Design and Development of Reliable and Economic Active Solar Tracking System

Major Project Report

Submitted in Partial Fulfillment of the Requirements

for the Degree of

Master of Technology

In

Electrical Engineering

(Power Electronics, Machines and Drives)

By

Parita .H. Gandhi

12MEEP05

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

May 2014

Undertaking for Originality of the Work

I, **Parita .H. Gandhi**, Roll No. **12MEEP05** , give undertaking that the Major Project entitled **"Design and Development of Reliable and Economic Active Solar Tracking System"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Power Electronics Machines and Drives, Electrical Engineering** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

Signature of Student
Date:
Place:
Endorsed by:

Industry - Guide
Mr. Asheesh Dhaneria
Dy. Manager(R&D)
ERDA,Vadodara

Institute - Guide
Prof. H. Amrolia
Asst. Professor
Department of Electrical Engineering
Institute of Technology
Ahmedabad

Certificate

This is to certify that the Major Project Report entitled **"Design and Development of Reliable and Economic Active Solar Tracking System"** submitted by Ms. **Parita .H. Gandhi (12MEEP05)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Power Electronics, Machines Drives of Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date:

Industry - Guide
Mr. Asheesh Dhaneria
Dy. Manager(R&D)
ERDA,Vadodara

Institute - Guide
Prof. H. Amrolia
Asst. Professor
Department of Electrical Engineering
Institute of Technology
Ahmedabad

Head of Department
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Director
Institute of Technology
Nirma University
Ahmedabad

Acknowledgement

I am deeply grateful to my Institute Project Guide Prof. H. Amrolia for his guidance in the project work and Head of Department (EE) Dr. P .N. Tekwani for allowing me to carry out the project in Electrical Research and Development Association (ERDA), Vadodara.

I also express my sincere thanks to my Industry Project Guide Mr. Asheesh Dhaneria, Dy. Manager (R&D), ERDA and Dr. V. Shrinet, Dy. Director and Head (R&D), ERDA for his invaluable support and motivation during the project work.

I would also like to thank Mr. Puran Gajera, Sr. Engineer (R&D), ERDA for his help in the project work. I would also like to thank Dr. S. H. Chetwani, Sr. Manager, ERDA for his invaluable guidance in the project work.

I am indebted to my friends who helped me in every possible way and who were always there when I needed the most.

Parita .H. Gandhi
12MEEP05

Abstract

The project aims at design and development of reliable and efficient active solar tracking system. The proposed single axis solar tracker device ensures the optimization of the conversion of solar energy into electricity by properly orienting the PV panel in accordance with the real position of the sun. By adopting solar tracking technique, efficiency of solar PV panel output can be increased by 25 - 30 percent as compared to normal efficiency of fixed tilt angle solar PV panel being 13 to 15 percent. It will be a horizontal single axis tracker i.e. having automatic control of solar module at elevation angle. Vertical manual seasonal adjustment will be done at azimuth angle. This tracking system is developed with LDR and low cost microcontroller making it less complex and reliable. DC gear motor will be used for rotation of solar panel providing high torque and low speed of solar panel rotation by its gear ratio adjustment for solar irradiance to fall perpendicular to the surface of solar module with rotation of sun. Thus optimization of output power and efficiency will be ensured by hardware implementation of proposed active solar tracker.

Terminologies

a. **Photovoltaic (PV) panel** -"Photo" means light and "voltaic" means voltage. Thus, a photovoltaic panel is a device that turns light into electric potential. Commonly, these devices are referred to simply as "solar panels.

b. **Photovoltaic cell** - A device that converts the energy of light into electric energy. Also called a PV cell or a solar cell (when the sun is the light source). Cells may be combined in a panel or array of panels to generate more energy as part of a PV system.

c. **Solar tracker** - Its an apparatus to track the suns position and rotate the panel accordingly to obtain maximum efficiency.

d. **Zenith angle** - This is the angle between the line that points to the sun and the vertical. At sunrise and sunset this angle is 90.

e. **Elevation angle/ Solar Altitude Angle** - This is the angle between the line that points to the sun and the horizontal. It is the complement of the zenith angle. At sunrise and sunset this angle is 0.

f. **Azimuth angle** - This is the angle between the line that points to the sun and south. Angles to the east are negative. Angles to the west are positive. This angle is 0 at solar noon. It is probably close to -90 at sunrise and 90 at sunset, depending on the season.

g. **Retrofit** - Property of a device in which it can be directly connected to the equipment without any additional construction or changes being made to save cost and time.

h. **Latitude** - The angle above or below the equator. The north pole is at 90 N and the south pole is at 90 S.

i. **Stow Position** - Position to which tracker moves to during adverse weather conditions like snow, extreme wind, rain etc.

j. **Payload** - Object moved by solar tracker. It may be a single PV module or an array of PV modules.

k. **Gear Ratio** - It is the ratio of input speed to output speed of the dc gear motor. For example if a dc worm gear motor has a gear ratio of 200:1; it implies 200 rotation of worm will result in 1 rotation of gear.

Contents

List of Tables

List of Figures

Chapter 1

Introduction to Solar Tracking System

Solar energy demand globally has been growing at about 30 percent per annum over last one and half decade. India has planned to install 20 GW solar plants by 2020. According to the survey, Gujarat has been a leader in solar power generation and contributes about two third of solar power installed capacity of the country. So far the efficiency of generating power of solar energy is relatively low. Majority of the solar panels are installed with fixed tilt angle so the transformation efficiency of solar energy is limited. Thus, how to increase the efficiency of generating power of solar energy is very important.

Solar cells or photovoltaic cells are semiconductor diodes that convert available sunlight into electrical power. They are basically P-N junction photodiodes with very large light-sensitive area. Each photodiode is a solar cell. All these cells are connected inside a module to form a solar panel. These solar panels are cascaded together to form arrays to generate high power electricity. To attain the maximum benefit from these solar panels, we need to position them in the direction that captures most of the energy. This direction depends on various factors. The panels are mounted at a fixed tilt, but because sun keeps changing its position due to the rotation as well as the revolution of earth, these panels can capture more energy if their tilt is adjusted according to sun's position.

The primary requirement for optimization of energy conversion is solar irradiance falling perpendicular to the surface of PV modules. This can be achieved by installation of solar trackers in the existing power plants. Use of solar PV tracker is not yet popular in India. The conversion efficiency of the PV panels is approximately 13 percent. It has been experienced that solar PV tracker increases electrical energy generation by 25-35 percent with respect to fixed panels.

There are various methods by which solar tracking system can be designed and developed. These are by using bimetallic strips or shape memory alloy (SMA) material or using solenoid or sensors for solar panel rotation. Unequal heating of dissimilar metals in bimetallic strip makes the panel rotate towards sun position. SMA is a heat responsive element which acts as both sensor and actuator to track sun position. Actuator mechanism can be established by using solenoid for solar panel rotation.

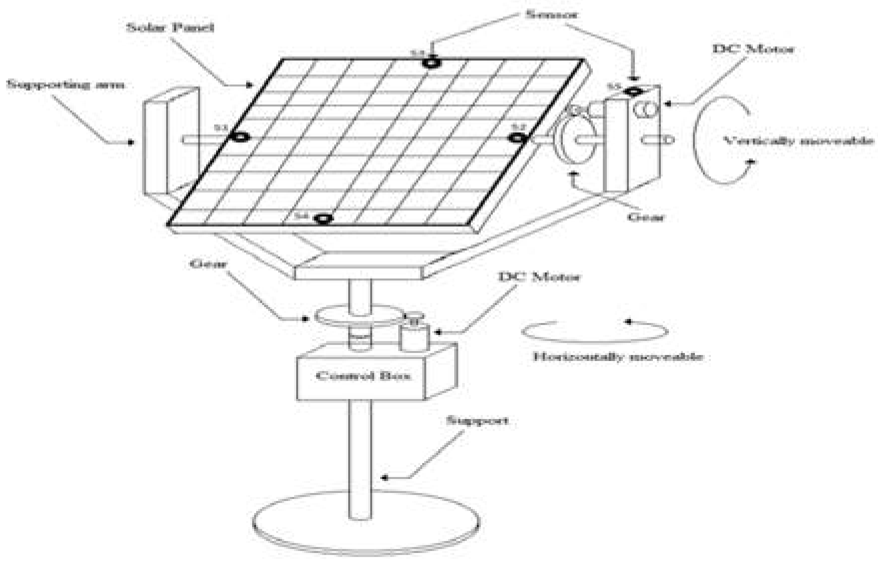

Figure 1.1: Structural view of two ways rotating freedom solar tracker

In the proposed solar tracking system, an effort has been made to develop a solar tracker prototype which is reliable and cost effective unlike above mentioned methods which are susceptible to environmental changes. The solar tracker will consider both normal and cloudy weather condition and will optimise the solar PV panel output in best possible manner, thus enhancing the efficiency.

1.1 Objective of dissertation

It has been estimated that more than 90 percent of solar power plants in India do not have solar tracker installed in them i.e. they have fixed tilt angle. The objective is to build a cost effective and reliable solar tracker. There is huge scope of enhancing the output of the installed solar PV plants by about 25 - 35 percent. Problems with solar tracker are economics and unstable operation in cloudy weather. The proposed solar tracker will try to remove this gap.

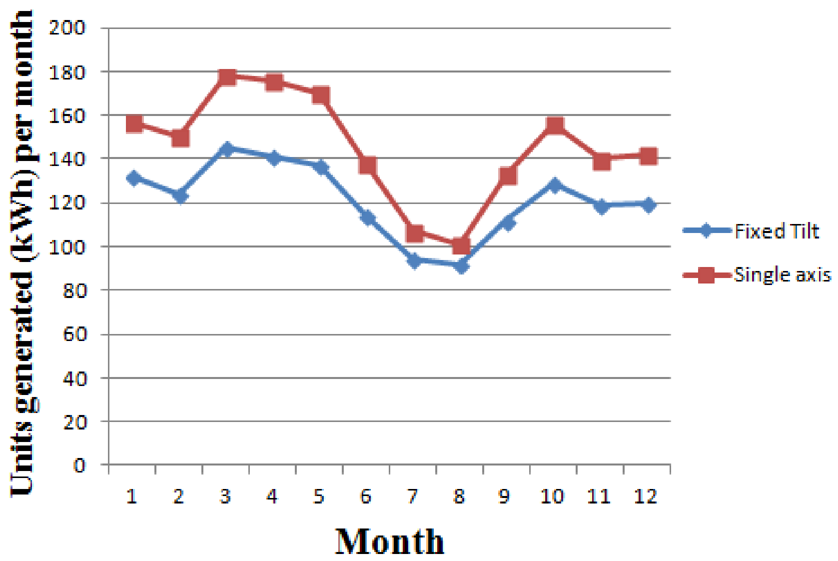

Figure 1.2: Graph of units generated per month by PVWatts solar calculator

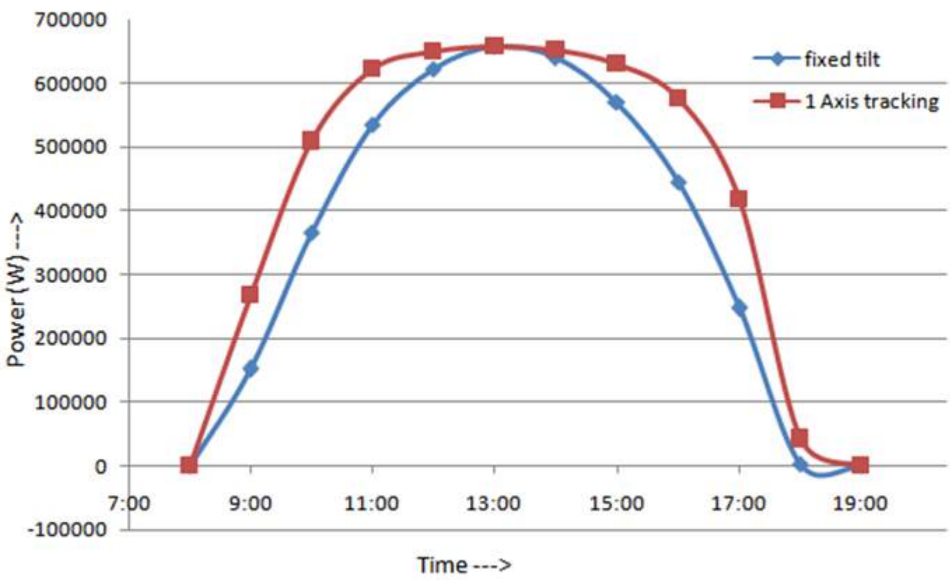

Figure 1.3: Graph of power generated in every hour in a day

1.2 Literature survey

Literature survey included study of published papers, patents and catalogues or brochures of companies for understanding of solar tracking system. There are only 8 indian companies manufacturing solar tracker and only 3 solar power plants with solar trackers installed in India. So the scope of this project is more.

Various published papers and patents were used for theoretical understanding of solar tracker and to study various modes of operation and working of the same. Patents helped in studying different technologies used for design and development of solar tracker.

The list of methodologies adopted by various authors for solar tracker are as follows:

a. SMA material is used for solar PV panel rotation which is a heat responsive element.

