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Design and Construction of a Bi–Directional Solar Tracking System.

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Abstract: *This paper concerns the design and construction of a bi-directional solar tracking system. The constructed device was implemented by integrating it with 900V inverter and 12volts, 100AH battery. The amount of power available from a photovoltaic panel is determined by three parameters, the type and area of the materials, the intensity of the sunlight and the wavelength of the sunlight. With advancement in solar panel technology, parameter one, the type and area of the material had been fully improved upon and standardized. In this research work the other two parameters were fully addressed, as this device ensures maximum intensity of sun rays hitting the surface of the panel from sunrise to sunset. Due to the atmosphere the sun energy is not as great in the morning and evening compared to noontime.*

Keywords: *Darlington pair, solar radiation, comparator circuit, orthogonal position*

I. Introduction

At present, there is a great interest towards solving the energy problems facing the world, more especially the third world countries. This has led to research on alternative energy source that would complement the conventional fossil fuel. The alternatives energy sources include; solar, nuclear and wind, but in this research work we focused on solar energy. Solar energy is the energy generated by harnessing the power of the solar radiation. It is the cleanest source of energy whose use can contribute to saving exhaustible energy sources. Photovoltaic panels converts the sun's radiation to electricity. The amount of power5 available from a photovoltaic panel is determine by three parameters first, the type and area of the material, secondly the intensity of the sunlight and the wavelength. With advancement in solar panel technology, parameter one had been fully improved upon and standardized. Inthis research work, the other two parameter were fully addressed. As this device, ''solar tracker'' ensures maximum intensity of sun rays hitting the surface of the panel from sun-rise to sunset. A solar panel must be able to follow the sun's movement to produce the maximum possible power. This is achieved through the designed and implementation of the tracker system, that maintains the panel orthogonal position with the light source. The device is implemented by integrating it with a 900V inverter and 12V, 100AH battery. The construction of the tracker is made up of two segments, the electrical and the mechanical part respectively. The electrical system consists of PV sensor, a comparator circuit and a battery. The mechanical system consists of the DC motors, worm gears and the frame that housed the entire system. Resistivity and induction tests were carried out on the DC motors to ensure their optimal performance in the construction.

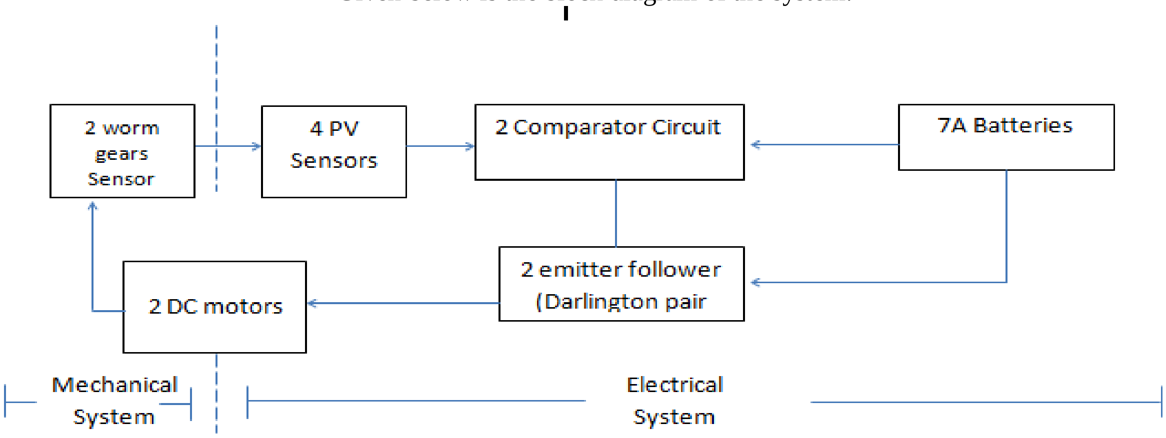
II. Literature Review

Photovoltaic power was first discovered by a French scientist's Antoinc Becquerel in 1839. The first working solar cell was successfully made by Charles frits in 1882. It was made of thin sheets of selenium and coated with gold. The use of solar panels for generating electricity and heat seems relatively like new development, it has actually been widely used to generate power since early 1900's. In 1954 bell laboratory mass produced the first crystal silicon solar cell. The bell PV cell converted 4% of the sun's energy into electricity a rate that was considered the cutting edge in energy technology. Scientists continued to reinvent and enhanced on the design of the original silicon cell and were able to produce a solar cell that was capable of putting 20% return electricity rate.In the late 1900's as awareness grew in the science community about the effects of global warming and the need for renewable energy sources, scientists continued to refine the silicon PV and by early 2000 they were able to make a solar cell with 24% electricity return. In just seven years scientists were again able to increase the electricity return of silicon solar cell using space age materials. By 2007, modern silicon PV solar cells were operating with 28% electricity return. Each photovoltaic cell produces a small amount of electricity so they are wired together into panels to provide enough current (D C) power so it must be converted to alternating current (AC) with the aid of an inverter.

