DESIGN AND CONSTRUCTION OF AN AUTOMATIC SOLAR TRACKING SYSTEM

CHUKWU MADUJIBE COLLINS

2004/18806EE

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

DECEMBER, 2009

DESIGN AND CONSTRUCTION OF AN AUTOMATIC SOLAR TRACKING SYSTEM

CHUKWU MADUJIBE COLLINS

2004/18806EE

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng.)

IN THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING,

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

DECEMBER, 2009.

DEDICATION

I dedicate this report to God Almighty for his unfailing grace, gift of life and steadfast love, and for his guidance all through my academic career; to my lovely mum Mrs. Regina Osinachi Chukwu for her love and care, and to Mr. Charles C. A. Utom for his fatherly love, care and support.

DECLARATION

I, Chukwu Madujibe Collins, hereby declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Electrical and Computer Engineering Department, Federal University of Technology, Minna.

CHUKWU MADUJIBE COLLINS
(NAME OF STUDENT)

7/12/09
(SIGNATURE & DATE)

MR. ENESI A. YAHAYA
(NAME OF SUPERVISOR)

12/12/09
(SIGNATURE & DATE)

For: ENGR. (DR.) ADEDIRAN YINUSA
(NAME OF H.O.D)

(May 6 2010)
(SIGNATURE & DATE)

DR. (Arch) B.A. ADEKUNLE
(NAME OF EXT. SUPERVISOR)

09/03/10
(SIGNATURE & DATE)

ACKNOWLEDGEMENT

I hereby thank my project supervisor Mr. Enesi A. Yahaya and my technical supervisor Mr. Kudu Bagudu for their counseling, encouragement, support and thorough review that resulted in the completion of this project.

My special thanks to my beloved mum Regina Osinachi Chukwu, and my ever loving siblings Ngozi, Maria, Augustine, Ijeoma, Chibuike, and Ebere for their ceaseless prayers, love and care toward me which significantly contributed to making me who I am right from birth. Thanks to all my nieces and nephews Jennifer, Jessica, Fatimatu, Joshua, Bakari, David, Chioma, Aminu, Emmanuella, Prince etc. I love you all, because you are the best of the best.

My profound gratitude goes to my in-laws Mr. C.A. Utom, Mr. Yusuf Bakari, Mrs. Charity Chukwu, Mr. Anthony Nwachi, may God bless you all for your kindness and support.

I am indebted to all the people who have in one way or the other impacted knowledge to me, more especially my teachers all the way from nursery school till university. Their enthusiasm and constructive criticism have been invaluable.

Finally, to all my wonderful friends, Winget, Nicholas, Mohammed, Basil, Abdurahaman, Ahmed, Ojima, Chi-Chi, ID, Blessing, Rose, and not forgetting those whose names were not mentioned here; to my course mates, relatives, and well wisher for their numerous assistance and meaningful contribution towards me.

ABSTRACT

Renewable energy is rapidly gaining importance as an energy resource in the world today as fossil fuel prices fluctuate. Solar panels are typically in fixed positions. They're limited in their energy-generating ability because they cannot consistently take full advantage of maximum sunlight. For more effective solar energy systems, the solar panels should be able to align with sunlight as it changes during a given day and from season to season. This article examines the design advantages of creating an intelligent solar tracking system using a comparator IC and light dependent resistor LDR sensors. The unique design and positioning of only two LDR sensors realize the single axis sunlight tracker for PV applications. A working system will ultimately be demonstrated to validate the design. Problems and possible improvements were also presented in this work.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

A solar tracker is a rack for photovoltaic modules (solar panels) that moves to point at or near the sun throughout the day. They are two mode of tracking the sun; a dual-axis mode and a single axis mode.

a. Single axis mode follows the sun accurately enough that their output can be very close to full tracking.

b. Dual axis mode also known as full tracking mode moves on two axes to point directly at the sun taking maximum advantage of the sun's energy.

Hence in tracking the sun, the tracker doesn't necessarily need to point directly to the sun for it to be efficient, because if the aim is off by ten degrees, the output is still about 98.5% of the full tracking maximum output.

In years to come the need for energy will increase while the reserve of conventional energy will deplete in rapid pace. To meet the growing demand of energy harnessing of non-conventional / renewable energy is the necessity. Among all the available non-conventional sources, solar energy is the most abundant and uniformly distributed. Though the technology of trapping the solar energy is in existence the process can be improved to increase efficiency and make it cost-effective. Solar energy is free; it needs no fuel and produces no waste or pollution. Solar power is renewable. The sun will keep on shining anyway, so it makes sense to use it. In this project, the design of existing solar collector system has been improved to provide higher efficiency for lower cost. The existing system receives maximum sun energy only from 11 am to 2 pm. A new method is developed, where sun light is tracked from morning 6 am to 6 pm by moving the solar collector along with the movement of the sun using a solar tracking device. When this system is implemented, at least 30% - 60% extra energy can be created compared with the existing stationary system. The solar panels are the fundamental solar-energy conversion component. A stationary solar panel limits their area of exposure from the sun during the course of the day. Therefore, the energy output of a stationary solar panel is not always maximized. Solar tracking systems are essential for many applications such as thermal energy storage systems and solar energy based power generation systems. In order to improve system performance, the change in sun's position is monitored and the system always keeps that the plane of the panel is normal to the direction of the sun. By doing so, maximum irradiation and thermal energy would be taken from the sun. The elevation angle of the sun remains almost invariant in a month and varies little (latitude ± 10°) in a year. Therefore, due to this little variation of the position of the sun in a year, the difference in output of a single axis tracker and that of dual axis tracker will be minimal.

1.2 AIMS AND OBJECTIVES

The aim of this project is to design and develop a solar tracker which gives a single degree of movement.

The design focuses on the utilization of solar electric power in rural areas to minimize development cost management, environment friendliness and economic viability.

To do a literature survey on components used in this project particularly the electronic components and the mechanical system used to determine various sun positions in different times of the day.

The primary objective of this project is to operate the solar tracker to use its light sensors (photo resistor) to feed voltage signals into the comparator to determine correct positioning of photovoltaic panel (PV) in relation to the sun and also tilting the panel to face the sun based on human judgment or at fixed angle.

The secondary objective of the project is divided into two categories of design:

a) **Mechanical:** To design a mechanical structure that is strong, whether durable, presentable, light in weight, and provides great precision in tracking the sun.

b) **Electronics:** To combine electronic components such as Integrated Circuit (comparator IC), DC motor, light dependent resistors (sensors), relay and other passive electronic components which were all used to accurately track the sun's position in the atmosphere.

1.3 ADVANTAGE OF SOLAR TRACKERS

The main reason to use a solar tracker is to reduce the cost of the energy you want to capture. A tracker produces more power over a longer time than a stationary array with the same number of modules. This additional output or "gain" can be quantified as a percentage of the output of the stationary array. Gain varies significantly with latitude, climate, and the type of tracker you choose as well as the orientation of a stationary installation in the same location.

1.4 PROJECT DESIGN METHODOLOGY

This section will discuss the methodology involved in the design of the solar tracker. The 9 volts regulated supply voltage is used to power the LM339 comparator and a 12 volts regulated supply voltage is used to power the relay and DC motor. The 7809 voltage regulator was used to provide this 9 volt and also to convert an unregulated supply of 12 volts from the transformer secondary to 9 volts for use by the circuit. Photo-resistor(s) is used as a photo sensor which is ganged with a resistor to generate a differential signal whenever the light incident ray that falls on the two light dependent resistor LDR are not equal and this signal is been feed into the comparator circuit which compares the two electrical signal and then give an output to correspond with the one with the highest electrical signal. The output from the comparator circuit is then fed into the motor controlling and switching unit which then determine the direction in which the motor should be rotated and when it should rotate and not.