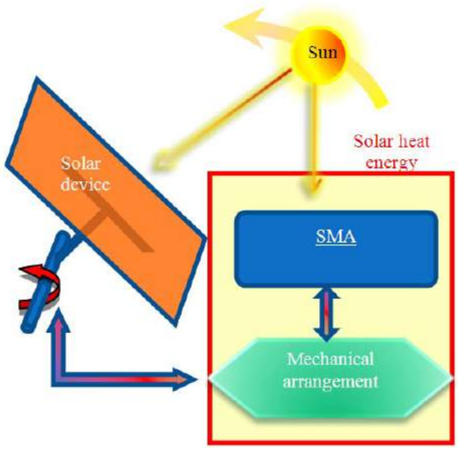

Figure 1.4: Block diagram of solar tracking system using SMA material

Nitinol (SMA material) is a Ni-Ti alloy and is in the form of spring which performs sensing and actuating. Spring is inactive when panel is aligned. When panel is unaligned, spring will get charged by direct sunlight via a focusing lens and will rotate the panel. Lens and panel are on same shaft. When panel is unaligned, rays get focused on SMA spring by lens and it contracts which causes rotation of pulley connected to a wheel by a cable thus making panel to rotate. A stopper is used to stop the rotation. SMA spring actuator can be used as a tension or compression spring. Load is used to bring back spring to normal position during low temperature.2 (Patent: US4628142)

b. The sun light illuminates CdS light sensitive resistor of the solar tracking device. A feedback analog signal will be produced and transformed into a digital signal through an analog to digital converter. When the voltage on the eastward-westward direction or the southward-northward direction is different, the differences will be delivered into the fuzzy controller. The fuzzy controller produces pulses given to motor drivers and the motor drivers produce PWM. Signals are given to control step motors for tuning desired angles. If the differences of sensors are zero, the sun is vertical to the solar panel. So the fuzzy controller will not work or LDR with PIC16F877A microcontroller can be used for sensing and giving signal to stepper motor.3

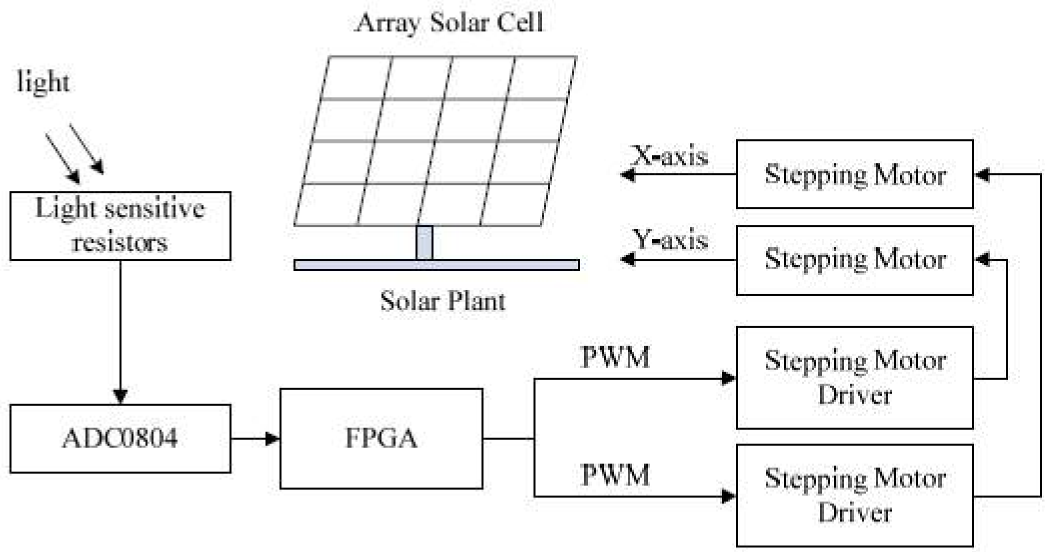

Figure 1.5: Block diagram of solar tracking system using fuzzy logic controller

Merits: No sensors and microcontroller used

Demerit: Unstable during cloudy weather

c. Using capacitors instead of battery to charge the control circuit. Capacitors are charged by solar panel output. Control circuit consists of Microprocessor, GPS, position sensor and motor. 4 (Patent: US20120227729)

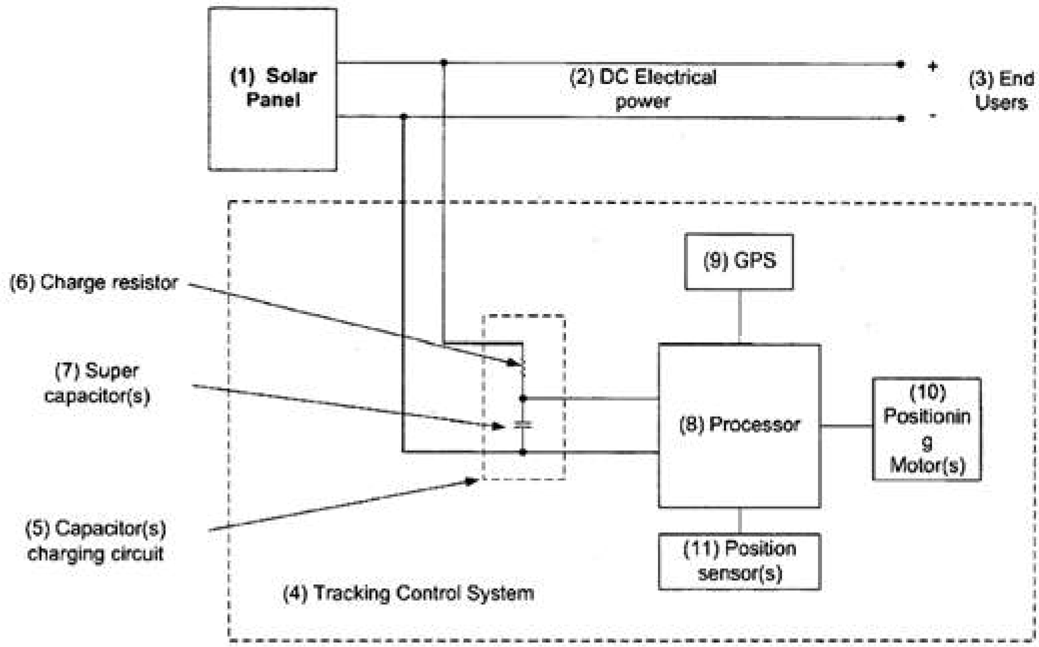

Figure 1.6: Block diagram of solar tracking system using capacitor

In the above Figure 1.6, the output of the solar panel charges the capacitor which gives supply voltage to the processor while discharging. Using GPS and position sensors, the processor gives signal to the positioning motors for rotation of panel in order to track the position of sun.

Merit: reliable

Demerit: costly & complex

d. Consists of a GPS receiver, microprocessor, transmitter, rechargeable batteries and photoelectric cells. GPS receiver will receive tracking data and the microprocessor will process the data into data packet. Transmitter transmits data packet to a remote receiving station for transmission to central base. Photoelectric cells provide power to rechargeable batteries which power components of tracking unit. Transmitter is a cellular telephone with an antenna. Tracking data is transmitted via cellular phone to cellular service provider which sends data over internet to database of a central server computer. This decodes the information & provides interface.

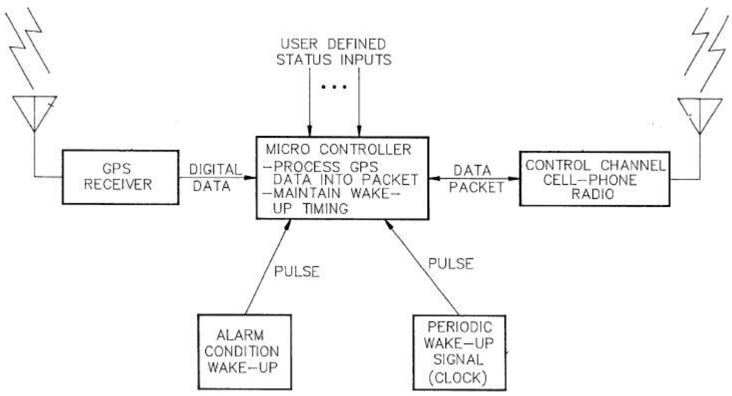

Figure 1.7: Block diagram of solar tracking system using GPS receiver and transmitter

Merit: Very reliable and accurate.

Demerit: Costly

10 (Patent: US6339397)

e. Use of capacitors, solenoid, plunger, LDR, microcontroller. Capacitors get charged by output of solar panel. LDR senses light falling on it. If light is sufficient, solar panel is aligned. If LDR senses less sunlight it switches on a relay which charges capacitors and charges solenoid due to which plunger enters the solenoid and moves the panel. If LDR senses enough light, it opens the relay, supply gets disconnected and plunger comes back to original position. Note that capacitors have to be discharged to charge the solenoid.

f. Patent: US4107521, Solar sensor and tracker apparatus, Gordon Robert Winders, Aug. 15, 1978. 11

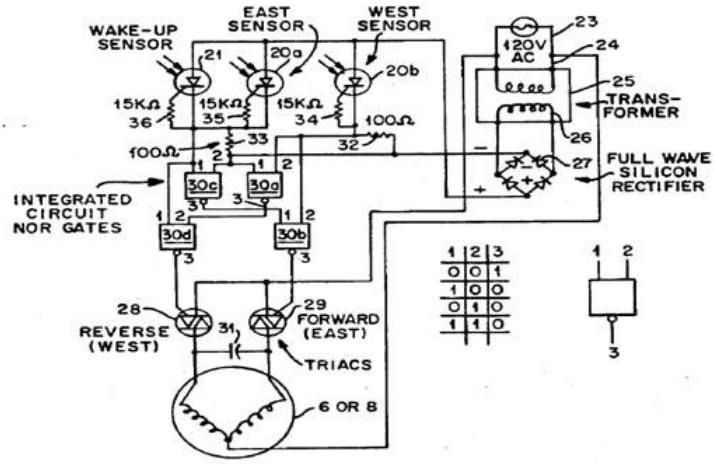

Figure 1.8: Control circuit diagram of solar tracker using gates

Here AC gets converted to DC by rectifier after step down and the supply is given to control circuit. Three sensors are used: wake up, east and west. NOR gates are used for logic comparison and accordingly signal is given to two traics to rotate the motor in corresponding direction.

1.3 Solar Power Fundamentals

Solar panels are formed out of solar cells that are connected in parallel or series. When connected in series, there is an increase in the overall voltage, connected in parallel increases the overall current. Each individual solar cell is typically made out of crystalline silicon, although other types such as ribbon and thin-film silicon are gaining popularity. PV cells consist of layered silicon that is doped with different elements to form a p-n junction. The p-type side will contain extra holes or positive charges. The n-type side will contain extra electrons or negative charges. This difference of charge forms a region that is charge neutral and acts as a sort of barrier. When the p-n junction is exposed to light, photons with the correct frequency will form an extra electron/hole pair. However, since the p-n junction creates a potential difference, the electrons cant jump to the other side only the holes can. Thus, the electrons must exit through the metal connector and flow through the load, to the connector on the other side of the junction.

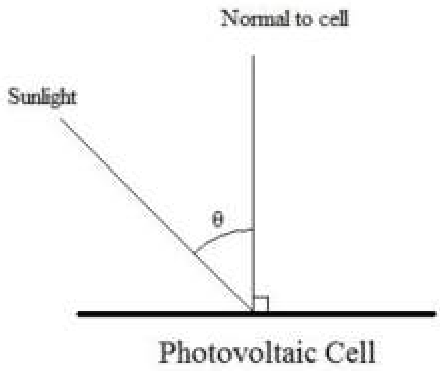

Figure 1.9: Angle of Incidence to Solar Cell

Solar Panels:

An individual PV cell typically produces between 1 and 2 W. A photovoltaic module is a packet of PV cells most of them connected in series and put together on a plate with an aluminum frame. A photovoltaic array is group of modules, generally an even number that is placed in the structure like a block as shown in the figure below:

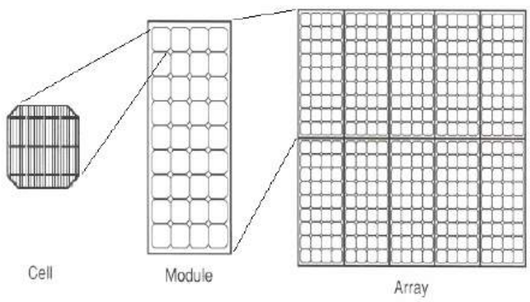

Figure 1.10: Solar PV cells, modules and arrays

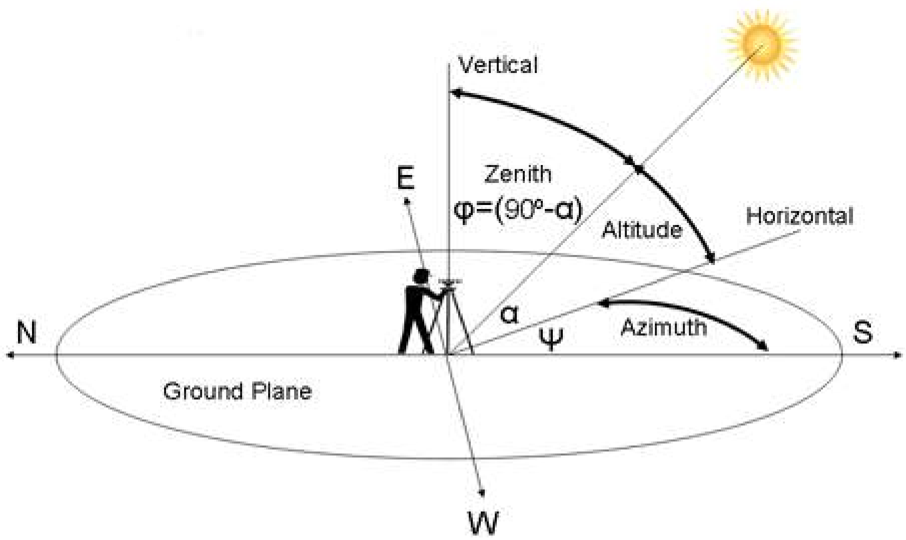

Figure 1.11: Geometric definition of the PV module

a. **Latitude**: The angle above or below the equator. The north pole is at 90 N and the south pole is at 90 S.

b. **Zenith angle**- This is the angle between the line that points to the sun and the vertical. At sunrise and sunset this angle is 90.

c. **Elevation angle/ Solar Altitude Angle** - This is the angle between the line that points to the sun and the horizontal. It is the complement of the zenith angle. At sunrise and sunset this angle is 0.

d. **Azimuth angle**- This is the angle between the line that points to the sun and south. Angles to the east are negative. Angles to the west are positive. This angle is 0 at solar noon. It is probably close to -90 at sunrise and 90 at sunset, depending on the season.

1.4 Definition of solar tracker

Its an apparatus to track the suns position and rotate the panel accordingly to obtain maximum efficiency. A device that orients a payload toward the sun. Payloads can be photovoltaic panels, reflectors, lenses or other optical devices. It consists of a control circuit to control the rotation of the PV panel with the help of a rotating equipment may be motor or any other device. Trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generating capacity. These may be either sensor based or astronomical based. Sensor based tracker will rotate the solar panel by sensing the position of the sun. Astronomical based tracker will rotate the solar panel by fixed degree within fixed interval of time according to earth's rotation.

1.5 Types of solar trackers

Solar tracking systems are of several types and can be classified according to several criteria.

1. **Based on number of rotation axis:**

1.1 **Single axis trackers** : Single axis trackers rotate the PV panel along only one axis.Types of single axis tracker are-

i. **Horizontal single axis tracker (HSAT)**:

Figure 1.12: Linear horizontal axis tracker in South Korea.

The axis of rotation for horizontal single axis tracker is horizontal with respect to the ground.

ii. **Vertical single axis tracker (VSAT)**:

The axis of rotation for vertical single axis trackers is vertical with respect to the ground.

1.2 **Dual axis trackers** : Dual axis trackers rotate PV panel along two axes. Types of dual axis tracker are-

i. **Azimuth altitude dual axis tracker (AADAT)**: An azimuth altitude dual axis tracker has its primary axis vertical to the ground. The secondary

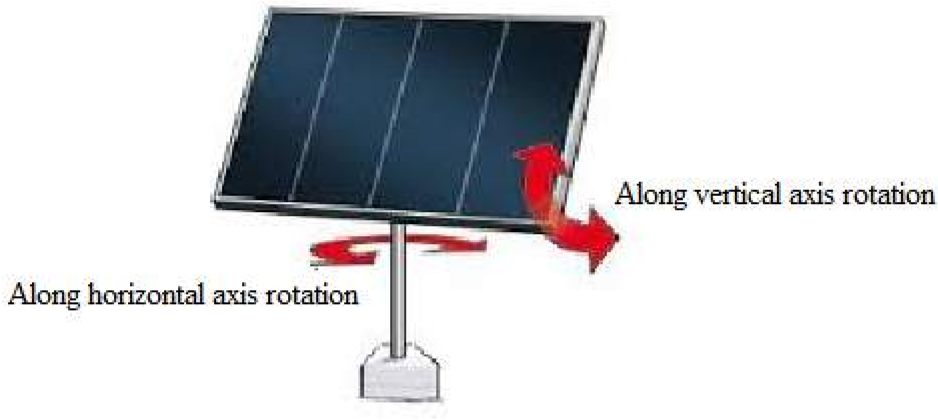

Figure 1.13: A solar tracker showing along horizontal and vertical axis rotation

axis is then typically normal to the primary axis i.e. it rotates both in horizontal and vertical direction.