III. Methodology

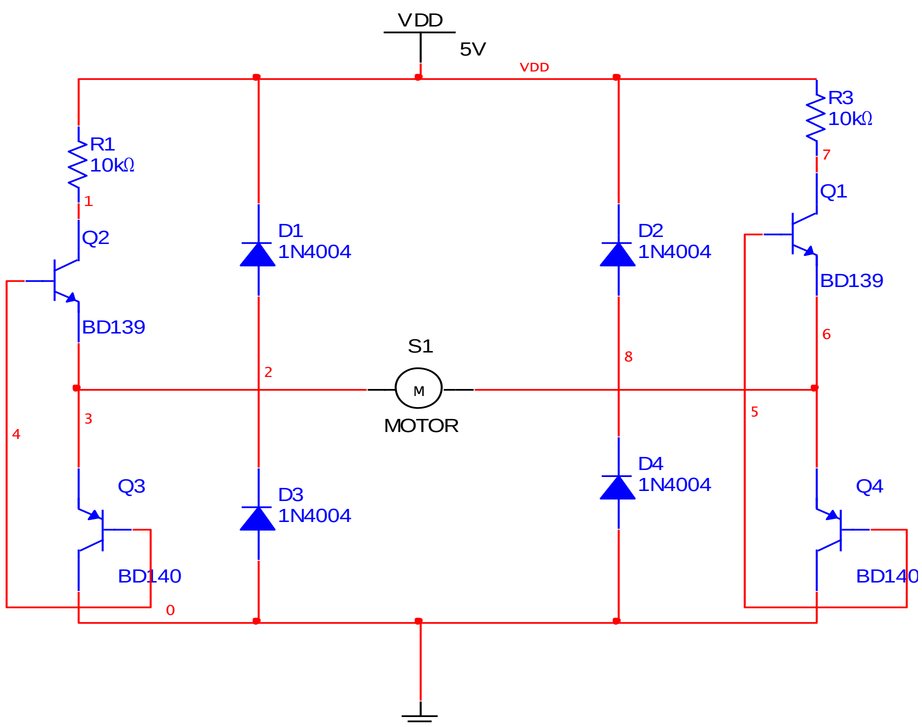
Here the actual circuit design, construction and implementation off the bi-directional tracking system are analyzed in a finite order. The components used, their specifications and tests carried out on some components to ensure their optimal performance.The construction was segmented into two, the electrical and mechanical segments.

Given below is the block diagram of the system.