1.5 SCOPE OF PROJECT

Although, this project idea is to adjust the photovoltaic array (solar panel) in only one axis and keep it perpendicular to the sun from sunrise in the morning through to sunset in the evening. This solar panel will be mounted on the rotating mechanism, and the tracking system will be using a comparator IC and a light dependent resistor LDR to detect maximum incident rays from the sun.

CHAPTER TWO

LITERATURE REVIEW / THEORITICAL BACKGROUND

2.1 LITERATURE REVIEW

The idea of transforming sunlight into energy is not a new concept; it has been around for centuries. Radiation from the sun can be converted into usable energy through thermodynamic processes. However, concentrating the energy from the sun can be difficult because the incident radiation that reaches Earth is spread out over a large area. The photovoltaic effect, discovered in 1839 by Alexandre E. Becquerel, showed that an electric current is created when light is directed on an electrode submerged in a conductive solution. It was not until more than twenty years after Albert Einstein explained the photoelectric effect that Russel Ohl in 1950 patented the modern solar cell with patent no: US2402662 which converts sunlight into electricity with an efficiency of ~6%. This sparked the development of a new industry of transforming sunlight into energy. [1]

Solar cells, also known as photovoltaic cells or panels, are expensive to manufacture which has made marketing this technology at an affordable large-scale energy source difficult. In the last few years, improving technology has increased the efficiency of photovoltaic processes. Efficiencies of 30-40% can be obtained when concentrating sunlight onto the newer photovoltaic panels. This development has opened possibilities for using solar energy in third world countries because large reflective areas, which are inexpensive, can be coupled with smaller photovoltaic surfaces (traditionally the most expensive part of a solar system). Reflecting this concentrated sunlight onto a photovoltaic panel reduces the cost of the entire system. There are significant challenges, including optics, tracking, and cooling, that must be overcome in designing an efficient solar system.

Solar energy systems have become important alternative solutions to environmental problems faced by the world today. The combustion of fossil fuels causes respiratory problems and also the destruction of ozone layer thereby exposing the earth inhabitant to the ultraviolet rays of the sun and it will also result in energy shortage in the not too distant future. Hence, it is rather tempting to exploit solar energy, which is available in abundance, in a practical and optimal manner as there is no remarkable effect associated with it. [1]

In remote areas the sun is a cheap source of electricity because instead of hydraulic generators it uses solar cells to produce electricity. While the output of solar cells depends on the intensity of sunlight and the angle of incidence, therefore in other to obtain maximum output efficiency; the solar panels must remain in front of sun during the whole day. Due to rotation of earth those panels can't maintain their position always in front of sun. This problem results in decrease of their efficiency. Thus to get a constant output, an automated system is required which should be capable to constantly rotate the solar panel.

A **solar tracker** is a device for orienting a solar photovoltaic panel or concentrating solar reflector toward the sun. Concentrators, especially in solar cell applications, require a high degree of accuracy to ensure that the concentrated sunlight is directed precisely to the powered device. Non-concentrating applications require less accuracy, and a tracker is not necessary, but can substantially improve the amount of power produced by a system by enhancing morning and afternoon performance. Strong afternoon performance is particularly desirable for grid-tied photovoltaic systems, as production at this time will match the peak demand time for summer season. A fixed system oriented to optimize this limited time performance will have a relatively low annual production. [1]

2.1 THEORETICAL BACKGROUND

This section presents background information on the main subsystems of the project. Specifically, this section discusses power unit, light sensor, comparator IC, motor controlling and switching system and DC motor theory in order to provide a better understanding as to how they relate to the solar tracker.

2.2 POWER UNIT

The power unit changes the available electric energy (usually ac) to the form required by the various circuits within the system (usually dc). The process of converting this alternating voltage to dc voltage is called rectification and it is accomplished with the help of the following as illustrated in the diagram below in figure 2.0. [4]

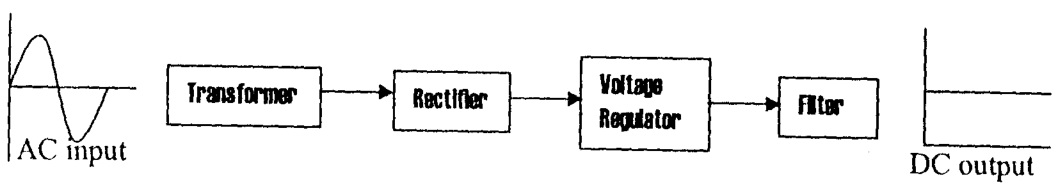


Figure 2.0: Block diagram of a regulated D.C power supply

2.2.1 TRANSFORMATION

This is a process of converting AC voltage from one voltage level to another through the use of a transformer.

Transformer: The function of a transformer is either to step-up or step-down voltage but in this case, a step-down transformer is required to step-down the ac supply voltage to suit the requirement of the solid state electronic devices and circuits fed by the dc power unit. It also provides isolation from the supply line for safety reasons. The transformer consists of two winding isolated from each other and wound on the same iron core. The primary winding receives the AC supply from the mains while the secondary winding produces the output voltage for rectification. The schematic structure of a transformer is as shown in figure 2.1. [4]

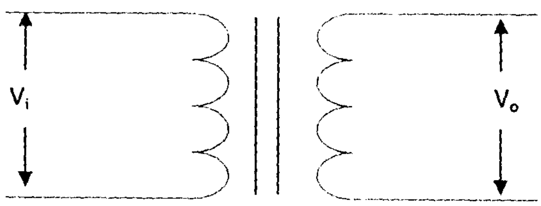


Figure 2.1: The schematic structure of a transformer

Transformer theory

Flux $\phi = \phi_m \sin wt$

But e.m.f., $e = \frac{Nd\phi}{dt}$ (2.1)

hence, $e = \frac{Nd(\phi_m \sin \omega t)}{dt}$ (2.2)

$e = \omega N \phi_m \cos \omega t$ (2.3)

If flux varies sinusoidally, the rms value of induced e.m.f. is obtained from factor ω

Where $\omega = 2\pi f$

E_{rms} of the e.m.f. per turn will be

$$E_{rms} = \frac{1}{\sqrt{2}} \omega \phi m \cos \omega t$$

$$= \frac{1}{\sqrt{2}} \times 2\pi f \phi m \cos \omega t \quad (2.4)$$

$Q = \omega t = 0$ (angle between the coil windings)

Therefore, $E_{rms} = 4.44f\phi_m \cos \omega t = 4.44f\phi_m$

$$e = 4.44f\phi_m \quad (2.5)$$

Total number of induced e.m.f./turn in the winding is

For primary winding, $E_1 = 4.44fN_1 \phi_m$ (2.6)

For secondary winding, $E_2 = 4.44fN_2 \phi_m$ (2.7)

Where N_1 and N_2 are primary and secondary number of turns respectively

From equation 2.6 and 2.7,

$$\frac{E1}{E2} = \frac{N1}{N2} = K$$

Where K is the voltage transformation ratio

However, the transformer chosen for this power supply is (240/12) V. This has the ability of giving peak voltage of $\sqrt{2}\ x\ 12 = 16.97\ V$

2.2.2 RECTIFICATION

This is the process of converting AC voltage to a DC voltage using diode.

