and to prevent overcharging.

Keywords: *solar photovoltaic cell; sun seeker; single-axis; sensors; comparators.*

I. INTRODUCTION

The utilization of renewable energy sources is the solution to the present global energy crisis, most especially in Nigeria [1, 2]. Solar energy is one of the primary sources of clean, abundant and inexhaustible energy that not only provides alternative energy resources, but also causes no environmental pollution. The most immediate and technologically attractive use of solar energy is through photovoltaic conversion. Photovoltaic (PV) cell converts energy from the sunlight into direct current (dc) voltage by photovoltaic effect [3]. A sun seeker, also called solar tracker, is a device for orienting a solar photovoltaic panel, day lighting reflector or concentrating solar reflector or lens toward the sun [4]. Solar photovoltaic panel, or simply solar panel, is a packaged assembly of connected photovoltaic cells. Solar panels collect maximum energy only when its position is normal to the sun, but the sunlight direction continually changes as a result of change in time and season. Presently, in most solar installations, solar panels are fixed and do not turn to follow the sun. The output power of a solar cell varies with irradiation level and the cell temperature. For a given irradiation level and cell temperature, maximum power is produced by the photovoltaic cell at a particular operating point, known as Maximum Power Point (MPP). This MPP varies with irradiance and temperature [5]. Hence, Maximum Power Point Tracking (MPPT) techniques are used for extracting maximum power from a stationary array of solar panels [5,6]. Various techniques of MPPT and their means of circuit realization are stated in ref. [5]. MPPT maximizes the output power from solar panel by keeping the solar panel's operation on the knee point of *P-V* characteristics [6]. Fig. 1 shows a typical I-V and P-V characteristics of a solar cell [7].

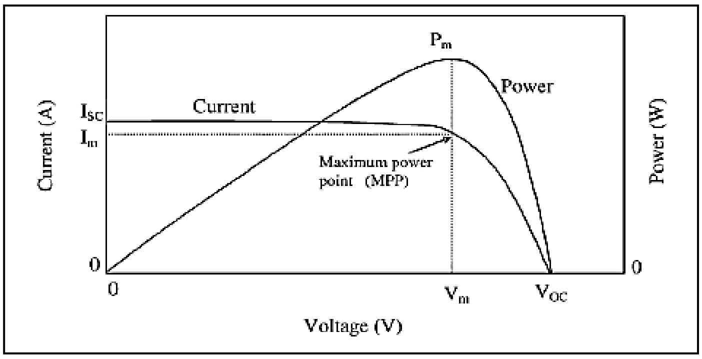

Fig. 1: P-V characteristics of photovoltaic cell

In order to ensure that the solar panels maintains the best angle of exposure to sunlight for energy collection, a tracking mechanism is required to keep the panels perpendicular to the sun at all time. Compared to a fixed panel, a mobile solar panel driven by a sun seeker can boost the energy output of the solar panel by 30% to 60% [8]. This implies that the number of solar panels required for solar installations of a particular capacity is less when a tracking system is incorporated. The cost of a sun seeker is less compare to the cost of additional solar photovoltaic panels [9].

II. REVIEW OF LITERATURE

Solar technology began with the discovery of photovoltaic power by a French scientist Antoine Becquerel in 1839 [10]. According to Encyclopedia Britannica, the first genuine solar panel was built around 1883 by Charles Frits [11]. According to ref. [10], the first silicon solar cell was produced in mass in 1954 in bell laboratory. The first solar tracker introduced by Finster in 1962 was completely mechanical. One year later, Saavedra presented a mechanism with an automatic electronic control, which was used to orient an Eppley Pyrheliometer [11]. In 1975, one of the earliest automatic solar tracking systems was presented by McFee, in which the algorithm was developed to compute total received power and flux density distribution in a central receiver solar power system. Several years later, Semma and Imamru used a simple microprocessor to adaptively adjust the position of the solar collectors in a PV concentrator such that they pointed toward the sun at all-time [12].

In recent years, several researches related to solar tracking systems have been carried by different researchers [7] [13-16]. However, in the existing research works, most of them used two sensors without a dedicated control unit to actuate the movement of the motor. In this work, three sensors were used. Two of the sensors control the movement of the tracker's tray, while the third sensor controls a special unit that actuates the motor using pulse width modulation scheme.