2. **Based on type of drive system**:

2.1 Active Tracker-

Active trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction.

2.2 Passive Tracker-

Passive trackers use a low boiling point compressed gas fluid that is driven to one side or the other (by solar heat creating gas pressure) to cause the tracker to move in response to an imbalance.

2.3 Chronological tracker-

A chronological tracker counteracts the Earth's rotation by turning at an equal rate as the earth, but in the opposite direction. The drive method may be as simple as a gear motor.

1.6 Proposed solar tracker description

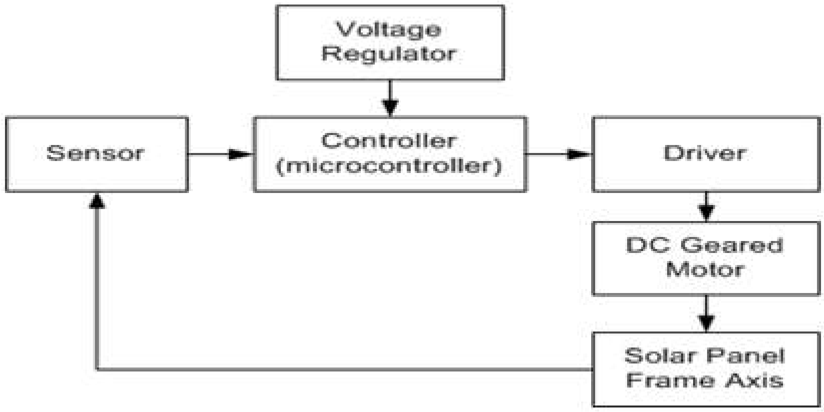

Figure 1.14: Proposed solar tracker overview.

The proposed solar tracker has the following features:

a. It will be horizontal single axis tracker (HSAT) with vertical manual seasonal adjustment by a screw-jack.

b. It will be active in nature with dc gear motor used for solar panel rotation and LDR used as light sensor.

c. During normal weather condition, LDRs will sense the position of sun, and motor will rotate the panel according to the microcontroller logic developed. During noon when output of both LDRs are same, the motor will not rotate and controller will execute no operation. During cloudy weather condition i.e. when output of both LDRs are low, controller will rotate solar module by 15 degrees per hour or by 1 degree per 4 minutes according to earth's rotation irrespective of sun's position to prevent unstable operation of solar module.

Chapter 2

Control System and Simulation

2.1 Basic block diagram of solar tracking system

Description:

Two LDRs are used for sensing solar radiation which will be kept on the solar panel facing east and west side respectively. The output of LDRs are given to two comparators for comparison with a fixed resistor. A capacitor is connected which is charged by solar output. At the output of capacitor, a voltage controlled switch is connected. The voltage controlled switch consists of a voltage comparator with high and low set voltage points and a relay with NO contact. If the capacitor voltage is higher than or equal to the high set voltage in voltage controlled switch, the relay will be in NO position. If the capacitor voltage is less than or equal to the low set voltage, the relay switch will close it's NO contacts. The capacitor will get discharged via a discharging resistor in the latter case. This voltage will be compared with a fixed reference set according to ideal voltage output of solar PV panel. The output of comparators will be then given to motor driver circuit to drive the dc motor.

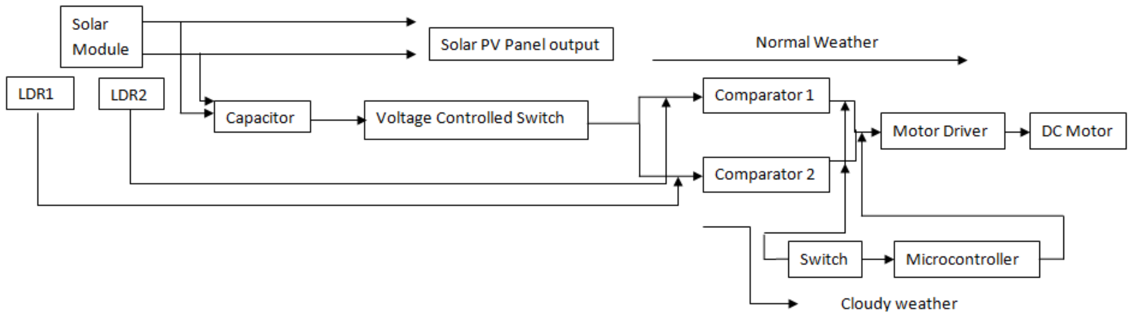

Figure 2.1: Basic block diagram of solar tracking system

Demerits:

a. Voltage controlled switch is redundant - Comparison of LDR output and set voltage in voltage controlled circuit was taking place and also comparison between LDR output and reference set voltage was taking place in comparator circuit. So two times comparison was being done which made the existence of voltage controlled switch redundant.

b. The output of comparator circuit was low both in case of maximum and minimum intensity. So it was difficult for microcontroller to know when to respond.

c. Complex circuit

2.2 Proposed control system block diagram

Description:

Two LDRs are placed on solar PV panel which are used for sensing. The control logic is developed in PIC18F4550 microcontroller. The output of these LDRs are compared with a fixed reference voltage. The output of these comparators are given to XOR gate and NAND gate. When the logic of XOR gate output is 1 and that

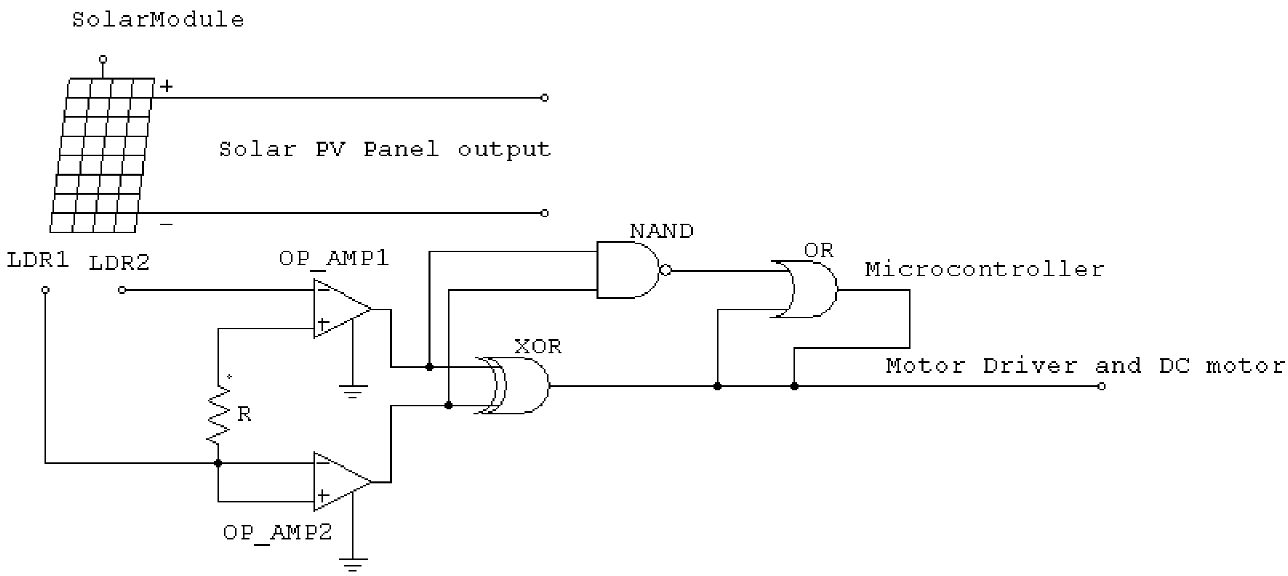

Figure 2.2: Proposed control system block diagram

of OR gate output is 1, on the basis of XOR gate output, PIC controller will give supply to motor driver circuit which will drive the DC gear motor and rotate PV panel according to position of sun during normal weather. When output of XOR gate is 0 and that of OR gate is 1, motor driver IC will not get supply and motor will not rotate the solar module which implies its noon time and both LDRs are recieving same sunlight. During cloudy weather condition, output of XOR gate will be 0 and that of OR gate will be 0. During this, the controller will rotate solar module by 15 degrees per hour or 1 degree per 4 minutes (earth rotates 360 degree on its axis in 24 hours) irrespective of sun's position to prevent unstable operation of panel.

Merits:

a. Less complex circuitry: PIC microcontroller utilises logic control which makes the circuit less complex.

b. Will work both in bright and cloudy weather: In normal weather condition, motor will rotate panel according to output sensed by LDRs and in cloudy weather condition controller will make panel rotate by fixed degree within fixed interval of time. So this circuit is more reliable than previous circuit.

c. Due to the logic developed in PIC microcontroller using gates, the control circuit is different than the usual control circuits used for solar tracker.

2.3 Truth Table

As shown below in the truth table, during normal weather condition, the output logic of XOR gate will be 1 otherwise 0. Logic 1 will make motor driver circuit acitve thus rotating the panel. During cloudy weather condition output logic of OR gate will be 0 otherwise 1. Logic 0 which will make the microcontroller active and will drive the motor.

Table I: Truth Table of Control Circuit

LDR1	LDR2	Fixed Reference	Opamp 1	Opamp 2	XOR	NAND	OR
0	0	1	1	1	0	0	0
0	1	1	1	0	1	1	1
1	0	1	0	1	1	1	1
1	1	1	0	0	0	1	1

2.4 Control Circuit Diagram of Active Solar Tracker

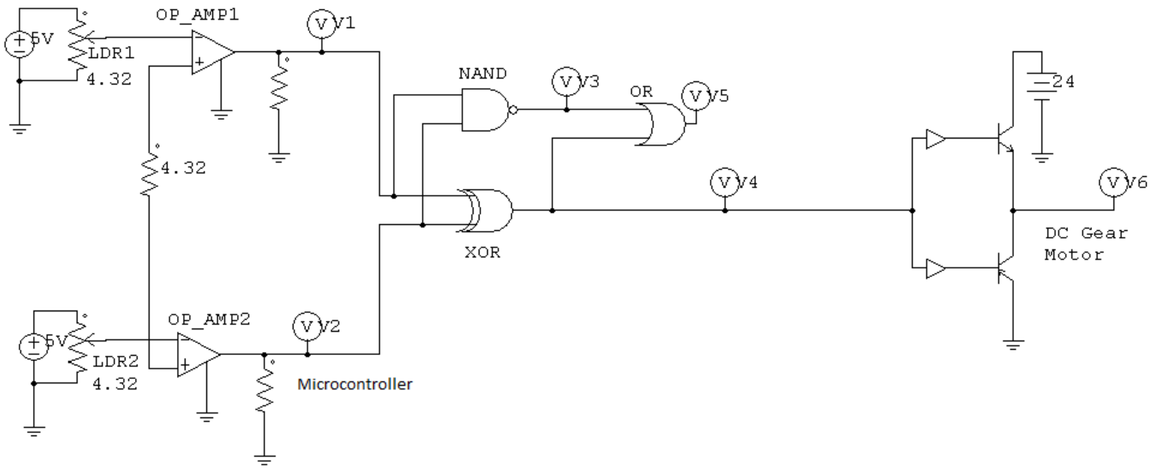

Figure 2.3: Simulation of control circuit diagram of solar tracker in PSim

Explaination:

1. The control circuit diagram of active solar tracker is designed and simulated in PSim as shown above.

2. The output voltages of both LDRs are given to PIC microcontroller as input.

3. This voltage is compared by a fixed reference voltage within the controller.

4. The output of comparators are given to XOR gate which supplies voltage to push pull transistors, one n-p-n and other p-n-p.

5. Motor is connected at voltage probe V6. Output of op-amps is also given to NAND gate.

6. Output of NAND gate and XOR gate is given to OR gate as an input.

7. Output of OR gate and XOR gate will determine the motor rotation.

8. If the logic of XOR gate is high and OR gate output is high, this indicates normal weather.

9. If the logic of XOR gate is low and OR gate output is high, this indicates noon time.

10. If the logic of XOR gate is low and OR gate output is low, this indicates cloudy weather.

Table II: Operation of push-pull transistor in control circuit of solar tracker

Output logic of XOR gate	**Output logic of OR gate**	**NPN Transistor**	**PNP Transistor**	**Remarks**
1	1	ON	OFF	Normal weather
0	1	OFF	OFF	Panel wont rotate as it is noon i.e. 12pm and LDRs receive same insolation
0	0	ON	ON	Cloudy weather

2.5 Simulated Results

The results obtained while doing simulation of control circuit in PSim are shown below. The results are for 4 cases.

Case 1: LDR1 receives maximum insolation and LDR2 receives minimum insolation.

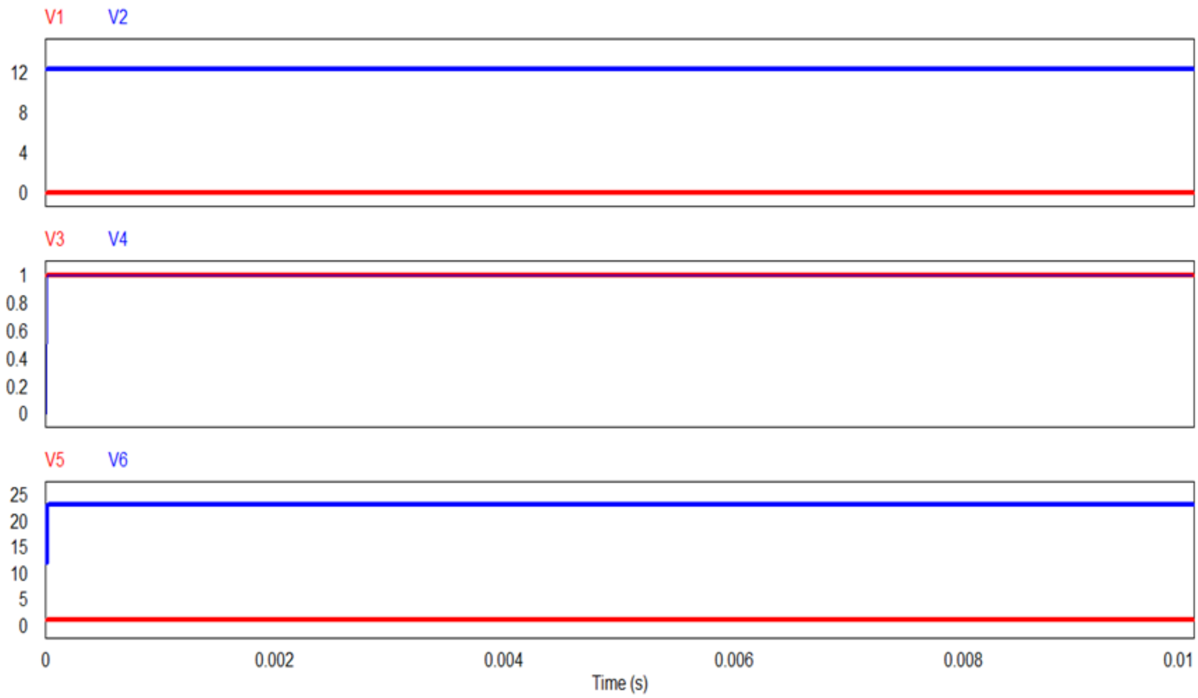

Figure 2.4: LDR1 receives maximum sunlight & LDR2 receives minimum sunlight

Where,

V1=Output voltage of opamp 1

V2=Output voltage of opamp 2

V3=Output of NAND gate

V4=Output of XOR gate

V5=Output of OR gate or input logic to microcontroller

V6=Motor input

In this case, since LDR1 is receiving maximum intensity of light and LDR2 is receiving minimum intensity of light, output of XOR gate is high which will give supply to motor driver circuit to drive the dc motor. Logic of OR gate is high.