Rectifier: This is a circuit which employs one or more diode to convert ac voltage into pulsating dc voltage. Diodes are used as rectifiers because they conduct in only one direction. They are three forms of rectifier circuits. [4]

Half-Wave rectifier: This uses only one diode for rectification and is a type in which one half of the ac waveform cycle is missing due to the blocking effect of the diode as it conducts in one direction. [4]

Full-Wave Rectifier: This uses a centre-tapped transformer secondary and two diodes. In this case, the two half of the ac waveform cycle are been rectified. [4]

Full-Wave Bridge Rectifier: This is the most frequently used circuit for electronic dc power supply. It requires four diodes but the transformer used is not center-tapped. The full-wave bridge rectifier circuit is as shown below in figure 2.2(a). [4]

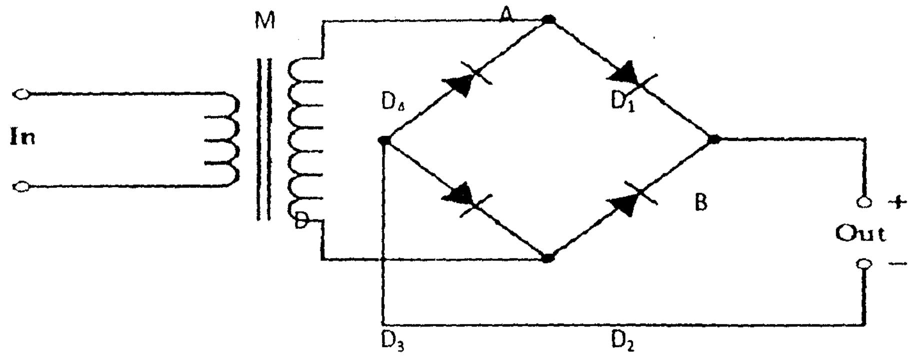


Figure 2.2(a) The full-wave bridge rectifier circuit

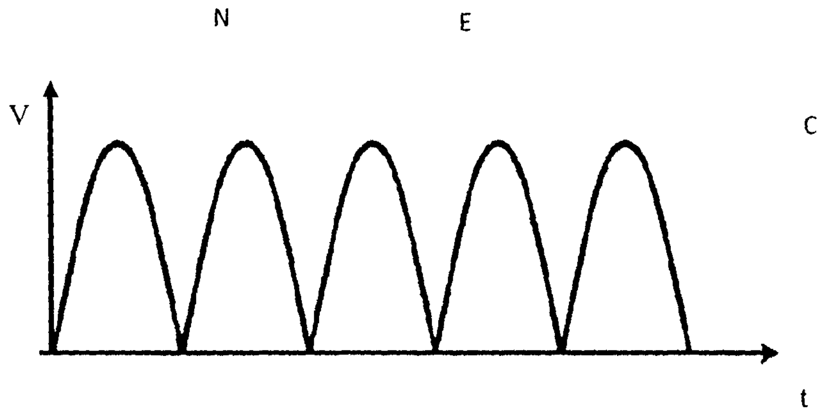


Figure 2.2(b): The output waveform of a bridge rectifier

During the negative input half-wave, the secondary terminal N becomes positive and M negative. Note that D2 and D4 are forward bias and current flow along the path NEBCDAM as shown in figure above hence keeps the current flowing through load resistor RL in the same direction. The output waveform is as shown above in figure 2.2(b)

During the positive input half wave, the secondary terminal M is positive and N is negative, hence diode D1 and D3 becomes forward biased, while D2 and D4 reverse biased, this result in the current flowing along MABCDEN path producing a drop. [4]

2.2.3 VOLTAGE REGULATOR

This is an Integrated Circuit IC which helps to keep the terminal voltage of the dc supply constant even when the ac input voltage to the transformer varies. The voltage regulators are of fixed and adjustable output and the fixed output type are either positive or negative. Power supply circuit suffers from the draw back that their D.C output voltage change with changes in loads or input voltage. Such D.C power supply is unregulated. Regulated supply is obtained by using a voltage regulator circuit. There are various types of regulator circuit such as zener diode shunt regulator, transistor series voltage regulator, switching regulators and so on. All the above mentioned circuit are made from discrete components. The type of voltage regulator used in this project is the integrated circuit (IC) voltage regulator for D.C voltages. This IC has more improved performance as compared with the other discrete component mentioned. They have unique built-in features such as current limiting self-protection against over temperature. [2]

2.2.4 FILTRATION

This is the process of removing excess A.C voltage or fluctuation which appears as ripples in the output voltage of a rectified A.C voltage by using filters. A filter consists of capacitor connected across a pulsating D.C voltage, which smoothens out the ripple voltage. Of course, no filter can, in practice, produce an output voltage as ripple free as that of a dc battery but it approaches so closely. This function of a capacitor is due to its property to change and store energy during non-conducting half-cycle. The effectiveness of capacitive filter is dependent on the size of the capacitor, the value of the load and time between pulsations (ripples). [4]

2.3 LIGHT SENSOR THEORY

One of our key modules in this project is the sensor. Because the sensor tracks the solar light source's orientation, selecting the right tracking sensor is very important. Light sensors are among the most common sensor type. The simplest optical sensor is a photo-resistor which may be a cadmium sulfide (CdS) type or a gallium arsenide (GaAs) type. The next step up in complexity is the photodiode followed by the phototransistor. The sun tracker uses a cadmium sulfide (CdS) photocell for light sensing. This is the least expensive and least complex type of light sensor. The CdS photocell is a passive component whose resistance in inversely proportional to the amount of light intensity directed toward it. CdS sensors as seen in the diagram below are cheap, reliable, and photo-sensitive. In this design, the CdS sensor has no polarity (ohmic structure), it have a photo-variable resistor in which the internal impedance changes with the intensity of light energy, and the CdS sensor's photo sensitivity (i.e., spectral characteristics) is 0.4 to 0.8 mm, which is close to the wavelength scope of visible solar light (0.38 to 0.76 mm), as shown in the figure 2.3 below.

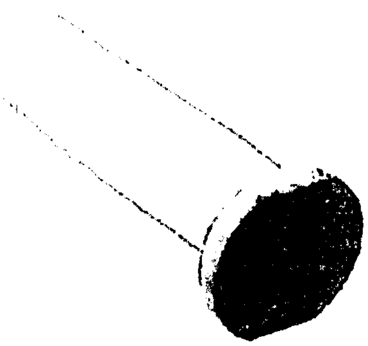


Figure 2.3(a): CdS Stereogram

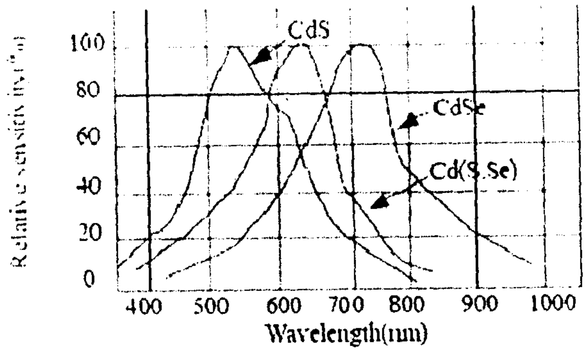


Figure 2.3 (b): CdS Sensitivity Scope

2.4 OPERATIONAL AMPLIFIER COMPARATOR

Operational amplifier or op-amp is a special type of amplifier with high gain. Op-amp is used for various different purposes. An op-amp can also be used to compare two different voltages (i.e. op-amp as a comparator). Generally an op-amp unit has two input terminals and one output terminal. Signal at the output terminal depends on the voltages at the input terminals. One of the input terminal is called a non-inverting (+) input terminal and the other input terminal is called inverting (-) input terminal. The schematic of a comparator is shown below in figure 2.4 [3]