III. MATERIALS AND METHODOLOGY

The materials used in designing this system include: Light Dependent Resistors, LDRs (used as sensors), 555 timer, comparators, transistors, resistors, diodes, relays, 12V battery and 12V DC motor. The block diagram of the sun-seeking system is shown in fig. 2 below. The sun seeker is divided into four major units namely: comparator unit, speed control unit, driver unit and battery charger unit. Each unit is described below with the aid of its circuit diagram.

A. Comparator Unit

As shown in figure 3, the heart of the above comparator circuit is formed by two comparators. LM358 Dual Op-Amp is used as a comparator. Here, each LDR is connected with a series resistor (R1 and R2), when the intensity of light falling on the LDR increases, the voltage across the corresponding resistor increases. The output of the voltage comparator will be high when the voltage at the non-inverting terminal is higher than the voltage at the inverting terminal. The inverting terminal of each comparator is connected to a variable resistor (VR1 and VR2 respectively), which is used to set the reference voltage. Thus, the sensitivity of both LDRs can be adjusted by varying the 10kΩ pot. The different combinations of these HIGH and LOW outputs of both comparators determine the direction of rotation of the motor or its non-rotation. However, the current sourcing of the output of LM358 used in the comparator circuit not enough to drive a motor. For this reason, a driving circuit was incorporated.

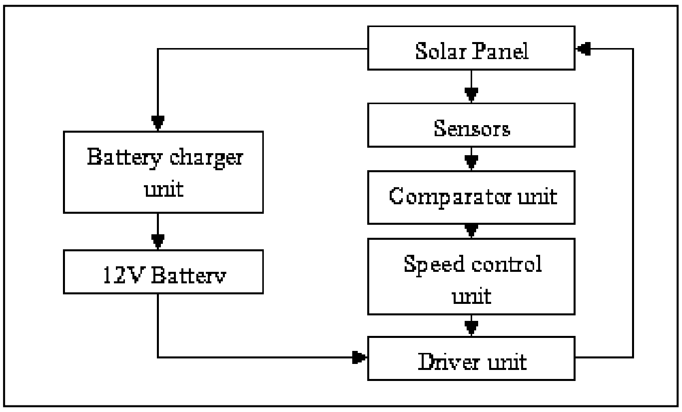

Fig. 2: Block diagram of a sun seeker

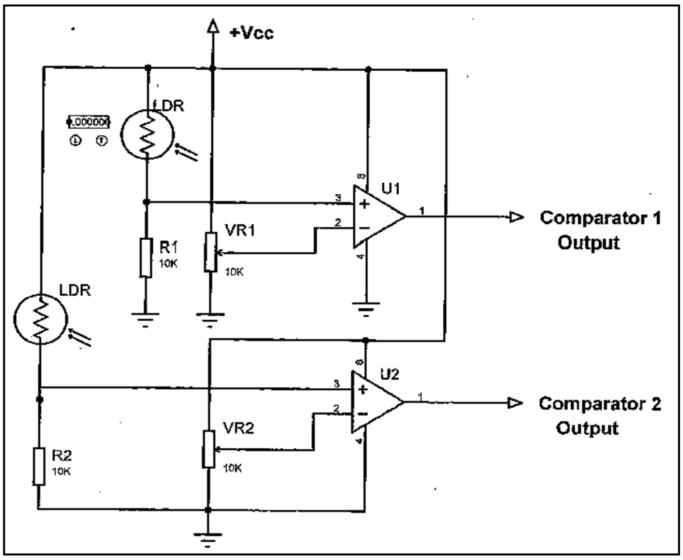

Fig. 3: Circuit Diagram of the Comparator Unit

B. Driver Circuit Unit

The circuit diagram of the driver unit is shown in fig. 4. The direction of motor rotation is controlled by two 12V relays, each connected to the output of the comparators via the collectors of transistors Q1 and Q2 with both transistors acting as switches. When the output of comparator U1 is high and the output of the comparator U2 is low, transistor Q1 switches ON and allows current to flow into the first relay, thereby switching ON the relay and the resulting current rotates the motor in clockwise direction. However, when the output of comparator

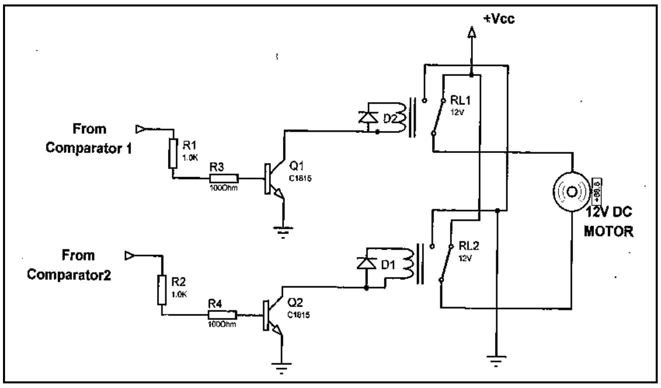

Fig. 4: Circuit Diagram of the Driver Circuit Unit

As shown in fig. 5, 555 timer IC wired as an astable multivibrator forms the heart of this unit.