Case 2: LDR2 receives maximum insolation and LDR1 receives minimum insolation.

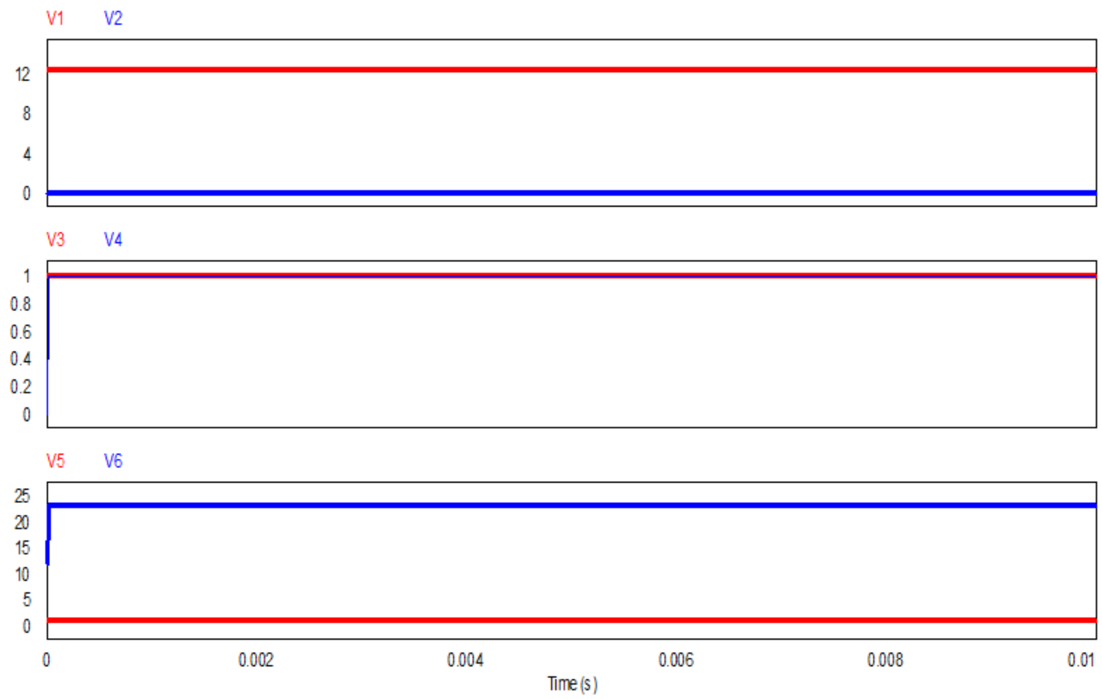

Figure 2.5: LDR1 receives minimum sunlight & LDR2 receives maximum sunlight

In this case, since LDR1 is receiving minimum intensity of light and LDR2 is receiving maximum intensity of light, output of XOR gate and OR gate is high. With this logic, the supply voltage will be given to the motor and motor will rotate the panel in anti-clockwise direction in order to track the position of sun.

Case 3: Both LDR1 and LDR2 receive same amount of insolation i.e. at noon time.

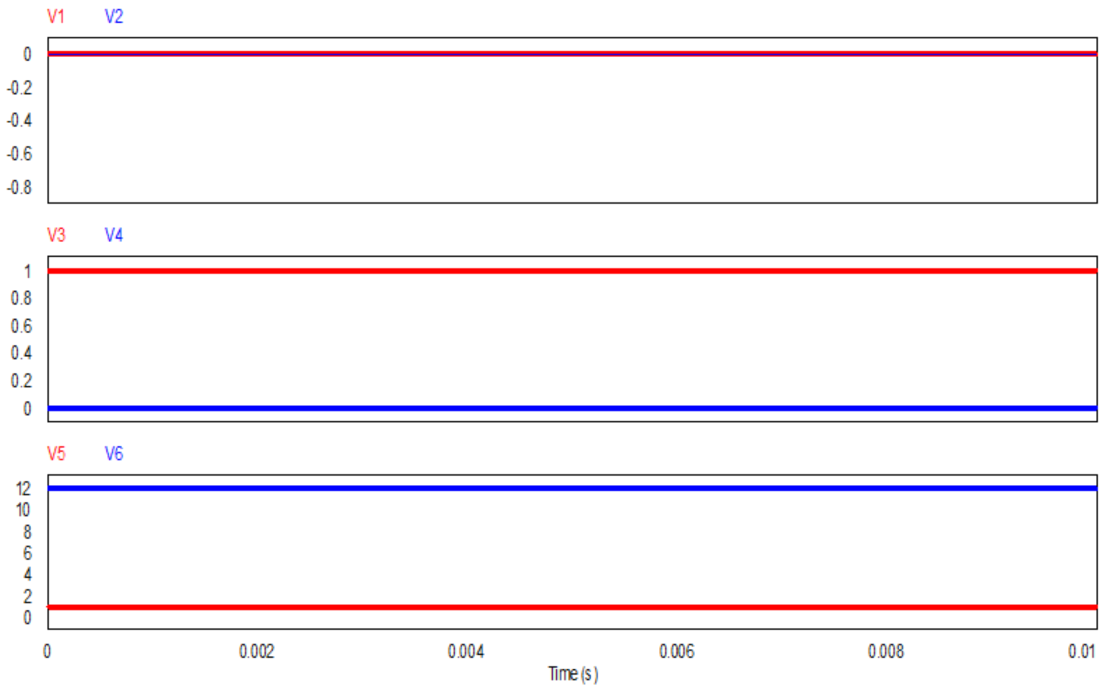

Figure 2.6: Both LDRs receive equal amount of sunlight

In this case, both LDRs are getting same intensity of light, which indicates its 12 pm i.e. noon. Logic output of XOR gate is low and OR gate is high. So solar PV panel won't rotate as optimization of solar PV output is obtained.

Case 4: Both LDR1 and LDR2 receive minimum insolation i.e. during cloudy weather condition.

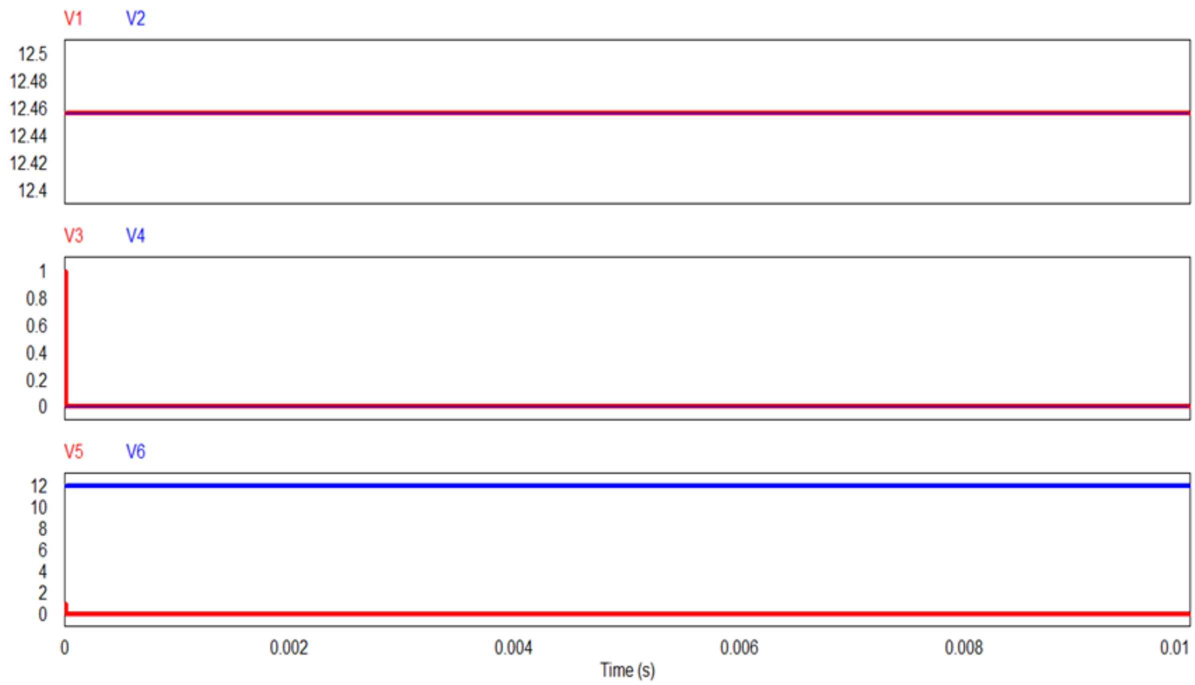

Figure 2.7: Both LDRs receive minimum sunlight (cloudy weather)

In this case, both LDRs are receiving minimum intensity of light. This indicates its cloudy weather. Also we can see that the logic output of OR gate in low and that of XOR gate in also low. The microcontroller will start rotating solar PV panel by fixed degrees within fixed interval of time irrespective of LDR output to prevent unstable operation during cloudy weather condition.

2.6 Comparison of Theoretical and Simulated Results

Table III: Comparison table of simulated and theoretical results

Voltage (V)	Theoretical results (V)	Simulated results (V)	Remarks
V1	0	0	**Since LDRs and reference are at same potential, output is 0**
V2	12	12	**Output is positive and is 12V as reference more than LDR2 output**
V3	1	1	**NAND output**
V4	1	1	**DC motor ON**
V5	1	1	**Normal weather**
V6	24	24	**Motor input**

The above table shows that the simulated and theoretical results are same. Thus this control circuit will be suitable for the proposed solar tracker.

Chapter 3

DC Gearmotor Calculation

A DC motor is a mechanically commutated electric motor powered from direct current. The dc motor has a stationary stator (field) winding and rotating rotor (armature) winding. The interaction of two magnetic fields produced by stationary permanent magnet on stator and current flowing in motor coil on rotor produces mechanical power. Torque is produced by the principle that any current carrying conductor placed within an external magnetic field experiences a force known as Lorentz force 14. A gearmotor consists of an electric motor and gear reduction box (gearbox). Types of gearmotors include stepper gearmotor, brushless gearmotor, dc gearmotor and ac gearmotor. Hear a dc gear motor will be used for solar module rotation.

3.1 Definition of gears

Gears are toothed members which transmit power or motion between two shafts by meshing without any slip. In any pair of gears, the smaller one is called pinion and the larger one is called gear. When pinion is the driver, it results in step down drive in which the output speed decreases and the torque increases. When the gear is the driver, it results in step up drive in which the output speed increases and the torque decreases. High gear ratios allow for more output torque and lower speeds, while lower gear ratios allow for higher output speed and less output torque. 15

3.2 Gearbox and types of gears

A gearbox is a mechanical device used to increase the output torque or change the speed of motor. The motors shaft is attached to one end of the gearbox and through the internal configuration of the gearbox, provides a given output torque and speed determined by the gear ratio. The types of gears are as follows 13:

a. **Spur Gears:** Spur gears have their teeth parallel to the axis. They are used for transmitting power between two parallel shafts. They are used in high speed and high load application.

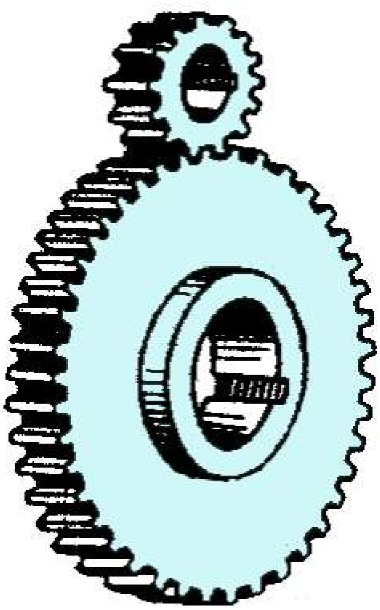

Figure 3.1: Spur Gear

Applications: Speed control, power plants.

Advantages: cost effective, high gear ratios available, compact, high torque output.

Disadvantages: Noisy, prone to wear and tear.

b. Helical Gears: Helical gears are used for parallel shaft drives. They have teeth inclined to the axis. Their efficiency is slightly lower than spur gears. The helix angle also introduces axial thrust on the shaft. Double helical gears have opposing helical teeth. Two axial thrusts oppose each other and nullify. Hence the shaft is free from any axial force. Though their load capacity is very high, manufacturing difficulty makes them costlier than single helical gear.

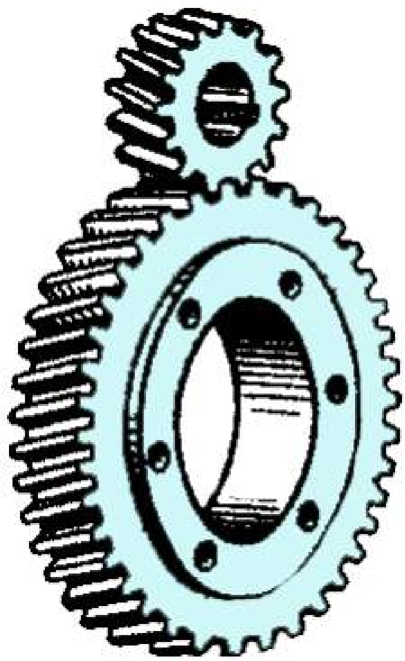

Figure 3.2: Helical Gear

Applications: Cement mills, crushers, oil industry, blowers, and elevators.

Advantages: Smooth and quiet operation, has high load capacity.

Disadvantages: costly, much lubrication requires, subjected to thrust along axis of gear.

c. **Bevel Gears:** There are two types of bevel gears: straight and spiral teeth gears. Bevel gears have straight and tapered teeth and are used for slow speed applications. Straight bevel gears are used for transmitting power between intersecting shafts i.e. these are right angle drives.

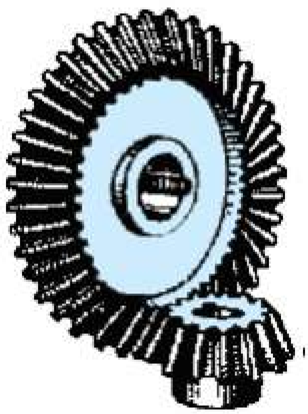

Figure 3.3: Straight Bevel Gear

Spiral bevel gears have curved teeth and are used for high speed applications. Spiral bevel gears are also used for transmitting power between intersecting shafts. Because of the spiral tooth, the contact length is more. They operate smoother than straight bevel gears and have higher load capacity. But, their efficiency is slightly lower than straight bevel gear.