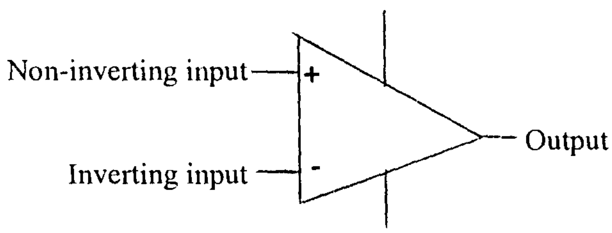


Figure 2.4: The schematic of a comparator

2.5 TRANSISTOR

Transistors are used in circuits to generate oscillating signal, amplification of signal and as a switch (on/off) in various circuits. Switching is very important in this design and other electronic devices. A common bipolar transistor is used in this case for the switching operation and it is working as an electronic switch. Power transistors are used in applications ranging from a few to several hundred kilowatts and switching frequencies up to about 10 kHz. Power transistors used in power conversion applications are generally *npn* type. The power transistor is turned on by supplying sufficient base current, and this base drive has to be maintained throughout its conduction period. It is turned off by removing the base drive and making the base voltage slightly negative (within – VBE(max)). The saturation voltage of the device is normally 0.5 to 2.5 V and increases as the current increases. Hence, the on-state losses increase more than proportionately with current. The transistor off-state losses are much lower than the on-state losses because the leakage current of the device is of the order of a few milliamperes. Because of relatively larger switching times, the switching loss significantly increases with switching frequency. Power transistors can block only forward voltages. The reverse peak voltage rating of these devices is as low as 5 to 10 V. Power transistors do not have $I2t$ withstand capability. In other words, they can absorb only very little energy before breakdown. Therefore, they cannot be protected by semiconductor fuses, and thus an electronic protection method has to be used. [2]

2.6 RELAY

This is an electromagnetic switch operated by magnetic force. This magnetic force is generated by the flow of current through a coil in the relay. The relay opens or closes a circuit, when current through the coil is started or stopped. The circuit that controls the relay is called switching circuit and it drives the relay to switch on/off another circuit, which is known as switched circuit. The schematic symbol and pictorial diagram of a simple relay is shown in figure 2.6 below.

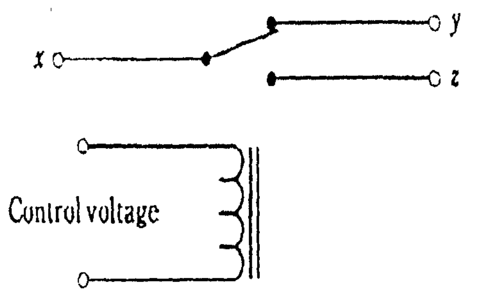


Figure 2.5(a): Schematic symbol of a simple relay

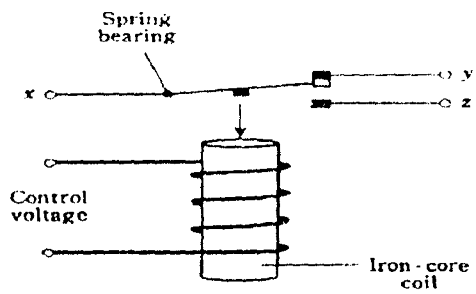


Figure 2.5(b): Pictorial diagram of a simple relay

2.7 DC MOTOR

An electric motor is a machine which converts electric energy into mechanical energy. In general, DC motors are similar to DC generators in construction. The action is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by fleming's left hand rule and whose magnitude is given by $F = BIl$ (Newton). When current is passed through the armature of a DC motor, a torque is generated by magnetic reaction, and the armature revolves. The action of the commutator and the connections of the field coils of motors are precisely the same as those used for generators. The revolution of the armature induces a voltage in the armature windings. This induced voltage is opposite in direction to the outside voltage applied to the armature, and hence is called back voltage or counter electromotive force (emf). As the motor rotates more rapidly, the back voltage rises until it is almost equal to the applied voltage. The current is then small, and the speed of the motor will remain constant as long as the motor is not under load and is performing no mechanical work except that required to turn the armature. Under load the armature turns more slowly, reducing the back voltage and permitting a larger current to flow in the armature. The motor is thus able to receive more electric power from the source supplying it and to do more mechanical work. The speed at which a DC motor operates depends on the strength of the magnetic field acting on the armature, as well as on the armature current. The stronger the field, the slower is the rate of rotation needed to generate a back voltage large enough to counteract the applied voltage. For this reason the speed of DC motors can be controlled by varying the field current. [4]

CHAPTER THREE

DESIGN AND IMPLEMENTATION

This chapter presents the design details and also the choice of components used in the realization of this project "solar tracking system".

3.1 BLOCK DIAGRAM

The diagram below in fig. 3.0 is the block diagram followed in the realization of this project. Each of the modules represents a major stage in the circuit of this solar tracking system.

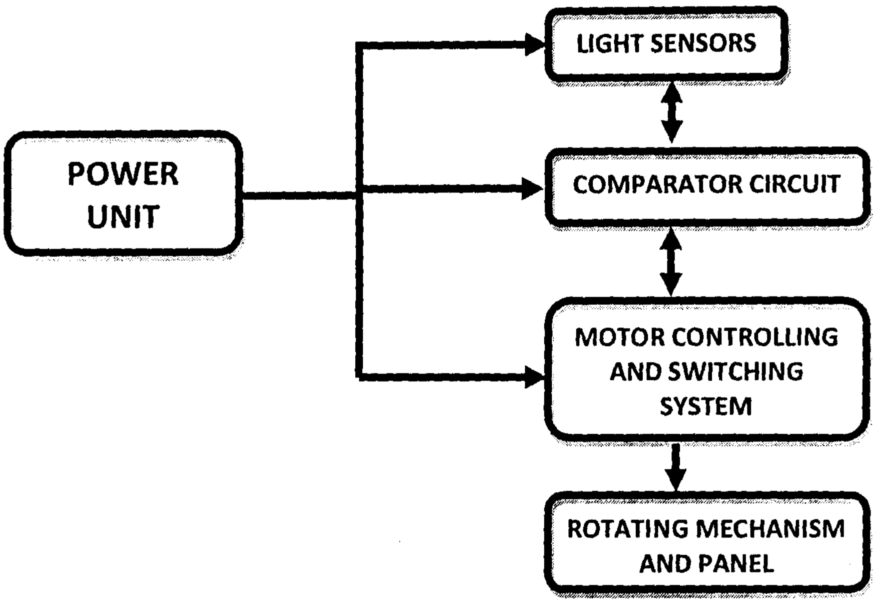


Fig 3.0: SOLAR TRACKING SYSTEM BLOCK DIAGRAM

The principle of operation of the various modular units including its circuit diagram and design are discussed below. The following are the modular units which make up this project.