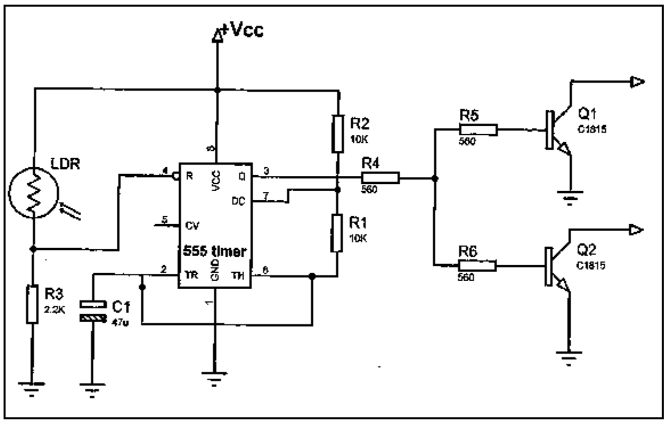

Fig. 5: Circuit Diagram of the Motor Speed Control Unit

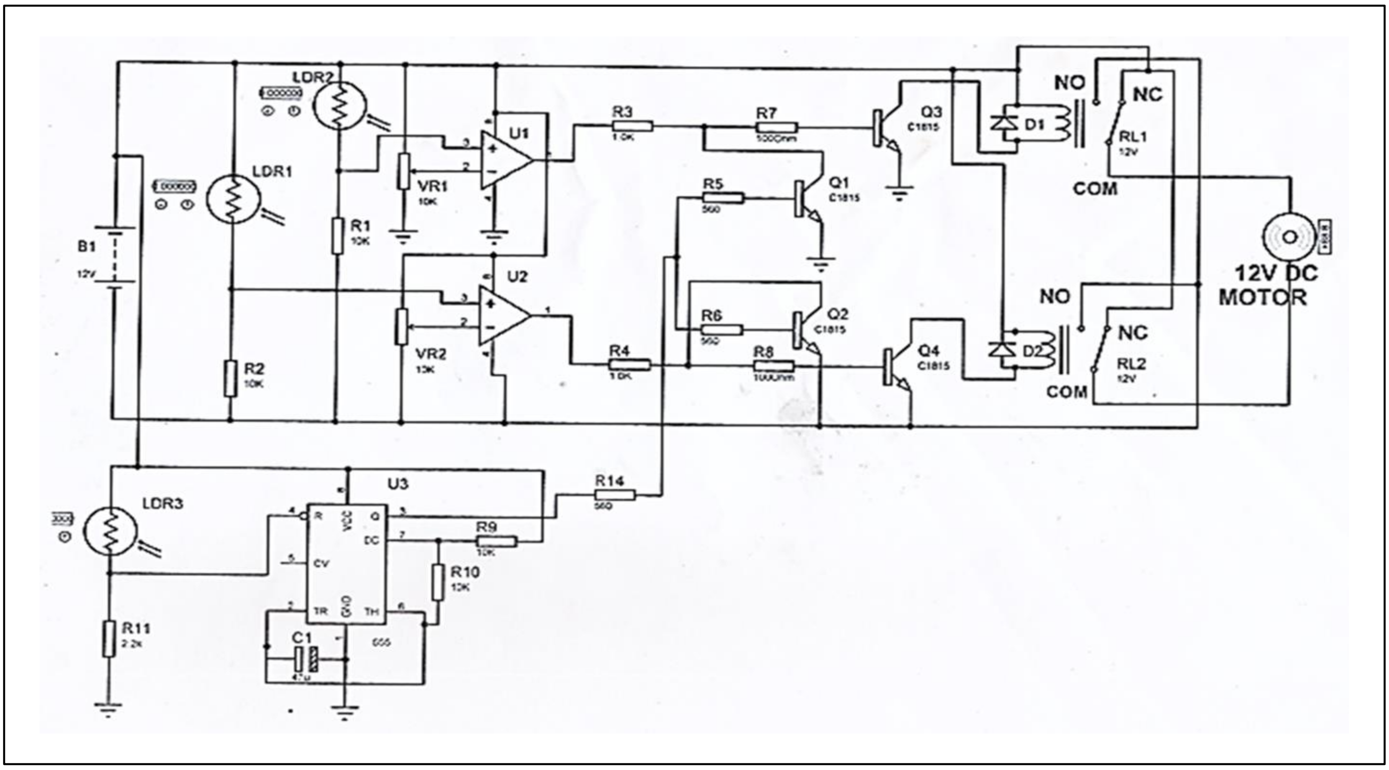

Fig. 6: Complete circuit diagram

U1 is low and the output of U2 is high, transistor Q2 is switched ON which in turn switches ON the second relay and the resultant current turns the motor in anticlockwise direction. The motor rotates only with HIGH-LOW combinations of both comparators. That is, the motor only moves when either of LDR1 or LDR2 receives more light intensity than the other, but the movement stops immediately when the two LDRs, which are fixed on the edge of the solar panel, gets to a position where they receive equal amount of light intensity, that is, when the sun's ray are perpendicular to the solar panel.

C. Motor Speed Control Unit