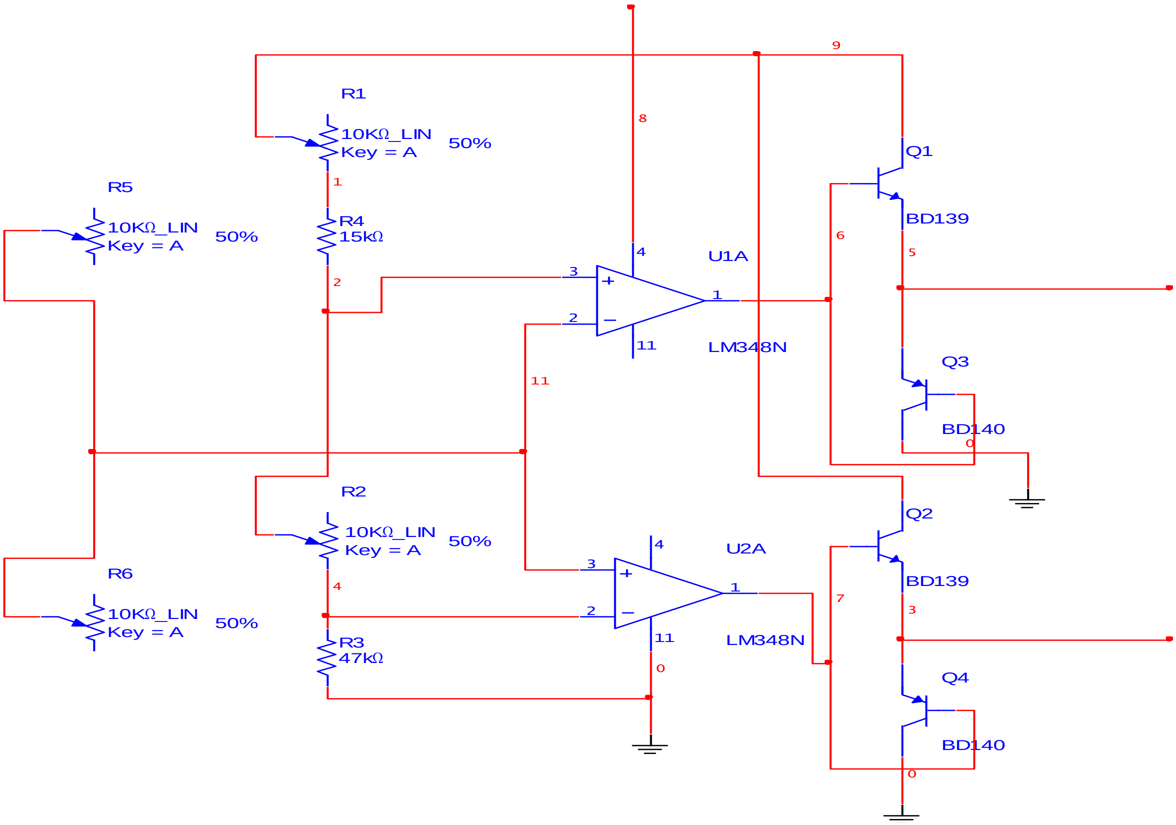
The electrical segment consists of the solar sensors, comparator circuit and the driver circuit all connected in Darlington pair (emitter follower). The mechanical system is made up of the DC motors and the worm gear assemblies the adjust the PV sensors.

SCHEMATIC DIAGRAM OF THE DRIVING CIRCUIT



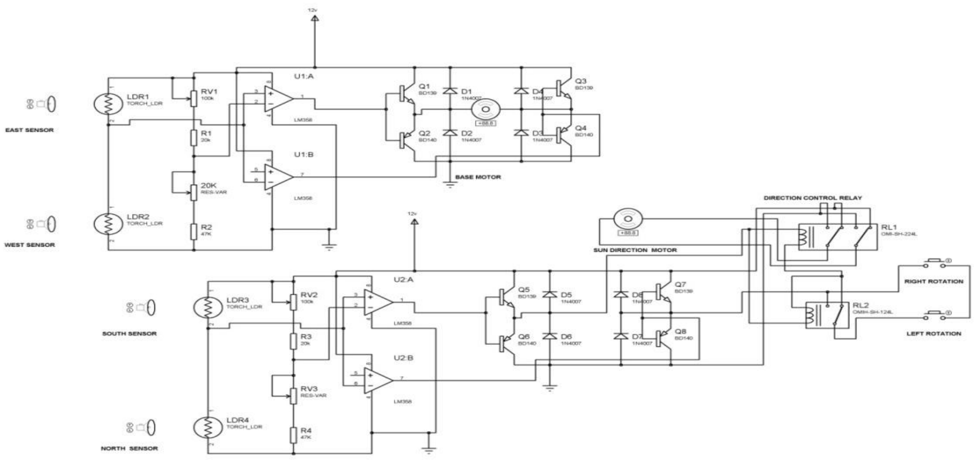
The power supply is from the 12volts battery and a DC motor is used because it rotates in both directions by reversing the direction of current supplied. The power supply to the tracking device has only one pole and the direction of the current to the motor need to be switched. And this was accomplished by the use of the BJT transistors connected in Darlingtonpair in the circuit. The two pair of transistors work in conjunction with each other to provide current through the motor in a certain direction. The upper transistor are PnP. When transistors Q2&Q3 are turn on they allows current to pass through, the motor spins in one direction. If they are turned off and transistor Q1&Q4 are turn on the motor spins in the opposite direction. The inputs to the driving circuit are inverted, a high signal turned on the NPN BJT and a low signal turned the PnP BJT on. The diodes are connected across the collector and emitter terminals of the BJTS, to eliminate the inductive kickback from the motor. This kickback is a high voltage spike that can easily damage the transistor (BJT). When the voltage gets above certain threshold value, the diodes effectively short the motor to the rails and the spike is eliminated.