- Power unit
- Tracking Sensor unit

- ❖ Comparator unit
- ❖ Motor controlling and swi{tching unit

3.2 POWER UNIT

The objective of this unit is to power the entire project circuit of the solar tracking system of which the voltage demand from each module were not the same and therefore it was put into consideration as 12V dc is needed to power the motor while the rest circuit needed the supply voltage of 9V dc. The diagram below in figure 3.1 is the circuit diagram of the power supply unit.

Table 4.1 Result table

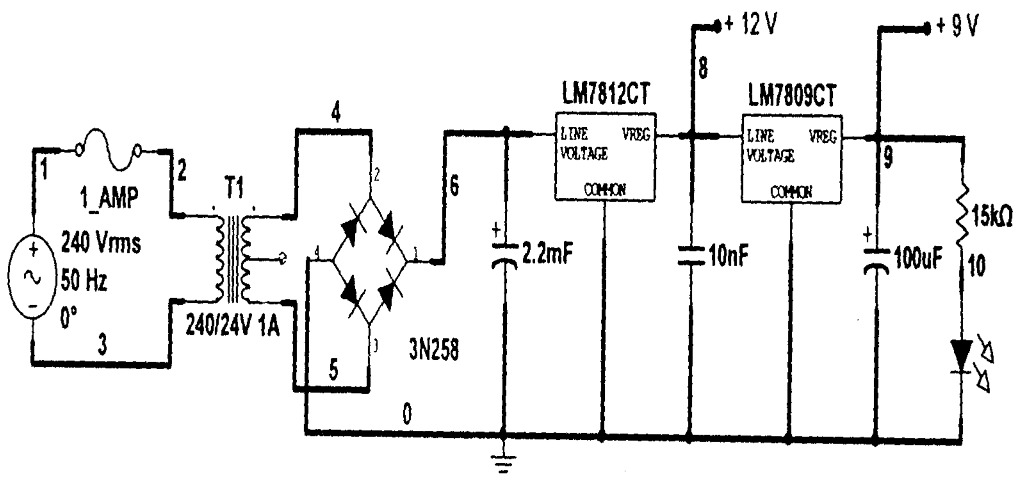


Figure 3.1 circuit diagram of power supply unit

3.2.1 Transformation

A 220/12V 500mA step-down transformer was used, therefore the power rating which is in VA is:

$$\text{Power} = V \times I \quad (3.1)$$

$$= 12 \times 500 \times 10^{-3}$$

$$= 6VA$$

3.2.2 Rectification

In this project a DC voltage is needed to power the circuit, therefore a full-wave bridge rectification was chose using a bridge rectifier IC for this purpose.

3.2.3 Filtration

Because pulsating direct current is not directly usable in most electronic circuits, something close to pure dc voltage is required. The effectiveness of a capacitance filter is determined by three factors namely:

- The size of the capacitor
- The value of the load
- The time between pulsations

These three factors are related by the formula:

$$T = RC \tag{3.2}$$

Where T = time in seconds (s)

R = resistance in ohms (Ω)

C = capacitance in Farads (F)

The product RC is called the time constant of the circuit. A charged capacitor will lose 63.2% of its voltage in T seconds and it will take approximately 5T seconds to completely discharge the capacitor.

Therefore the choice of capacitance of the filter capacitor used is calculated below:

From the formula, T = RC

$$\text{Where } V = IR, \tag{3.3}$$

then $R = {}^{V}/_{I}$

$$\text{Therefore, } T = \frac{V_{p-p} \times C}{I} \tag{3.4}$$

$$\text{Then, } V_{p-p} C = I\,T \tag{3.5}$$

$$C = \frac{IT}{dV} \quad (3.6)$$

Where $T = \frac{1}{2f}$ (for full-wave rectification calculation)

$$C = \frac{I}{2 \times f \times dV} \quad (3.7)$$

But $V_{rms} = 24V$

$V_{av} = 0.9V_{rms}$ (for full wave) (3.8)

$= 0.9 \times 24 = 21.6V$

Hence, $V_p = 1.414V_{rms}$ (3.9)

$= 1.414 \times 24 = 33.94V \approx 34V$

But, $V_{p\text{-}p} = 2V_p$ (3.10)

Note: for a rectified voltage $V_{p\text{-}p} = V_p$

$V_p = 33.94V$

Assuming 15% for ripple factor

Therefore, $dv = \text{ripple factor} \times V_p$

$dv = 0.15 \times 33.94 = 5.09V$

Substituting the above values into equation (3.7)

$$C = \frac{I}{2 \times f \times dV}$$

Where I = 0.5A (from the transformer specification)

Therefore, $C = \frac{1}{2 \times 50 \times 5.09} = \frac{1}{509}$

$= 1.965 \times 10^{-3} = 1965\mu F$

The standard working capacitor which is 2200μF was used.

0.01 ceramic capacitors were used in the power circuit for stability due to the fact that it blocks A.C signal and also the inductive reactance that will be generated from the dc motor coil.

3.2.4 Regulator

This device is used to regulate the supply voltage to a constant value required by the circuit which is 9V and a 7809 voltage regulator IC from the 7800 series of voltage regulator was used, for a positive fixed output.

3.2.5 Power Unit Indicator

A red LED is used as an indicator to show if the power unit and the circuit is working properly. The calculation of the value of the resistor used is as follow:

$$V = IR \quad (3.11)$$

Where $R = \frac{V}{R}$

And $V = Vcc - Vd$

Therefore $R = \frac{Vcc - Vd}{Id} = \frac{9 - 0.7}{0.00055} = 15.091\Omega = 15K\Omega$

3.3 TRACKING SENSOR UNIT

The tracking sensor is composed of two similar CdS sensors, which are positioned to face the east and west to detect the light source intensity in the two orientations. The CdS sensors are about 4cm apart and is been separated by a thin sheet of metal of about 7cm high, so as to form an angle of 15° with the height of the separating metal. It is known that the sun rotates an angle of 15° in 1hr, this is to maintain a uniform rotation of the solar panel at this given time interval (1 hour). At the CdS sensor positions, the thin metal sheet isolates the light from the other sensor to achieve a wide-angle search and quickly determine the sun's position.

The voltage input to the comparator circuit is been determine by the CdS sensor as a result of the amount of light intensity that falls on each of them. The CdS sensor used has a range of resistance value as shown in the table 3.1 below.

CdS Sensor Measurement @	Resistance Value
Light (12noon)	35Ω
Dark (7pm)	30Kω

Table 3.1 Light and Dark resistance value of CdS Sensor (LDR)

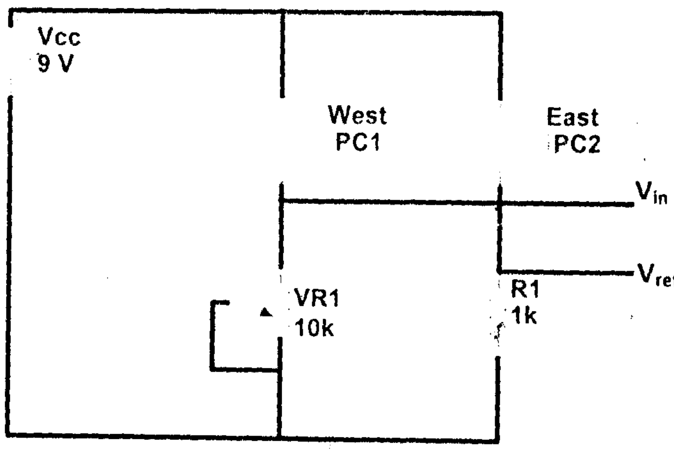


Figure 3.2 Tracking Sensor unit

3.3.1 CALCULATIONS ON SENSOR UNIT

For V_{ref} when the CdS sensor resistance (Rs) is 35Ω at day (12noon)

$$V_{REF} = \frac{Vcc\ X\ R1}{Rs + R1} = \frac{9\ X\ 1000}{35 + 1000} = 8.696V$$

For V_{REF} when the CdS sensor resistance (Rs) is 30kΩ at night (7PM)

$$V_{REF} = \frac{Vcc\ X\ R1}{Rs + R1} = \frac{9\ X\ 1000}{30000 + 1000} = 0.29V$$