The output of the astable multivibrator is fed to two parallel NPN transistors Q1 and Q2 which act as switch to the signal going to the base of the relay-switching transistors Q3 and Q4. This unit is included in the design in order to pulsate the movement of the motor in both directions. This eliminates any indiscriminate movement of the motor.

IV. DESIGN ANALYSIS AND RESULTS

A. Design calculation for the switching transistor

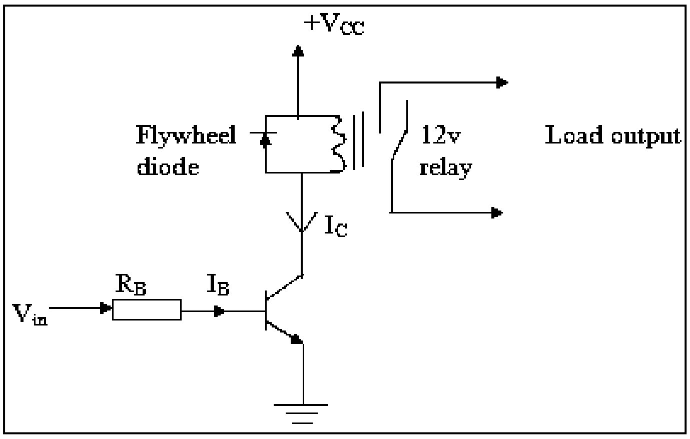

Fig. 7: Switching circuit of a transistor

From (1), $\beta I_B > I_C$

$50\ ((8.58 - 0.8)/R_B) > ((12 - 0.2)/400)$
$(389/R_B) > 11.8/400$
$389 > 0.0295R_B$
$\therefore R_B < 13k\Omega$
$(389/0.0295) > R_B$
$13186 > R_B$
$R_B < 13k\Omega$

A resistor of 1.1kΩ, which is less than 13kΩ, will be used. This offers a base current of 7mA which is actually more than the basic 0.59mA required to turn ON the transistor. The transistor selected for this design (C1815 general purpose transistor) can handle up to 50mA base current.