THE COMPARATOR CIRCUIT



It provides interface between the photovoltaic solar sensors and the driver circuit. It accurately senses the voltage difference between the photo sensors and provides inputs to the driver circuit. The first segment of this circuit that detects the voltage difference, is the analog comparator circuit and the second segment, that provides the control input to the driver circuit consists of logic gates. As stated above, the LM348N is operational amplifier with a power dissipation of 830MW. The two LM348W are connected to two sensors voltage dividers. This comparator setup has overall power dissipation of 1 W.The sun rotates at 2n radians/24 hours or 7.272×10^{-5} rad/s that corresponds to a frequency of about 1.16×10^{-5}Hz. The comparator circuit cannot handle such fast such switching speeds and the logic gates can't handle high frequency input signals hence there is the inclusion low pass fitter that allows roughly 10HZ orlower in the circuit. Low pass fitter 15.KΩ resistor is used in the 10Wpass fitter. This value is gotten with this calculation. $R = 1/(2\pi \times 10Hz \times 1\mu F) = 15K$The output from the comparator circuit were not discrete hence a transistor was used to ensure this four of this transistor were used in the circuit and they are connected in Darlington pair. When the light intensity is on one photo sensor, a pair of these transistors whose inputs are connected to the comparator output to which this photo sensor is connected will be biased and so turned on the motor. When the light radiation is equal on both photo sensors, both pair would not biased. The driver circuit requires accurate control inputs to each of the four transistors, however, the comparator only provides two inputs, the set of the logic gates were used to obtained the four inputs. When the comparator outputs two high signals thatcorrespond to the tracker being pointed to the light source, outputs to the transistor pair T_1 and T_3 in the driver go low and the outputs to T_2 and T_4 goes high. If one sensor shows a higher intensity, the corresponding output goes high. The logic circuit sends signal to the driver to turn on the T_1 T_3& T_2 T_4 that corresponds to the rotation of the system in the direction of the light. The reverse goes for the opposite sensor.

THE FULL SOLAR TRACKER CIRCUIT



The two op-amps are connected to form a window comparator. it monitor the voltage at point ‘’A’’ and keeps it within a particular range sets by the two potentiometers. The voltage of point A vary only when the light intensity falling on the two LDRS are not equal if the intensity of light hitting the upper LDR reduces its resistance and rays crosses the reference level set by the upper potentiometer, that triggers the upper op-amp whose output instantly goes low and turns on the driver transistors T_1& T_3. The motor M_1 connected to the transistors activates and adjust the solar panel to face the sun rays at 90˚ degrees. When the light rays falling over the lower LDR crosses the reference level set by the lower potentiometer. The level at point A will fall and that input of the lower op-am goes low. Its output will invert to activates transistors T_2& T_4. The motor rotates but in the opposite direction to correct the filt of the solar panel until everything is back to normal.

ENTIRE SYSTEM IMPLEMENTATION

Finally the designed circuit and its accessories were arranged and packed in the mechanical casing made of clear acrylic aluminum and steel. Solar panel dimension 28 × 21 × 1.7cm, flat form 45 × 30cm, column 45 × 2.5cm, bearing 17cm base 33 × 25 ×8cm.

The constructed prototype is shown in figure below.

Test were carried out to find the resistance (R), inductance (L) and back electromagnetic force (EMF) constant (K) of the motor.

(1) The equation for voltage across the DC motor is given below

$$V = Ri + \frac{\partial i}{\partial t} L + k\omega$$

(2) The equation for the torque produced by the motor is given as

$$T = ki = D\omega + \frac{\partial \omega}{\partial t} J + To$$

Where J, is constant of inertia, D damping factor, and TO, opposing torque. These values are required in conformity with DC motor equations in order to determine power requirements.
Resistance: is calculated using ohm's law, V =IR.
Shown in the table 1 below are the results of the measurements. The average current, voltage and resistance were 88.923, 0.213 and 1.994 respectively.

Table 1:Preliminary Motor Tests Results

Position	**Current (mA)**	**Voltage(V)**	**Resistance(Ω)**
1.	76.3	0.24	2.1926
2.	115.1	0.190	1.5468
3.	105.2	0.206	1.8210
4.	96.2	0.220	2.1683
5.	100.0	0.214	2.1282
6.	106.5	0.202	1.8767
7.	112.1	0.200	1.6672
8.	86.2	0.230	2.5522
Average	88.923	0.213	1.994

INDUCTANCE OF THE MOTOR

The inductance was solved for by creating an LC circuit and the values for the resistor and capacitor were measured to be 98.50Ω and 96 nf respectively. The resonant frequency was found to be 15.8KHZ. going by the equation for resonant frequency:

$\omega R = 1 / (L*C)^{1/2}$

The inductance was calculated to be 1.057mH.