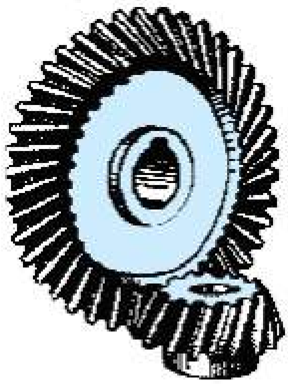

Figure 3.4: Spiral Bevel Gear

Applications: print press, power plants, automobiles, drives, steel plant.

Advantages: right angle configuration and durable.

Disadvantages: poorly cut teeth may result in vibration and noise during operation.

d. Worm Gears: Worm and worm gear pair consists of a worm, which is very similar to a screw and a worm gear, which is a helical gear. Worm gears are used for transmitting power between two non-parallel shafts. High gear ratios of 200:1 can be got. These are right angle drives. Efficiency of these gears is low anywhere from 90 percent to 40 percent. The drives are very compact. The worm gear increases torque and reduces speed. The output shaft is at a 90-degree angle to the input shaft. Direction of rotation can be reversed, but the gear cannot drive the worm.

Figure 3.5: Worm Gear

Applications: mining, rolling mills, elevators, escalator drive system, for intermittent duty cycle application.

Advantages: low noise, maintenance free, inherent locking system.

Disadvantages: low efficiency, gear cannot drive the worm .

Gearbox Control:

The ratio and size of the drive are determined by the output torque, the output speed and load.

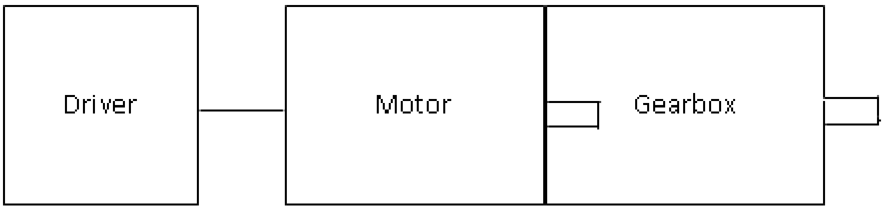

Figure 3.6: Driver, Motor and Gearbox assembly

The output of the motor is used as an input of the gearbox. When the driver is powered, the motor will be turned on as a result output shaft of the gearbox will rotate. The output speed and torque is dependent on the internal configuration of the gearbox.

3.3 Sizing Calculation

Sizing calculation of DC worm gearmotor for 300W capacity

Dimensions of 300W capacity solar module: 2m x 1m x 0.05m

Supply voltage: 24 V

Weight to be rotated = 26 kg

1. **Force required = mass x gravitational acceleration**

$$F = m * g = 26 * 9.81 = 255N \tag{3.1}$$

Since the solar module will be resting on a structure and the weight of the module resides at the module's centre of gravity, the force required to rotate the solar module will be half of the calculated force.

$$Force = 128N \tag{3.2}$$

2. **Torque required = force x distance**

The solar panel will be rotated along its length. Therefore, the distance in the torque calculation is half of the panel length.

$$T = f * d = 128 * 0.5 * 2 = 128Nm \tag{3.3}$$

3. **Input and output speed assumption**

3.1 Input speed (N1)= 50rpm

3.2 Output speed (N2) = 0.25rpm

4. **Gear ratio**

$$= \frac{Inputspeed}{outputspeed} = \frac{50}{0.25} = 200 : 1 \tag{3.4}$$

5. Output power = torque x output speed

$$Po = \frac{T * N_2 * 2 * 3.14}{60} = \frac{128 * 0.25 * 2 * 3.14}{60} = 6W \tag{3.5}$$

6. Efficiency

$$= 74 - (0.66 * (Gearratio)) = 74 - (0.66 * \frac{1}{200}) = 0.74 \tag{3.6}$$

7. Input power

$$= \frac{Outputpower}{efficiency} = \frac{7}{0.74} = 10W \tag{3.7}$$

Chapter 4

PIC Microcontroller

4.1 Introduction

PIC is a family of Harvard architecture microcontrollers made by microchip technology with built-in RAM, memory, internal bus, and peripherals that can be used for many applications. It is derived from the PIC1640 originally developed by general instruments microelectronics division. The name PIC initially referred to Programmable interface controller, but shortly thereafter was renamed as programmable intelligent computer. PIC is popular due to their low cost, wide availability, large user base, availability of low cost or free development tools and serial programming (and re-programming with flash memory) capability. It has Reduced Instruction Set Computer (RISC) i.e. only 37 instructions to remember. 18

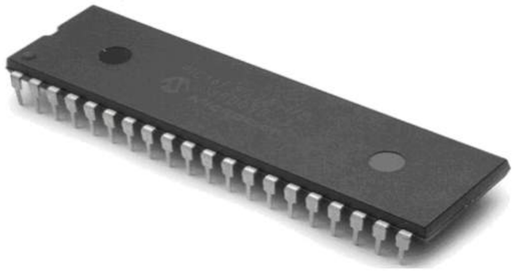

Figure 4.1: PIC18F4550 IC Diagram

The PIC18F4550 features 256 bytes of EEPROM data memory, self programming, an ICD, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM functions. All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications 19.

Harvard architecture:

PIC18F4550 microcontroller uses Harvard architecture as shown below:

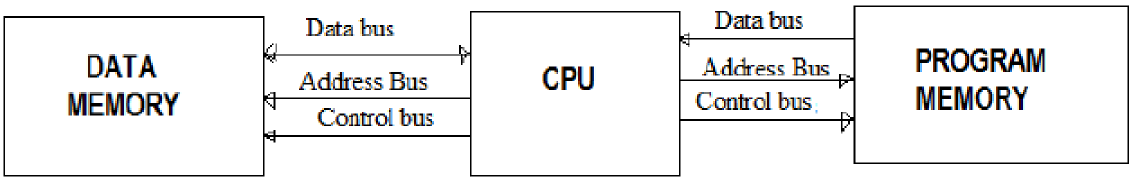

Figure 4.2: Harvard architecture

The data bus and address bus are separate. A greater flow of data is possible through the CPU and a greater speed of work. With Harvard architecture, the instruction is fetched in a single instruction cycle (14-bits). While the program memory is being accessed, the data memory is on an independent bus and can be read and written. These separated buses allow one instruction to execute while the next instruction is fetched resulting in double execution speed.

4.2 Flowchart of PIC Microcontroller Programming

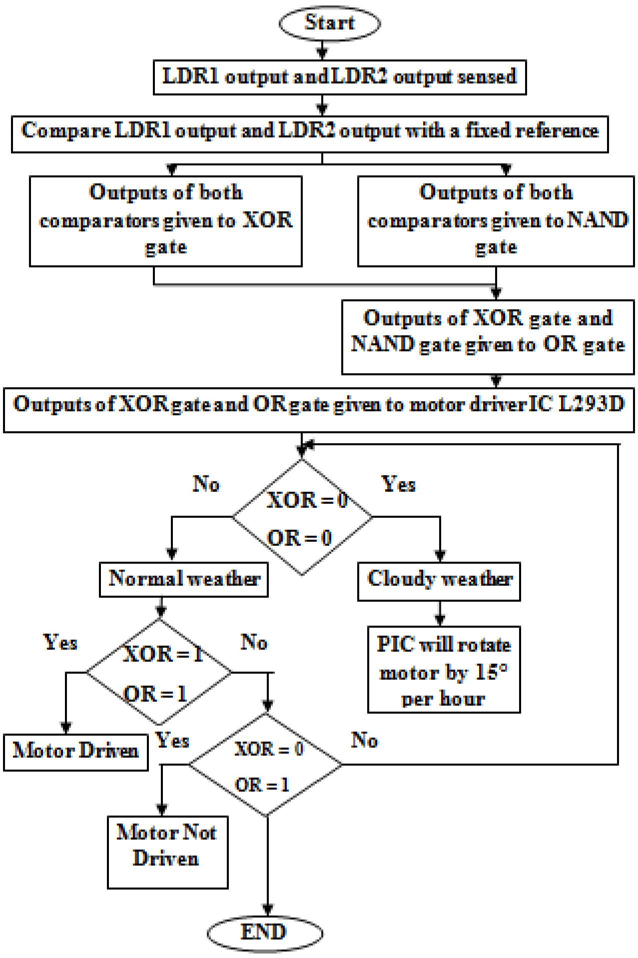

Figure 4.3: Flowchart of PIC microcontroller programming

4.3 Simulation of Hardware Circuit

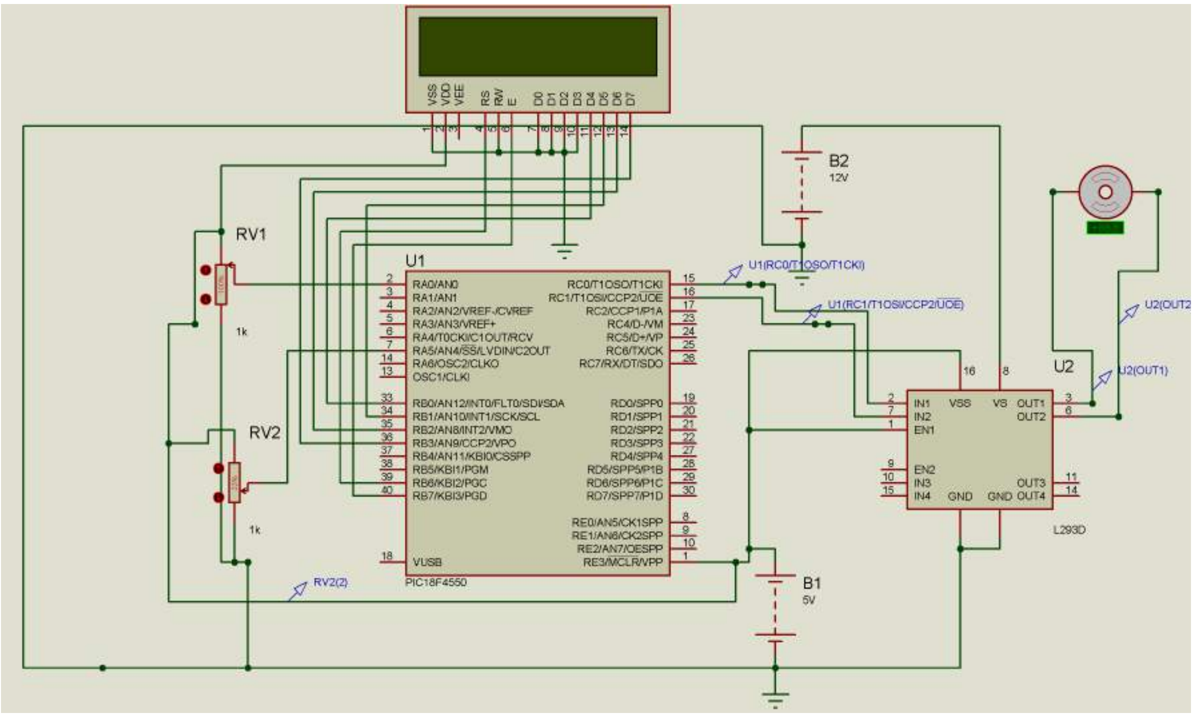

Figure 4.4: Interfacing diagram of PIC18F4550 with DC gear motor

In Figure 4.4, PIC18F4550 is supplied with 5V at pin 1. PORTA of controller will receive LDR outputs. PORTC pins which are output pins of PIC, are connected to input pins of L293D which is the motor driver IC. The enable pin of L293D is connected to same supply as that of PIC i.e. 5V. The Vs pin of L293D is supplied with 24 V which is the supply voltage of DC gear motor. The two output pins of L293D IC are connected to two leads of DC gear motor.

Case 1: LDR1 receives more insolation than LDR2

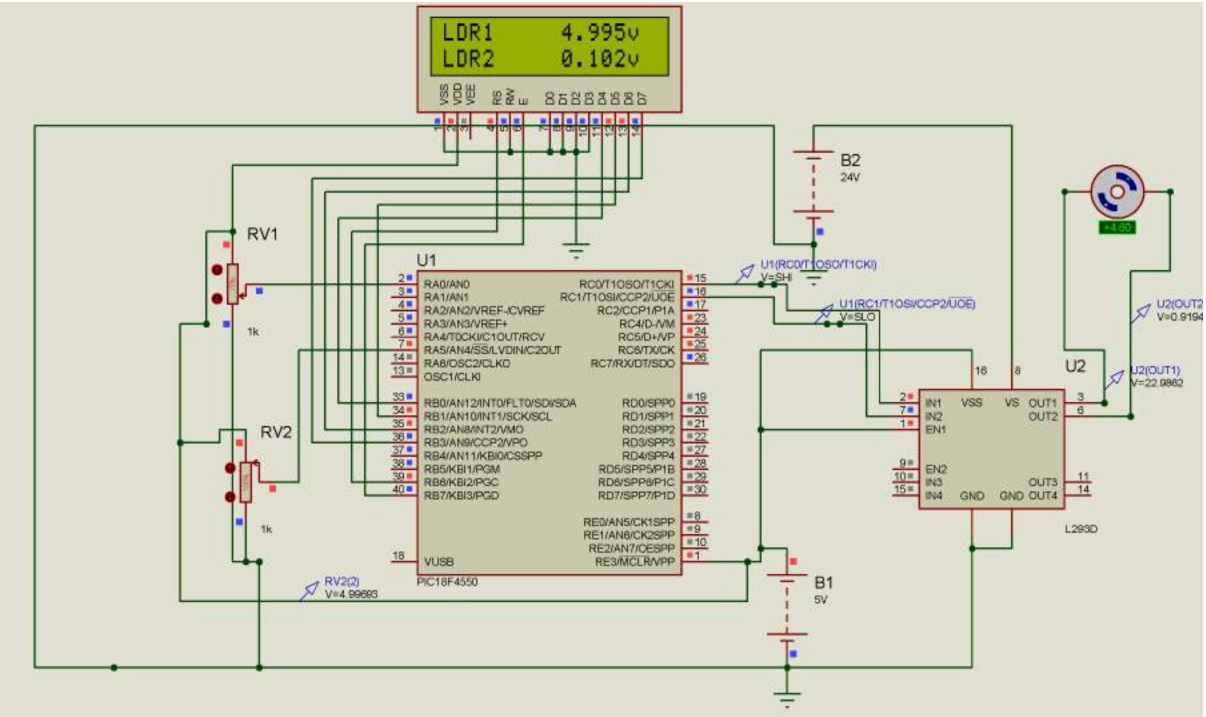

Figure 4.5: Simulation in Proteus software for Case 1

In Figure 4.5, LDR1 receives more insolation than LDR2 as seen on the LCD. This will create a logic of 1 and 0 which will be given to motor driver IC L293D. This will provide the DC motor with the required supply voltage. This will lead to rotation of dc motor in clockwise direction form east to west in order to track the position of sun as shown in the figure.