For V_{IN}, when the CdS sensor resistance (Rs) is 35Ω

Therefore for $V_{IN} = V_{REF}$, at day (12noon) the value of V_{R1} will be set at:

$$V_{R1} = \frac{Vin\ X\ Rs}{Vcc - Vin} = \frac{8.696\ X\ 35}{9 - 8.696} = 1001.2\Omega$$

When VR1 = 1001.2Ω, Rs = 35Ω, at day (12noon) for VR1 at minimum

$$\text{Then } V_{IN} = \frac{Vcc\ X\ VR1}{Rs + VR1} = \frac{9\ X\ 1001.2}{35 + 1001.2} = 8.696V$$

When VR1 = 1001.2Ω, Rs = 30kΩ, at night (7PM) for VR1 at minimum

$$\text{Then } V_{IN} = \frac{Vcc\ X\ VR1}{Rs + VR1} = \frac{9\ X\ 1001.2}{30000 + 1001.2} = 0.29V$$

3.4 COMPARATOR UNIT

In this design, the comparator is of a Non-inverting configuration mode with Hysterisis.

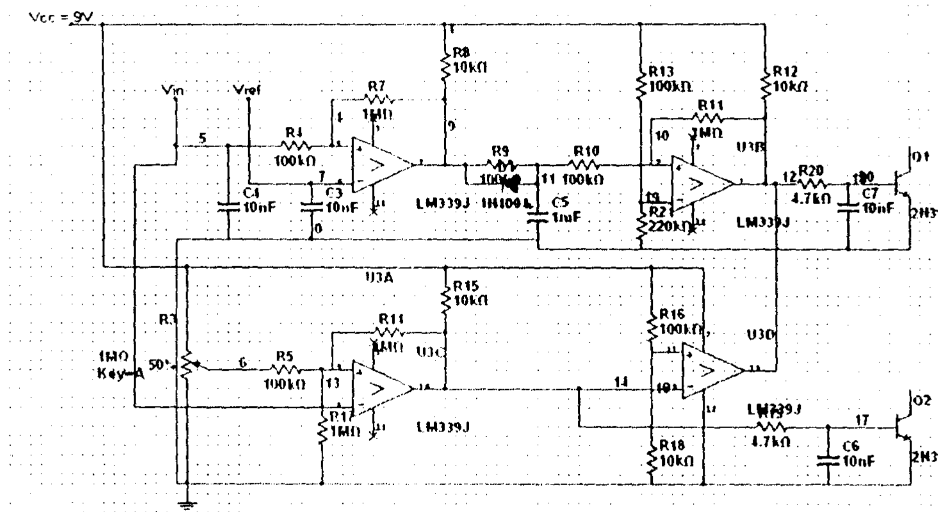


Figure 3.3 *LM339 Comparator Unit Circuit Design*

3.4.1 CALCULATIONS ON COMPARATOR UNIT

For analysis, assume that the input voltage, V_{IN} is low so that the output voltage, Vo is also low (Vo = GND). For there to be an output, V_{IN} must rise up to V_{IN1}, where V_{IN1} is given by:

$$V_{IN1} = \frac{Vref\ X\ (R4+R7)}{R7}$$

For V_{IN1} when V_{REF} = 8.696V at day (12noon)

$$V_{IN1} = \frac{8.696\ X\ (100000+1000000)}{1000000} = 9.566V$$

For V_{REF} = 0.29V, V_{IN1} at night (7PM) will be:

$$V_{IN1} = \frac{0.29\ X\ (100000+1000000)}{1000000} = 0.32V$$

As soon as Vo switches to Vcc, V_A will step to a value greater than V_{REF} which is given by:

$$V_A = V_{IN} + \frac{(Vcc-Vin1)\ R4}{R4 + R7}$$

For V_A, when V_{IN} = 8.696V and V_{IN1}= 9.566V at day (12noon)

$$V_A = 8.696 + \frac{(9-9.566)\ 100000}{100000 + 1000000} = 8.645V$$

For V_A, when V_{IN} = 0.29V and V_{IN1}= 0.32V at night (7PM)

$$V_A = 0.29 + \frac{(9-0.32)\ 100000}{100000 + 1000000} = 1.08V$$

To make the comparator switch back to its low state (Vo = GND) V_{IN} must go below V_{REF} before V_A will again equal V_{REF}. This lower trip point is now given by:

$$V_{IN2} = \frac{Vref\ X\ (R4+R7) - VccR4}{R7}$$

For V_{REF} = 8.696V, then V_{IN2} at day (12noon) will be:

$$V_{IN2} = \frac{8.696\ X\ (100000+1000000) - (9\ X\ 100000)}{1000000} = 8.666V$$

For V_{REF} = 0.29V, then V_{IN2} at night (7PM) will be:

$$V_{IN2} = \frac{0.29\ X\ (100000+1000000) - (9\ X\ 100000)}{1000000} = -0.58V$$

The Hysteresis for this circuit, ΔV_{IN} is the difference between V_{IN1} and V_{IN2} and is given by:

$\Delta V_{IN} = V_{IN1} - V_{IN2}$

ΔV_{IN} at day (12noon) will be:

$\Delta V_{IN} = 9.566 - 8.666 = 0.9V$

ΔV_{IN} @ night (7PM) will be:

$\Delta V_{IN} = 0.32 - (-0.58) = 0.9V$

For Comparator 2, the reference voltage V_{REF} is

$$V_{REF} = \frac{Vcc\ X\ R21}{R13 + R21} = \frac{9\ X\ 220000}{100000 + 220000} = 6.188V$$

The input voltage V_{IN} of comparator 2 will be as a result of the output voltage V_O from comparator 1.

But before the V_{IN} terminal of comparator 2 there is a time delay circuit which is calculated as follows:

T = RC

Where T is time in seconds, R = 100KΩ, C = 1000μF

T = 100000 X 0.001

T = 100 seconds

The reference voltage for Comparator 3 is the input voltage of comparator 1 at day and night which are:

$V_{REF} = V_{IN} = 8.696V$ at day (12noon)

$V_{REF} = V_{IN} = 0.29V$ at night (7PM)

The input voltage V_{IN} of comparator 3 is also a range of value, which is

$$V_{IN} = \frac{Vcc \ X \ R17}{R5 + R17} = \frac{9 \ X \ 1000000}{100000 + 1000000} = 8.182V$$

$$V_{IN} = \frac{Vcc \ X \ R17}{R5 + R3 + R17} = \frac{9 \ X \ 1000000}{100000 + 1000000 + 1000000} = 4.286V$$

This shows that comparator 3 can only have an output at night because the range of the input voltages is only higher than the reference voltage at night.