THE BACK EMF CONSTANT (K) AND THE DUMPING FACTOR

The back EMF constant holds a linear relationship with the rotational speed (w) of the motor. With the steady state equations give below:
$V = Ri + k\omega$
Where V is the total voltage across the motor, iis the current through it and R the resistance of the motor.
To find the constant K, the voltage and current for the motor were measured over different speeds. The results are shown in table 2 below:

Table 2

Frequency in Hz	Voltage in V	Current in A	ω In rad/s	K in Vs/rad	D (ω)
1.130E+01	1.880	0.179	7.728E+01	2.069E-02	3.691E-05
1.670E+01	1.750	0.182	1.112E+02	2.124E-02	2.476E-05
1.826E+01	1.920	0.184	1.210E+02	2.097E-02	2.189E-05
2.026E+01	2.220	0.185	1.336E+02	2.116E-02	1.930E-05
2.378E+01	2.680	0.184	1.557E+02	2.118E-02	1.503E-05
2.602E+01	3.010	0.183	1.698E+02	2.132E-02	1.299E-05
3.142E+01	4.500	0.185	1.911E+02	2.153E-02	1.084E-05
3.195E+01	3.880	0.189	2.070E+02	2.163E-02	1.863E-05
3.224E+01	5.270	0.193	2.717E+02	2.160E-02	1.435E-05

The final measurement was the mechanical damping inherent in the unloaded motor. At Constant speed the damping is exactly equal to the torque generated by the motor. The torque generated is given below as

$$Ki = Dw$$

Where D is the damping factor. It was also calculated and found that, it changes with respect to the speed as shown in table 2 above.

TRACKER POWER CONSUMPTION MEASUREMENTS

To ensure that the tracking system produces more power it uses measurements were taken for power consumption of each individual components of the system.The first measurement was of the total system, with the shunt between the battery and the rest of the system. The current were measured when the system was stationary and that of all others.

The results are given in table 3 below.

	VR1 (mV)	Current (mA)	Power (W)
Stationary	18.2	36.40	0.46
Altitude Axis moving	88.0	100.0	2.20
Azimuth Axis Moving	136.0	200.0	2.60
Both Axis Moving	186.0	300.0	3.60

IV. Analysis Of Result Of Some Components

The bipolar junction transistors (BJT) were used in the construction because of their light power efficiency and switching capabilities.The IN4004 rectifier diodes were used in the circuit construction because of their high current surge capabilities. It eliminates the high voltage spike or kickback from the motor from damaging the transistors.

4.1 ANALYSIS OF RESULTS OF TABLE 3 ABOVE

From these result the following were deduced. The comparator and the quiescent current to the driver circuit consume 0.48w when the system is stationary. The attitude axis consumes 2.4 – 0.48 = 1.92W when moving sensor through maximum load point. The azimuth axis consumes 3.60 – 0.48 = 3.12W at its maximum load point. The total power consumption at maximum load point is equal to o.48 + 1.92 + 3.12 = 5.52W.The difference between this and the measured amount is due to the tracker not moving through both maximum points at the same time. These measurements conclusively showed that the power consumption when the system is not moving is less than a one watt and when is rotating it consumes 5.52W.

The bill of quantities for the solar tracker prototype is given in Table 4.

Description	**Quantity**	**Unit cost**	**Price (naira)**
Solar panel 10watt	1	15,000	15,000
Solar controller 8amps	1	5,000	5000
Battery 12v	1	3,000	3000
Relay 12v	2	100	200
Transistor BD139 and BD140	8	50	400
Resistors	8	50	400
LDR sensors	4	150	600
LM358 ICs	2	100	200
Vero board	2	100	200
Motor 12v	2	1,000	2000
Mechanism construction and casing	1	5,000	5000
Cables and screws	1	500	500
Belt and grease	1	7,000	7000
Total			39,500

V. Conclusion

Upon completion of the solar tracker prototype it was tested to ensure it meet design requirements and specifications. It functioned properly in accordance to design specifications. Test showed that power used by tracker system is less than the power gain by tracking the sun accurately. The most important conclusion of this research, is the total cost of construction of the tracker system is very low, less than $500 (₦ 50,000.00). This means the system can be mass produced at lower cost and at affordable rate by many communities in the developing countries.

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