Case 2: LDR2 receives more insolation than LDR1

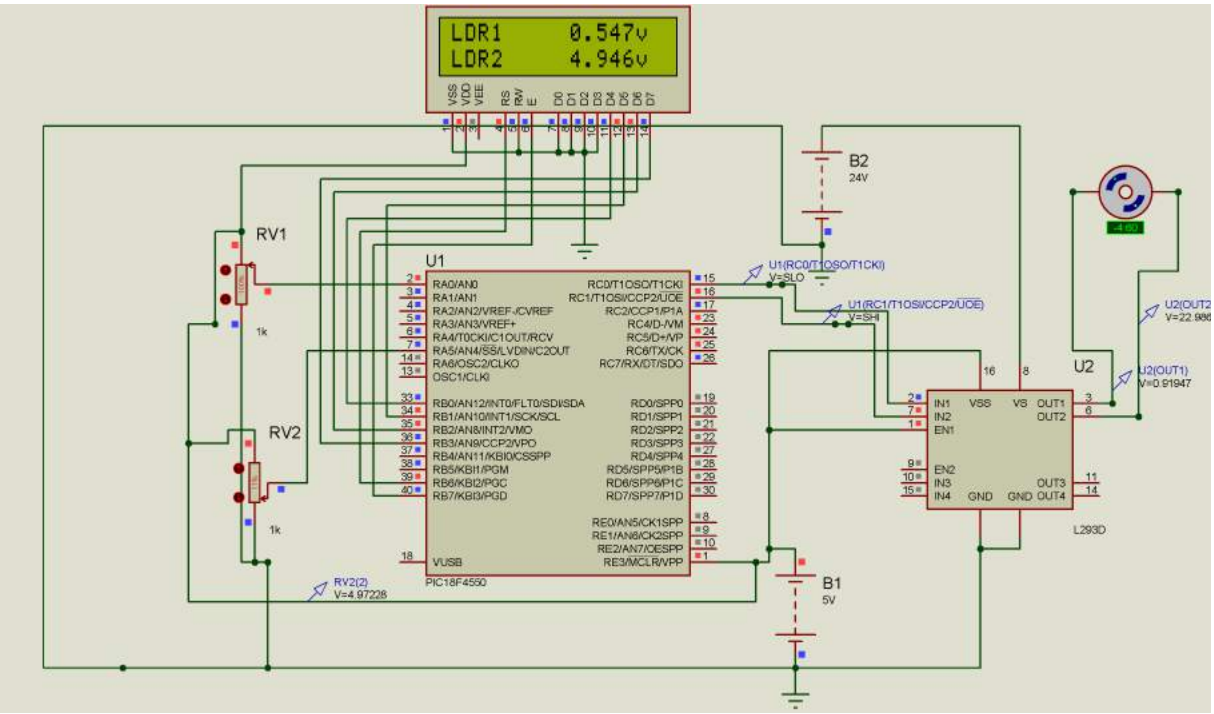

Figure 4.6: Simulation in Proteus software for Case 2

In Figure 4.6, LDR2 receives more insolation than LDR1 as seen on the LCD. This will create a logic of 1 and 0 which will be given to motor driver IC L293D. This will provide the DC motor with the required supply voltage. This will lead to rotation of dc motor in anti-clockwise direction form west to east in order to track the position of sun as shown in the figure.

Case 3: Both LDRs are receiving same insolation (noon)

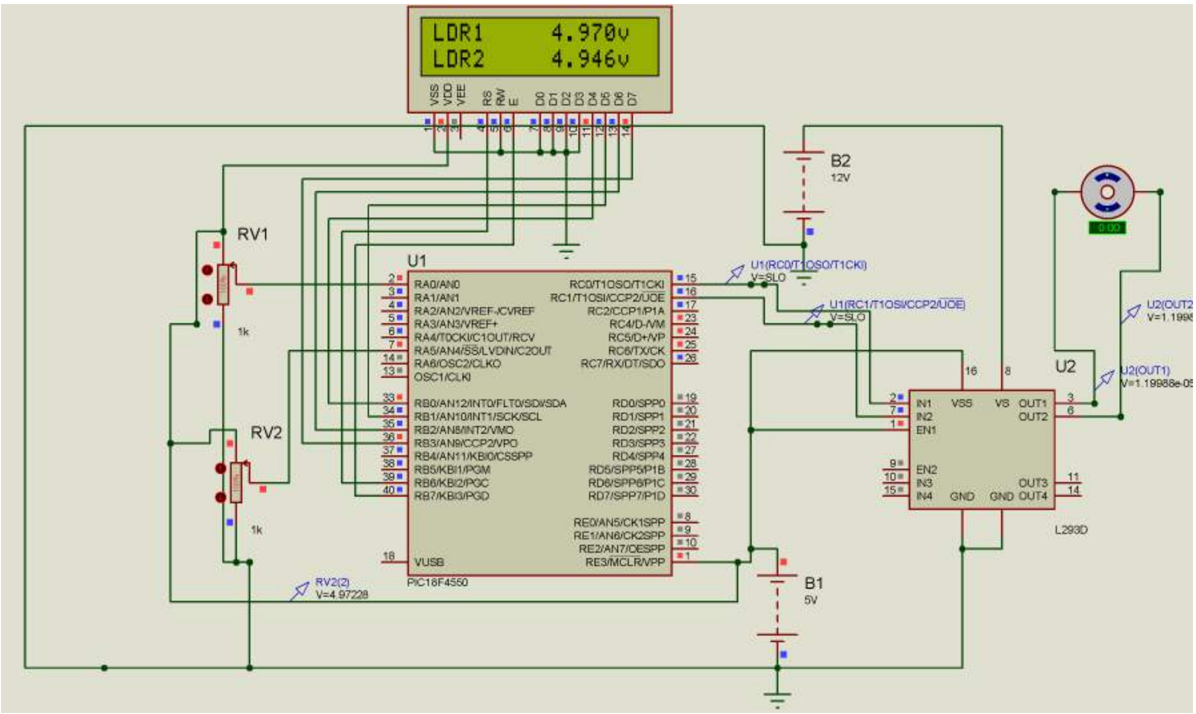

Figure 4.7: Simulation in Proteus software for Case 3

In Figure, 4.7, both LDRs receive same insolation as it is noon time. This will create a logic of 0 and 0 which will be given to motor driver IC L293D. This will not rotate the motor as optimization of solar PV panel output is obtained.

Chapter 5

Maximum Power Point Tracking

5.1 Introduction to MPPT

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from solar panels. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed using the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power. For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. The power delivered from or to a device is optimized where the derivative dI/dV of the I-V curve is equal and opposite the I/V ratio where dP/dV=0. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

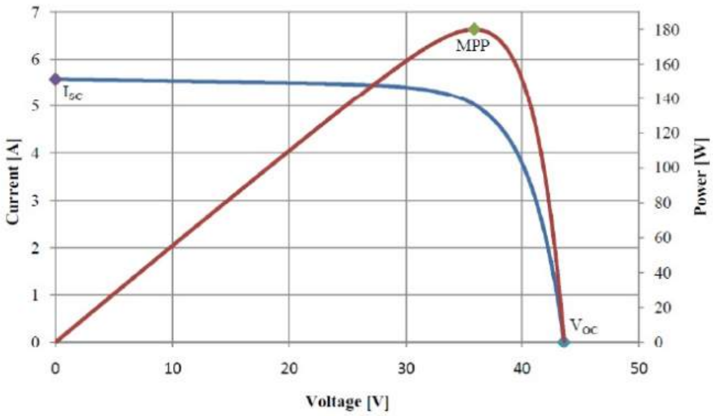

Figure 5.1: Solar cell I-V curve

The figure below is a block diagram of tracking system using MPPT controller.

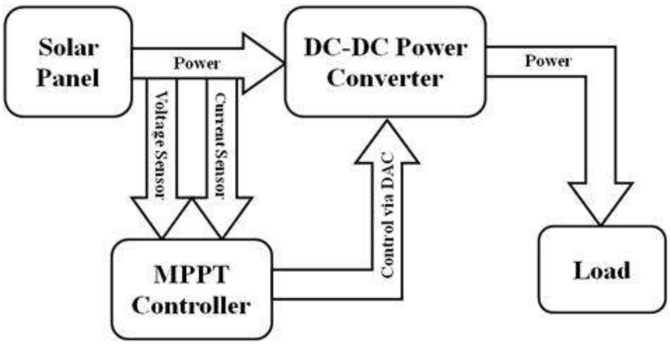

Figure 5.2: MPPT Block Diagram

Maximum Power Point Tracking makes use of output voltage and output current from the solar panel to generate a reference voltage which is fed to DC-DC converter. This voltage is supplied to load or grid connected inverter. A load with resistance R=V/I equal to the reciprocal of this value draws the maximum power from the device. This is called the characteristic resistance of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be.

5.2 Classification of MPPT techniques

Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

1. **Perturb and observe:** In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This method can result in oscillations of power output. It is referred to as a hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point.

2. **Incremental conductance:** The controller measures incremental changes in array current and voltage to predict the effect of a voltage change. This method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV). The incremental conductance method computes the maximum power point by comparison of the incremental conductance (I / V) to the array conductance (I / V). When these two are the same (I / V = I / V), the output voltage is the MPP voltage. The controller maintains this voltage until the irradiation changes and the process is repeated.

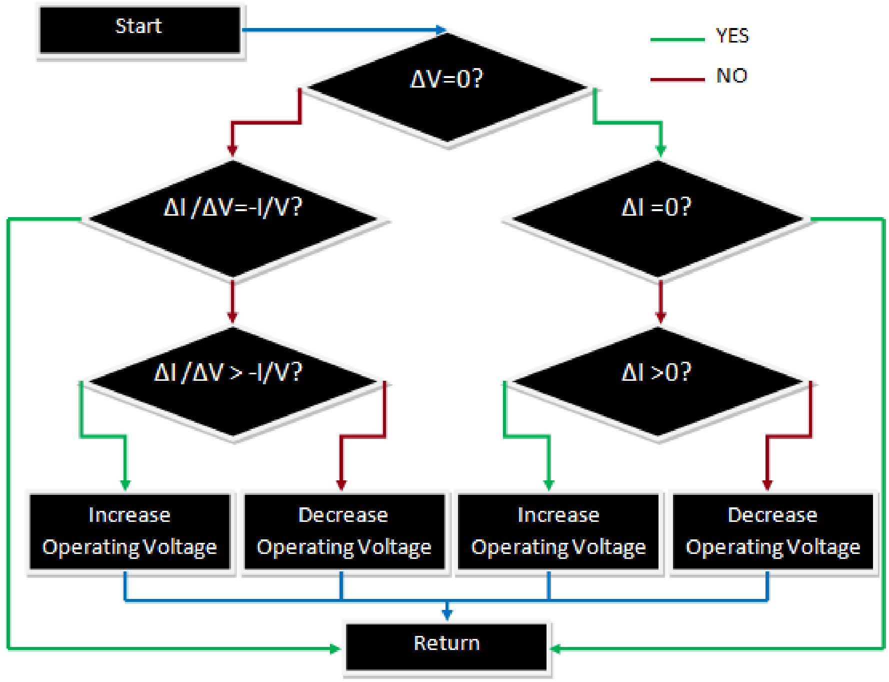

Figure 5.3: Flowchart of Incremental conductance method

3. **Current Sweep Method:** The current sweep method uses a sweep waveform for the PV array current such that the I-V characteristic of the PV array is obtained and updated at fixed time intervals. The maximum power point voltage can then be computed from the characteristic curve at the same intervals.

5.3 MPPT versus Solar tracking system

Solar trackers make use of mechanical movement of solar panel for optimization of solar panel output. Solar tracking system controls the panel output current to obtain the same. Maximum power point tracker makes use of an algorithm for optimum conversion of solar to electrical energy. This tracker controls the panel output voltage to obtain the same.

Solar tracking system will make the sunlight fall perpendicular to the panel surface so that maximum power is generated whereas MPPT controller will generate a reference voltage using the algorithm to produce maximum voltage.

The disadvantage of MPPT appears when the MPPT is not properly tuned. In this instance the MPPT is slow. The MPPT can also be confused by a rapidly changing operating point. Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows through all panels in the string. Because different panels have different IV curves and different MPPs (due to manufacturing tolerance, partial shading etc.) this will make some panels performe below their MPP, resulting in the loss of energy.

5.4 Simulation based on MPPT

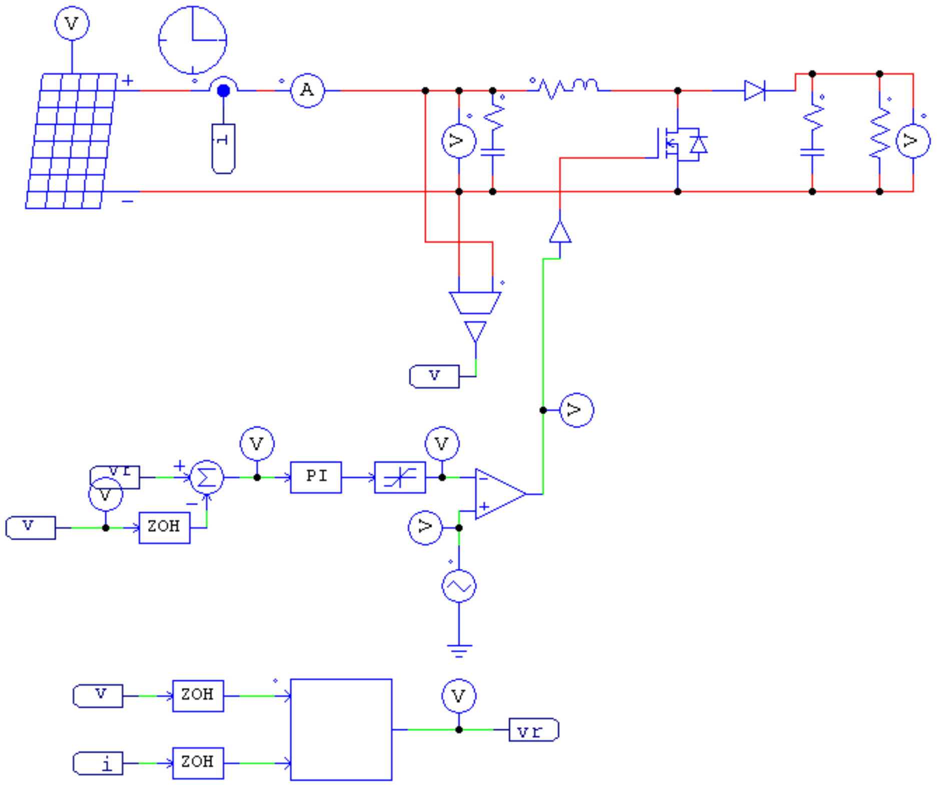

Figure 5.4: Simulation based on MPPT

Panel rating= 300W

Voc= 45V

Isc= 8.9A

Vmax= 36V

Imax= 8.33V

In Figure 5.3, the solar panel output voltage and current is sampled and fed as an input to the algorithm generated. With this a reference voltage is produced. In the closed loop feedback system, an error voltage signal is generated using the reference voltage Vref and actual panel voltage. This error signal is fed to PI controller to nullify the error which in turn is compared with a traingular carrier waveform. With this, gate pulses are generated. These gate pulses are fed to the IGBT used as a switch in the boost converter. We obtain final output voltage at the load side. Thus the load will always get optimum voltage with the help of MPPT algorithm generated.