The reference voltage and input voltage con only be equal if the variable resistor VR2 is set to values for day and night which is not obtainable from the predefined value. This is justified by the calculation below.

$$VREF = \frac{Vcc \ X \ R17}{R5 + R17 + VR2}$$

Therefore, $VR2 = \frac{VccR17 - VrefR5 - VrefR17}{Vref}$

When VREF = 8.696V at day (12noon)

$$VR2 = \frac{9 \ X \ 1000000 - 8.696 \ X \ 100000 - 8.696 \ X \ 1000000}{8.696} = -65K\Omega$$

When VREF = 0.29V at night (7PM)

$$VR2 = \frac{9 \ X \ 1000000 - 0.29 \ X \ 100000 - 0.29 \ X \ 1000000}{0.29} = 29.9M\Omega$$

For comparator 4 which is of open-loop configuration, the input voltage to the non-inverting terminal is

$$V_{IN+} = \frac{Vcc \ X \ R16}{R18 + R16} = \frac{9 \ X \ 10000}{100000 + 10000} = 0.82V$$

And that of the inverting terminal is as a result of the output voltage from comparator 3.

3.5 MOTOR CONTROLLING AND SWITCHING UNIT

In this section of the design, an NPN transistor and a relay are the main component. The NPN transistor is been biased by a positive voltage at its base terminal so that the transistor will be switched ON. These transistor are used to determine which of the relay is been excited in order to rotate the motor either towards the West direction or East direction. The circuit in figure 3.4 below shows the connection configuration of this unit.

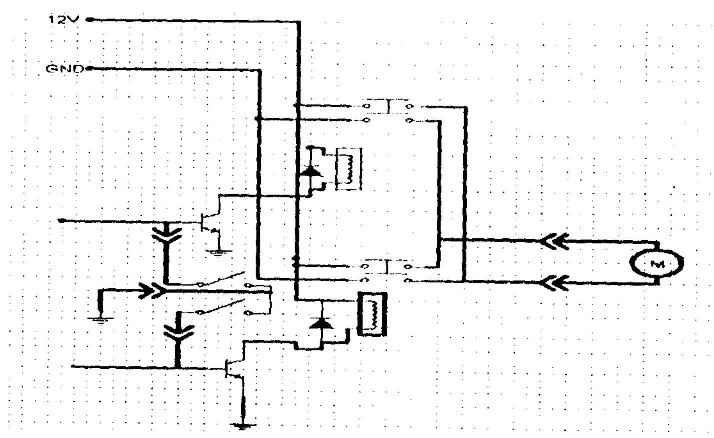


Figure 3.4 Circuit connection of motor controlling and switching unit

3.6 CIRCUIT DIAGRAM

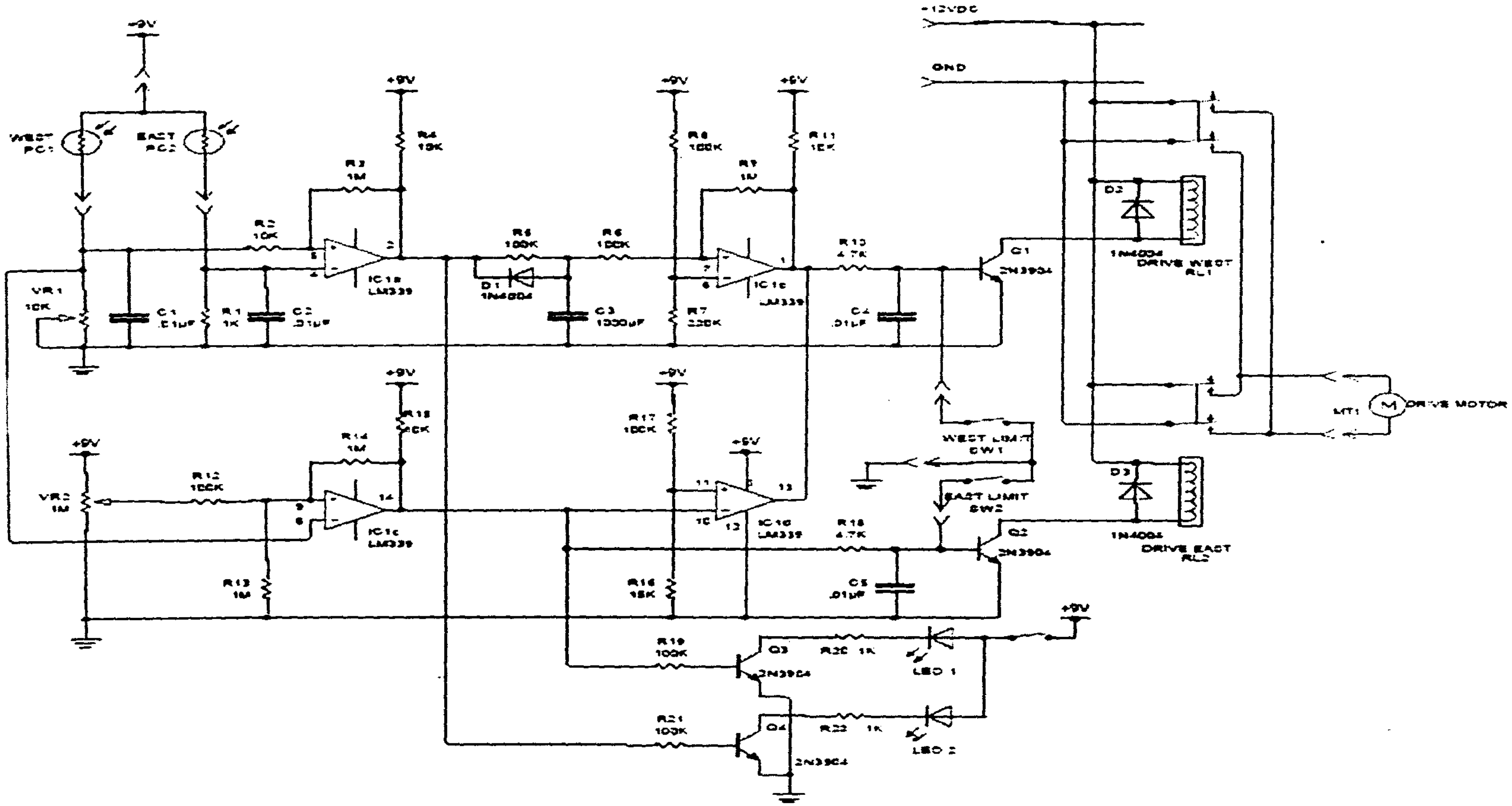


Figure 3.5 Circuit Diagram

CHAPTER FOUR

TESTS, RESULTS AND DISCUSSION

In this chapter, the testing of the project, and the result obtained were ascertain to check the output behaviour of system whether it correspond or not to the design specification of the project.

4.1 TESTS

The testing of the system was done in a modular form. In this way, the output of each module/unit is check with reference to the expected output from the design. If the output of the tested unit corresponds with the expected output within the tolerance range ($\pm$ 5%) then the unit is considered to be quality assured. However, if the unit tested has it result out of expectation range or not within tolerance value, then each of the components used in the unit is tested to ascertain correctness of the component. In this way, the malfunctioning component is detected and corrective measures will be taken to rectify such fault(s).

This modularized approach of testing the entire system was chosen to ensure effective and efficient testing of the system and easy tracing of faulty components. The digital multi-meter was used throughout the testing stage.