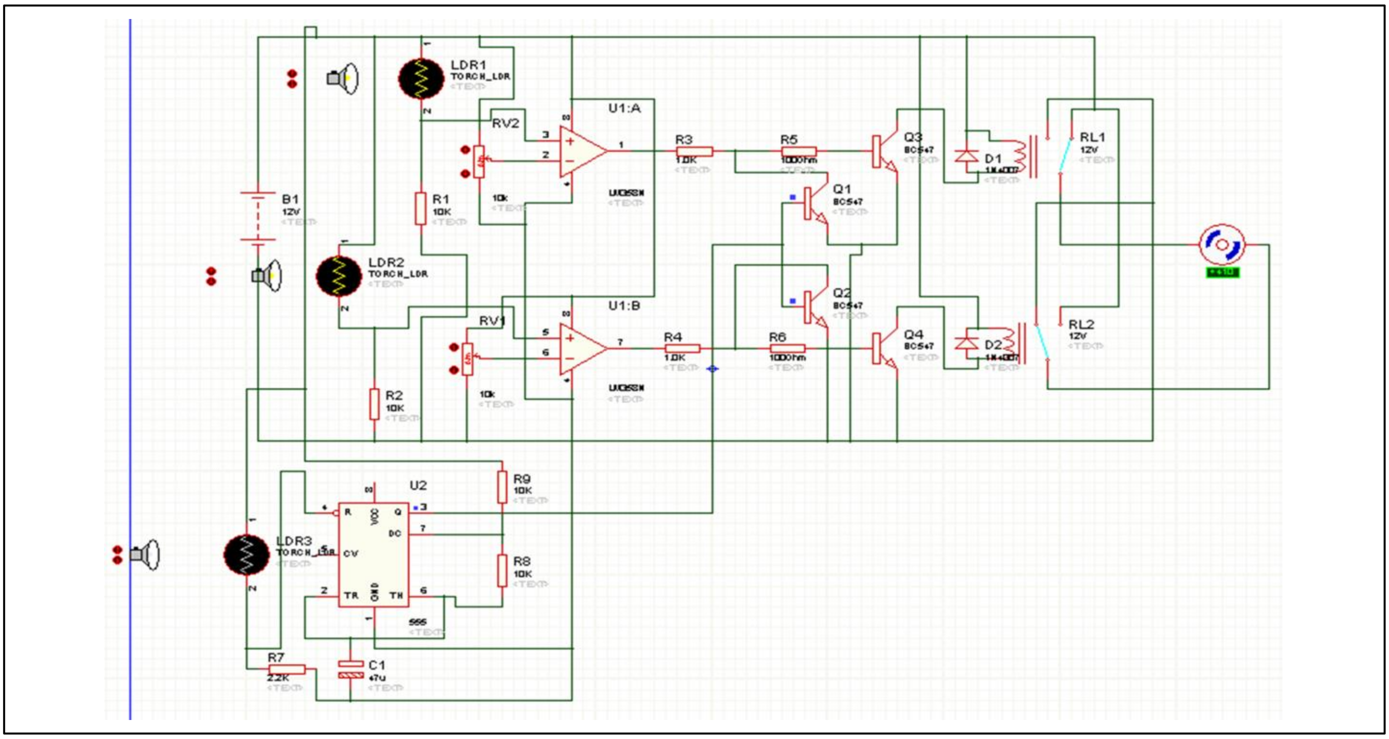

Fig. 8: Simulation of the complete circuit of the Solar Tracker

1) *For fully "switch on":*

For the switch to turn on, the output of the comparator must swing to logical high (which is 8.58V for this design)
For transistor in saturation,

$\beta I_B > I_C$; $V_{CE} = 0.2V$; and $V_{BE} > 0.7V$ (0.8V will be used in this case)

$$\beta I_B > I_C \quad (1)$$
$$I_B = (V_{in} - V_{BE})/R_B \quad (2)$$
$$I_C = (V_{CC} - V_{CE})/R_L \quad (3)$$

where:
V_{in} = Output voltage from comparator
$V_{in} = 8.58V, V_{BE} = 0.8V,$
$V_{CC} = 12V, V_{CE} = 0.2V,$
R_L = Coil resistance of the relay = 400Ω
$\beta = 50$

2) *For fully "switch off":*

The transistor automatically switches off when the comparator output swings to logical "0". Under this condition, as discussed earlier, the cut-off characteristics of a transistor are satisfied. That is,

V_in=0,I_B=0,and I_C=0

With inductive loads such as relays, a flywheel diode is placed across the load to dissipate the back electromotive force (EMF) generated by the inductive load when the transistor switches "OFF" in order to protect the transistor from damage. If the load is of a very high current or voltage nature, such as motors which is the case here, then the load current can be controlled via a suitable relay as shown figure 7.

B. Results

The overall electronic design was simulated on PROTEUS as shown in the fig. 8. The result of the simulation of the complete solar tracker on PROTEUS as captured in figure 10 below shows that the normally open contact of relay RL1 is closed when the output of comparator U1:A is high and that of comparator U1:B is low. This makes the motor to move in clockwise direction. Also, the normally open contact of relay RL2 is closed when the output of comparator U1:B is high and that of comparator U1:A is low. But this time, the motor moves in anticlockwise direction. However, the motor remains static when the outputs of both comparators are in the same state.

V. CONCLUSION

This paper presents the design and construction of a sun seeker using three sensors. The system is a closed loop automatic solar tracking system for maximum solar energy absorption. Specifically, it demonstrates a working hardware solution for maximizing solar cell output by positioning a solar array at the point of maximum light intensity from the sun. Dual-axis solar tracking using three sensors can be considered in future research. Also, artificial intelligence approach to sun-seeking can be considered.

VI. DECLARATION

All authors have disclosed no conflicts of interest. The research work was self-funding.

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