Simulation results:

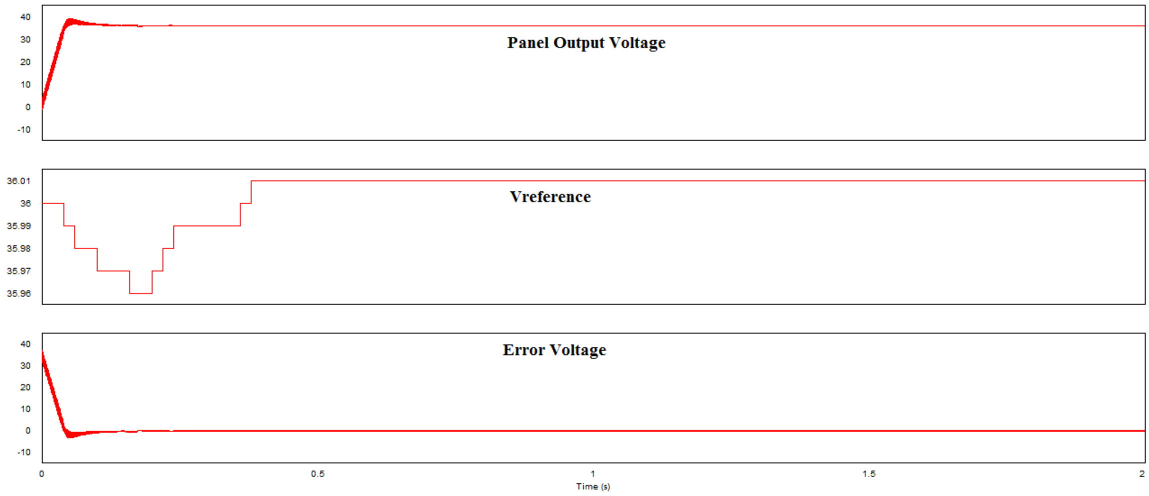

Figure 5.5: Panel voltage, reference voltage, error voltage

Figure 5.4 shows the waveforms of actual panel output voltage, reference voltage generated with the help of the algorithm and the error voltage signal generated respectively.

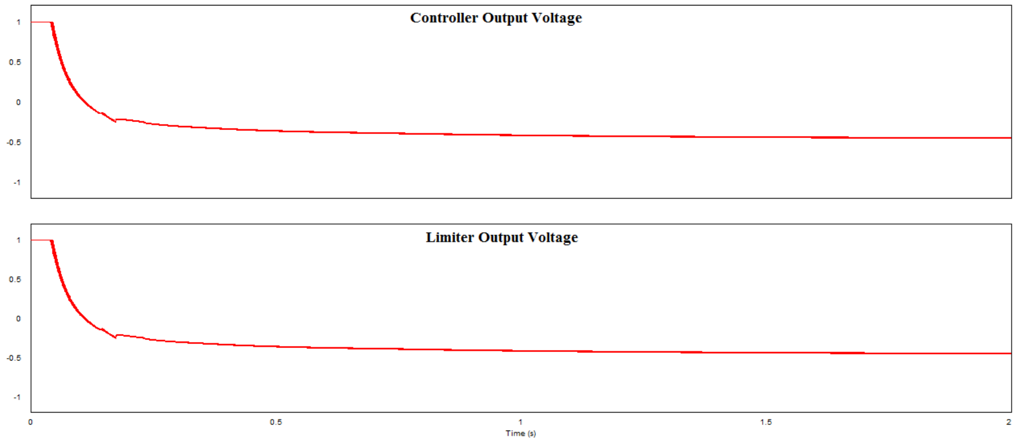

Figure 5.6: Controller and limiter voltage waveforms

Figure 5.5 shows the waveforms of controller output voltage and limiter voltage respectively. Since the controller voltage is between -1 and 1 which is the limit set in the limiter, both controller and limiter voltages are same.

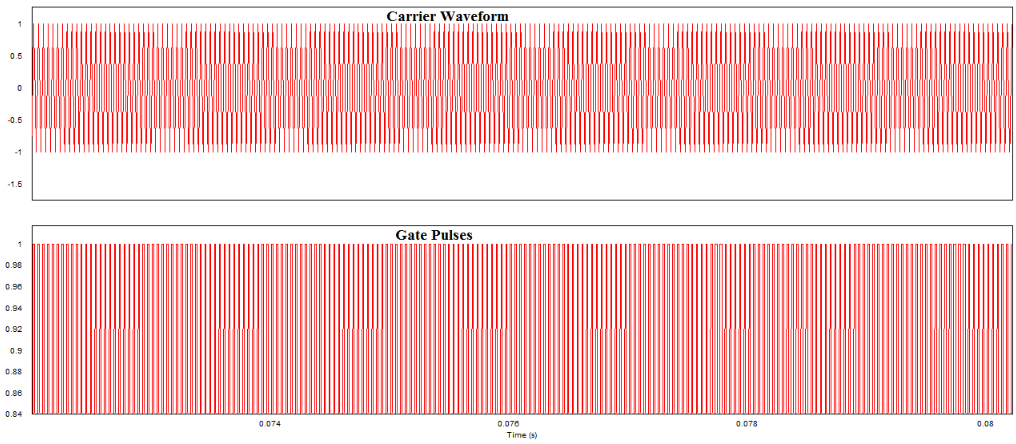

Figure 5.7: Carrier waveform and gate pulses

In Figure 5.6, first waveform shows the carrier waveform. Second waveform shows the gate pulses given to the IGBT which are continuous in nature.

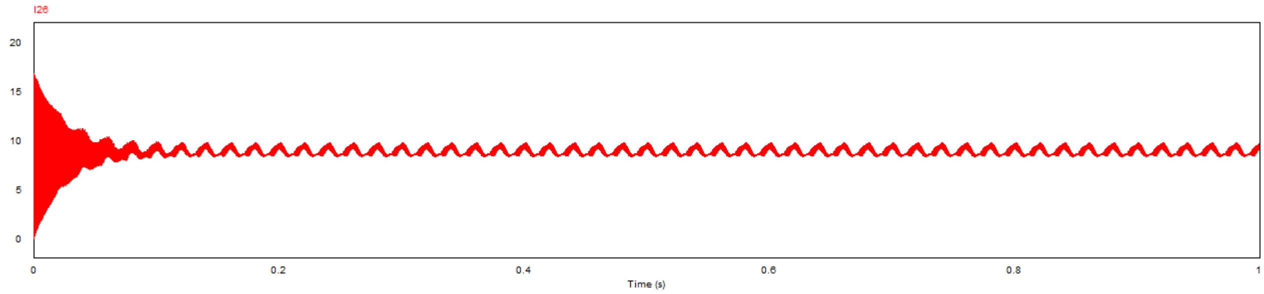

Figure 5.8: Inductor current

Figure 5.7 denotes the inductor current of the boost converter.

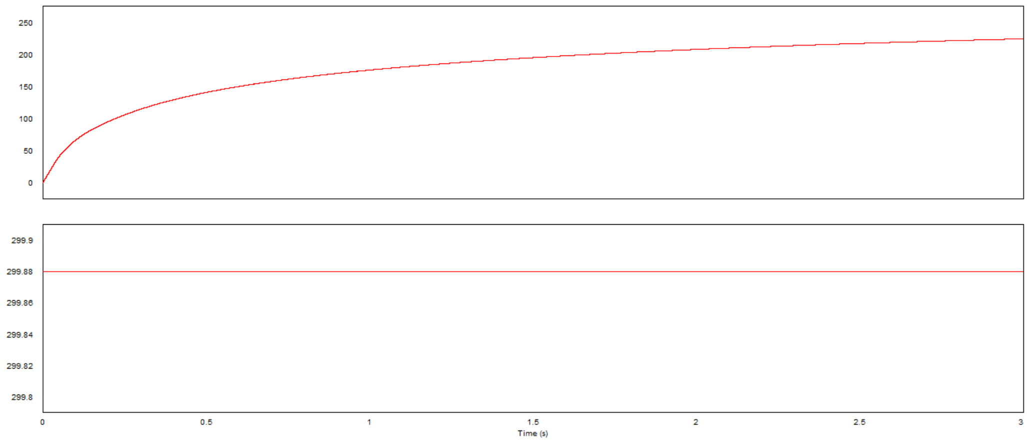

Figure 5.9: Boost output and maximum power

Figure 5.8 shows the boost output voltage waveform which is nearly 230V and waveform below shows the maximum power generated by the solar panel which is 300W.

5.5 Simulation based on MPPT with Grid connected Inverter

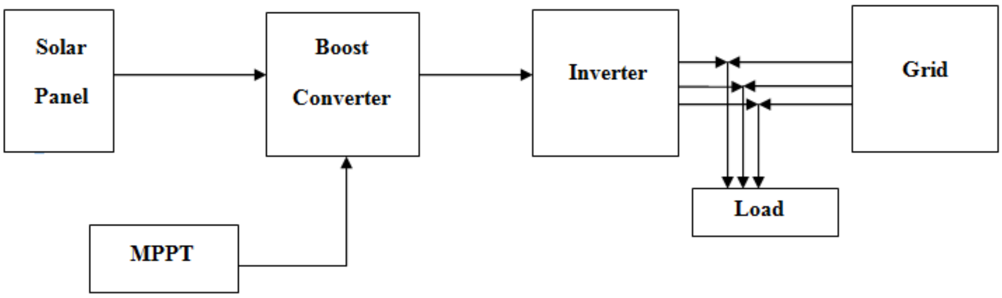

Figure 5.10: Block diagram of MPPT with Grid connected Inverter

Figure 5.9 shows the block diagram of MPPT with grid connected Inverter. The solar panel output voltage is boosted with the help of boost converter and converted to AC with the help of 3 phase unipolar PWM inverter. This supplies current to the load as per its requirement and excess current required by the load is supplied by grid.

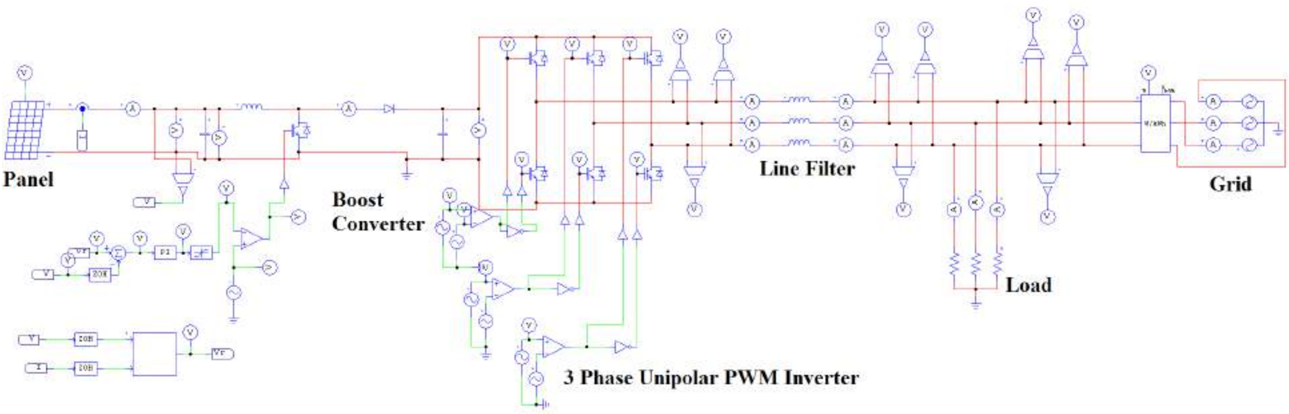

Figure 5.11: Simulation based on MPPT with Grid connected Inverter

In above Figure 5.10, the solar panel output is sensed and a reference is generated using mppt algorithm. The gate pulses to the IGBT of boost converter are given accordingly to obtain optimum output always. The boost output voltage is given as an input to 3 phase unipolar PWM inverter. The inverter output is given to line filter for smoothening of the waveforms. This AC output is given to the load as per the requirement. Here R load has been used for simulation. If the value of resistance is less, more current will flow through it and if the inverter cannot fulfil the requirement, excess current will be supplied by grid.

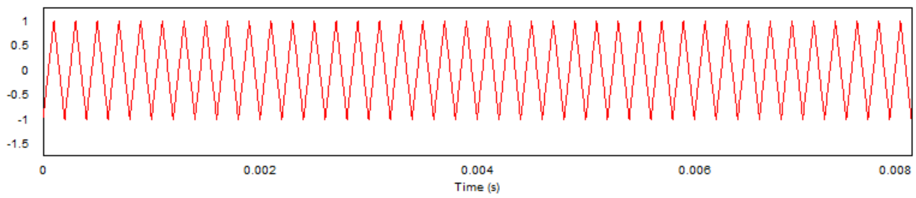

Figure 5.12: Inverter carrier waveform

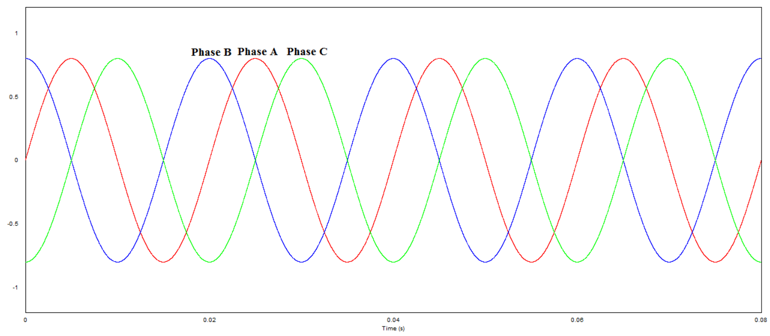

Figure 5.13: Inverter 3 phases fundamental waveforms

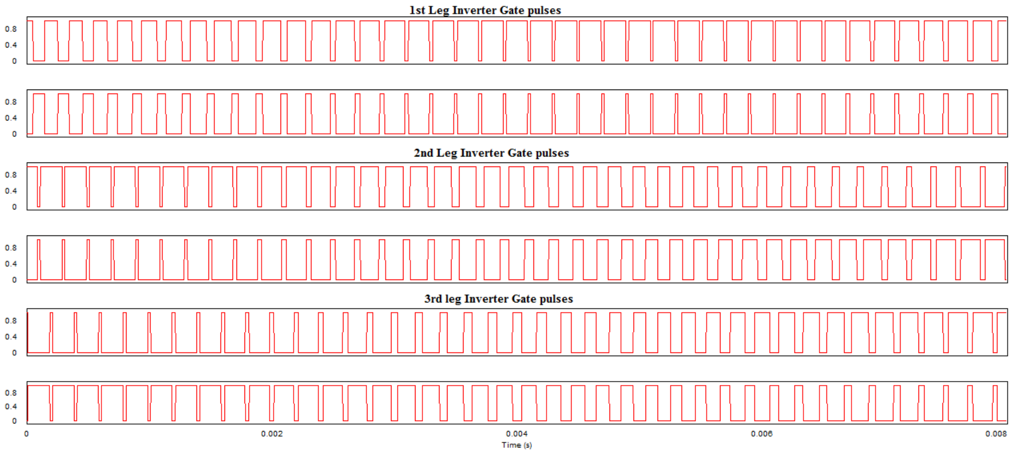

Figure 5.14: Inverter gate pulses

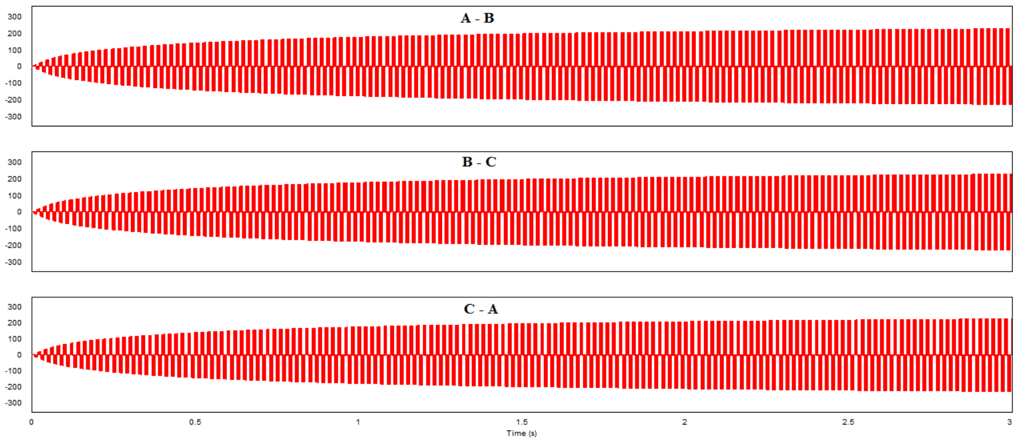

Figure 5.15: 3 phase unipolar PWM Inverter output

The above Figures 5.13 and 5.14 show the 3 legs gate pulses given to each IGBT and 3 phase unipolar PWM inverter output voltage waveforms respectively.