4.2 RESULTS

Based on the testing carried out the following table shows the result allowed for the various units for varying input conditions.

UNIT	INPUT VALUE	OUTPUT VALUE	EXPECTED VALUE
Power Unit	240V(A.C)	+8.96V D.C, +11.97V D.C,	+9V D.C, +12V D.C
Relay Voltage	12V (D.C)	11.97 V D.C	12V
Motor Voltage	12V (D.C)	11.95 V D.C	12V

Table 4.1 Result table

4.3 DISCUSSION

Testing and ascertaining of required result is very important to ensure that a system's design works within the required specification.

The power unit was tested at the output 7812 and 7809 voltage regulator to check if the outputs fall within the specification. If not, the transformer input (primary and secondary is tested for continuity, the bridge rectifier output voltage is tested, the capacitor is tested for continuity and each regulator input and output voltage level is tested. By so doing, the power unit can be troubleshoot and repaired.

The input and output voltages of the comparator were tested, if the obtained result deviates from the expected result, then the comparator is checked for proper grounding or if the voltage source is properly connected. Before the DC motor is connected, the output voltage from the relay unit was checked using voltmeter to affirm the correctness of the voltage. At the end, the variable resistors VR1 and VR2 were varied for proper functioning of the system.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

In this project, an economical single axis solar tracking system has been developed to increase the amount of power generated by the solar panel as the sun traverses across the sky. For this purpose, the solar tracking circuit was designed considering some factors such as cost and availability of components. Based on these factors, the project was constructed using discrete electronic components and integrated circuit (IC). This project presents a method of searching for and tracking the sun and also resetting itself for a new day at sunset.

The simple LDR sensors with unique designs in their positioning enable the tracker work properly. Energy saving factors is essential for this system and they are taken into account in the sun position sensor's design as it known that the sun rotates for 15° in one hour.

5.2 RECOMMENDATION

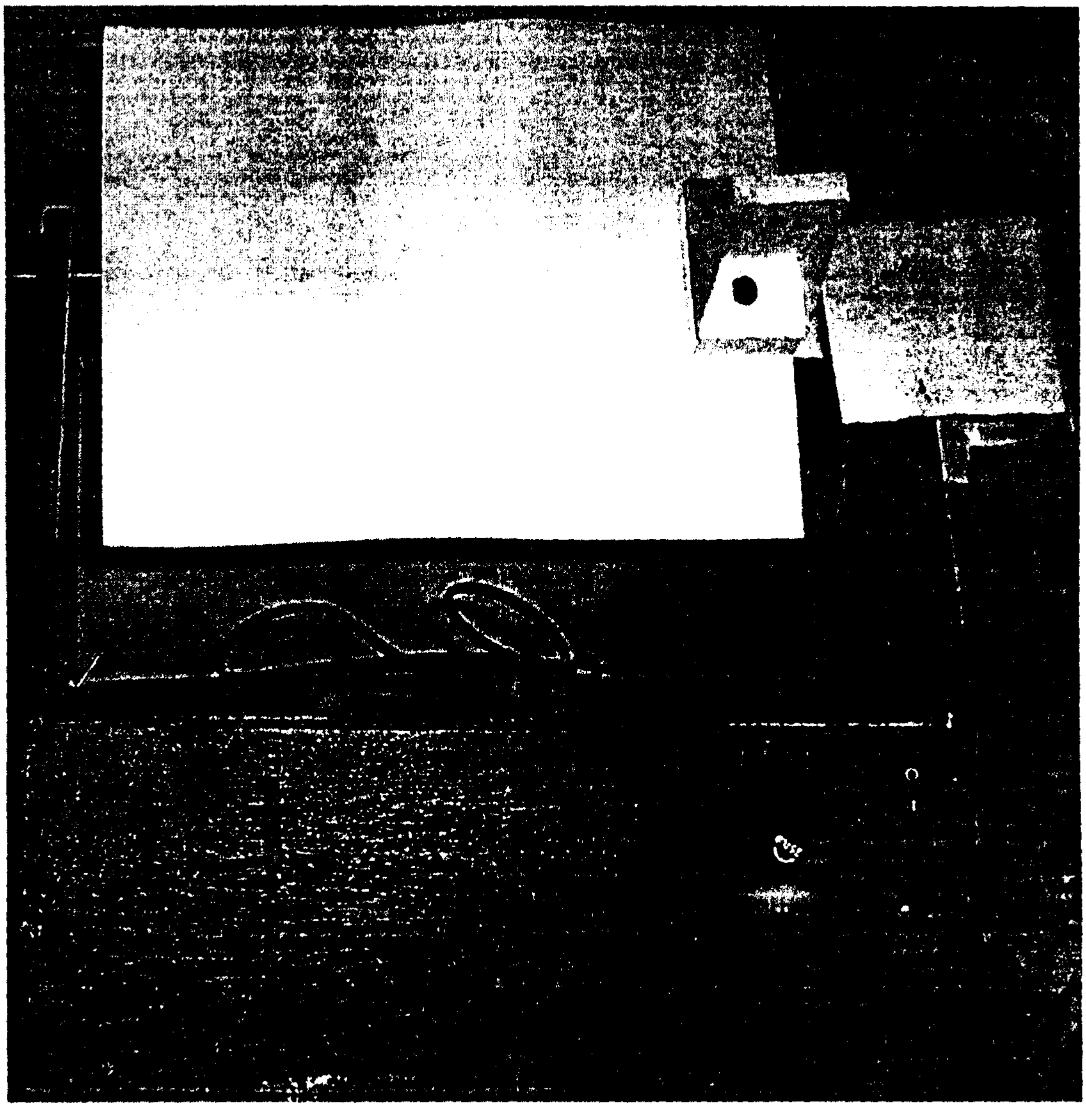
The goals of this project were purposely kept within what was believed to be attainable within the allotted timeline. As such, many improvements can be made upon this initial design. It is felt that this design represents a functioning miniature scale model (prototype) which could be replicated to a much larger scale. The following recommendations are provided as ideas for future expansion of this project:

- Instead of using a small DC motor in the project, a larger motor with more torque should be preferable in other to give the model a very rigid stability.
- Increase the sensitivity and accuracy of tracking by using a different light sensor. A phototransistor with an amplification circuit would provide improved resolution and better tracking accuracy/precision.
- The use of a microcontroller should be more efficient and accurate and reliable than the comparator IC so as to reduce the number of discrete components used.
- To utilize a dual-axis design instead of a single-axis to increase tracking accuracy.

REFERENCES

1. G.O.J. Harper, Solar Energy: Projects for the evil Genius, McGraw-Hill Companies, Inc, 2007, pp.1-16, 81-104, 119-134
2. C.A. Schuler, Electronics: Principles and Applications (5th Edition), McGraw-Hill Companies, Inc, 1999, pp.55-124, 221-255
3. D.A. Neamem, Electronic: Circuit Analysis and Design (2nd Edition), McGraw-Hill Companies, Inc, 2001, pp.947-959, 871-911, 521-553
4. B.L. Theraja and A.K. Theraja, A textbook of Electrical Technology, (23rd Edition), S. Chand & Company Ltd., 2002,
5. http://www.phoenixnavigation.com/ptbc/home.htm
6. http://www.sullivan-county.com/ele/index.htm
7. http://home.cogeco.ca/~rpaisley4/CircuitIndex.html
8. http://www.elecfree.com/electronic/
9. http://www.picotech.com/index.html

APPENDIX



Project working model