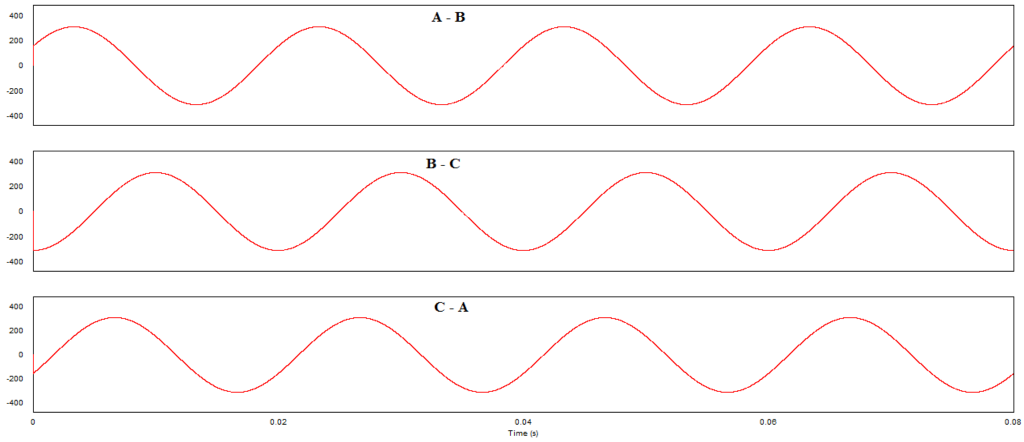

Figure 5.16: 3 phase unipolar PWM Inverter output voltage after line filter

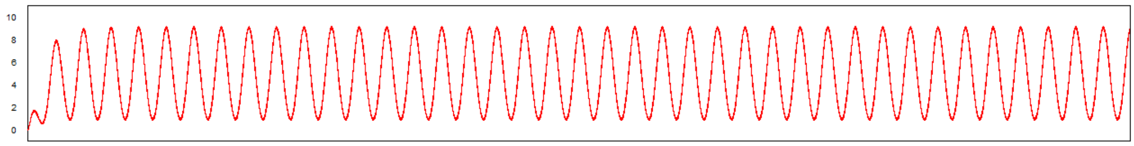

Figure 5.17: 3 phase unipolar PWM Inverter output current after line filter

The above Figures 5.15 and 5.16 show the inverter output voltages and current after the line filter.

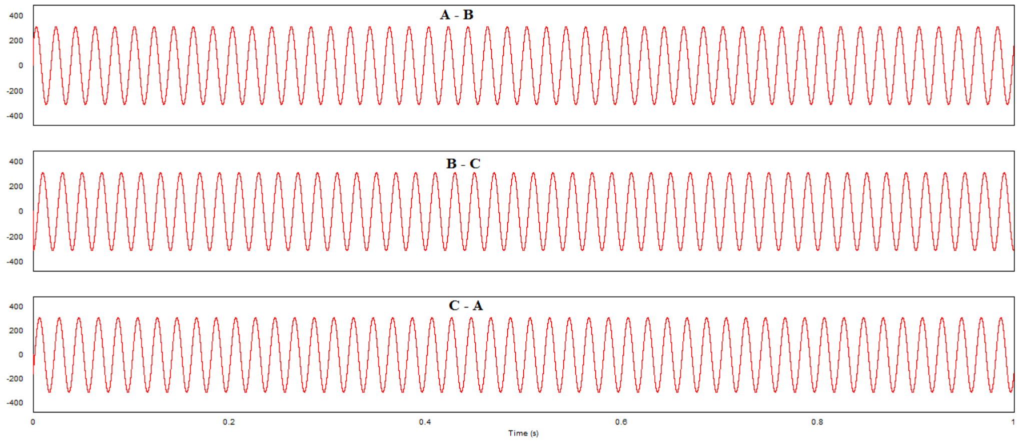

Figure 5.18: Grid Voltage

In the above Figure 5.17, we can observe that the grid voltage is 230V. The grid current will vary according to the load requirement.

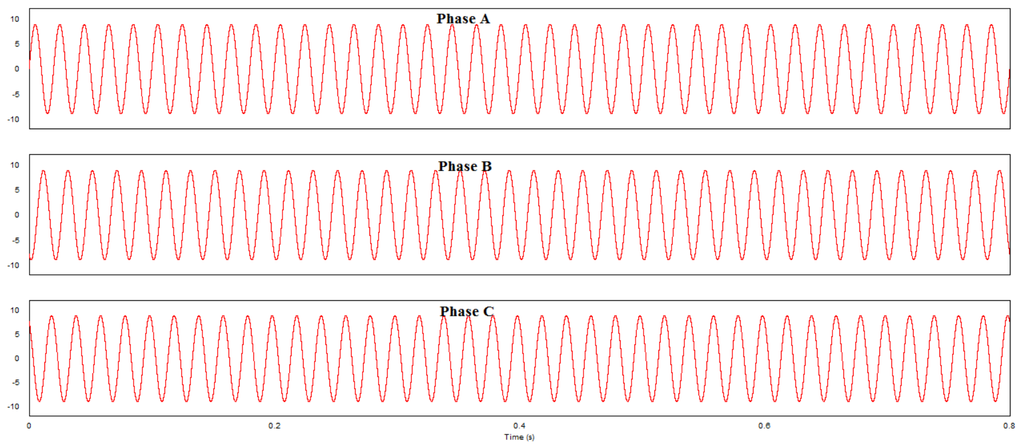

Figure 5.19: Load current for a load resistance of 25 ohms

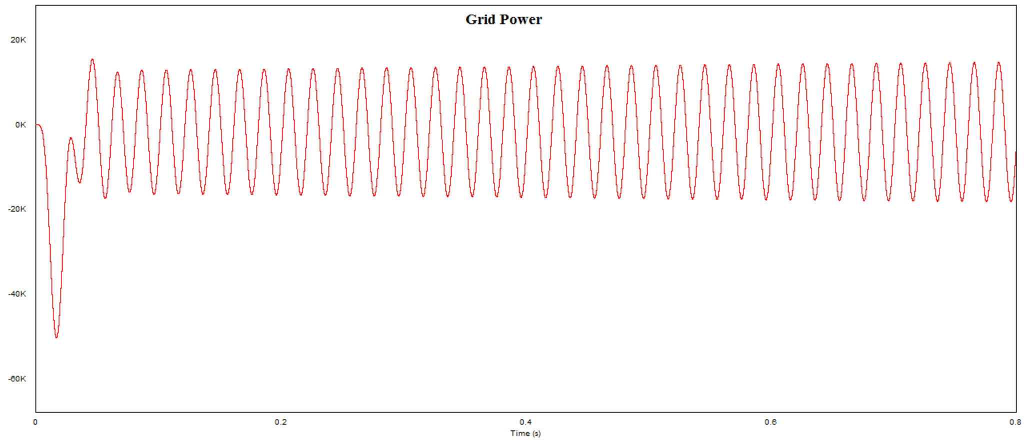

Figure 5.20: Grid power for a load resistance of 25 ohms

The Figure 5.18 and Figure 5.19 show the load current and grid power waveforms for a load resistance of 25 ohms respectively. Here we can observe that the grid power is alternating and positive. This implies that the power is flowing towards the grid as the inverter output is sufficient enough to take care of the load requirement which is 25 ohms.

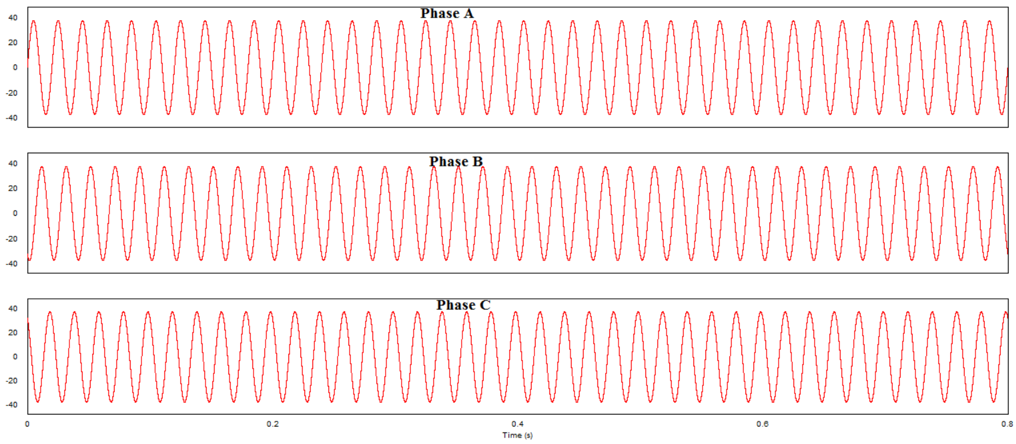

Figure 5.21: Load current for a load resistance of 5 ohms

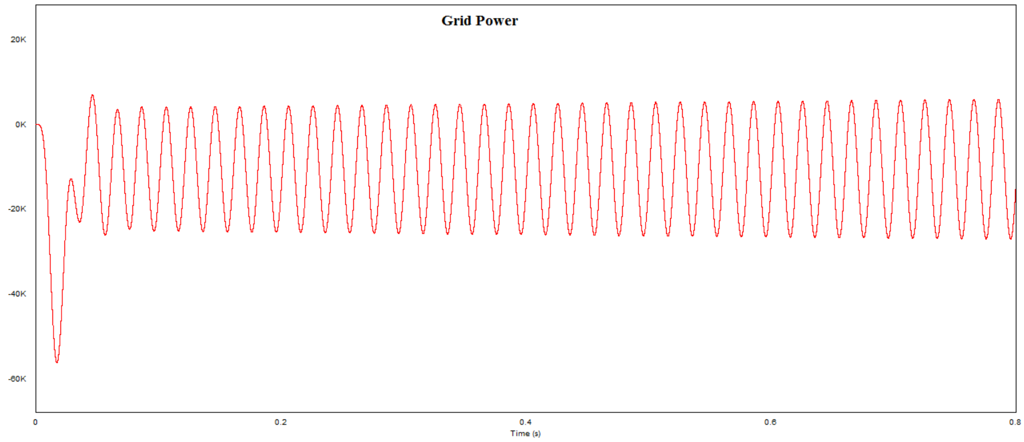

Figure 5.22: Grid power for a load resistance of 5 ohms

The above Figures 5.20 and 5.21 show the load current and grid power waveforms for a load resistance of 5 ohms. Here we can observe that mojority of the grid power is going in negative half cycle which implies the power is flowing from grid towards load in order to meet the requirement as the inverter can only supply 8.9 A. The excess current requirement will be fulfilled by the grid current.

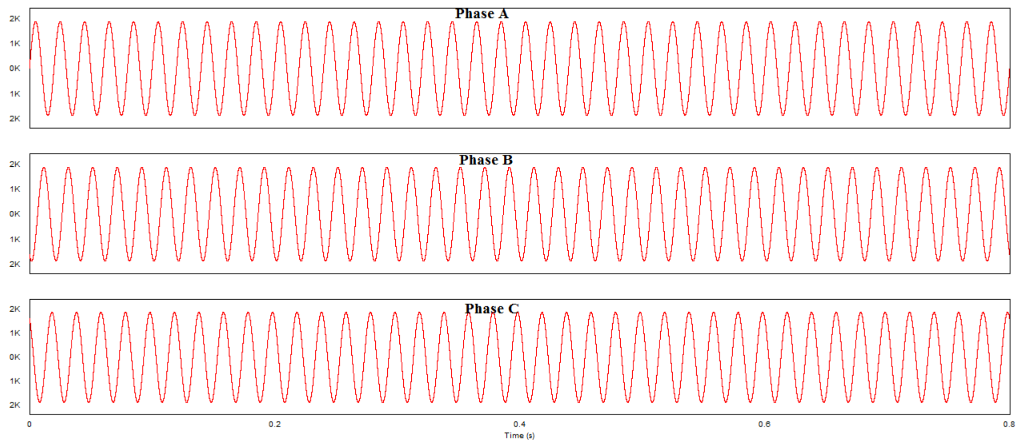

Figure 5.23: Load current for a load resistance of 0.1 ohms

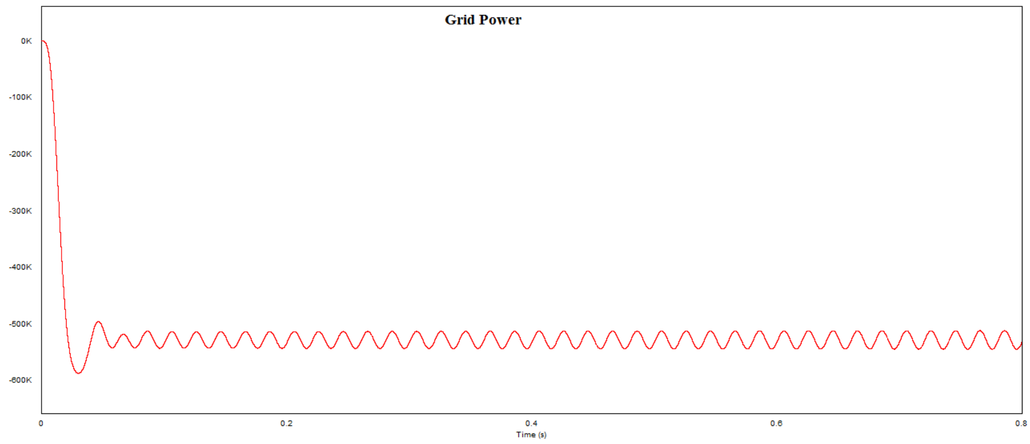

Figure 5.24: Grid power for a load resistance of 0.1 ohms

The above Figures 5.22 and 5.23 show the load current and grid power waveforms for a load resistance of 0.1 ohm. Here we can observe that all of the grid power is going in negative half cycle which implies the power is flowing from grid towards load in order to meet the requirement as the inverter output is not sufficient enough to do so.

Chapter 6

Experimental Results

6.1 LDR Characteristics

A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistivity is a function of the incident electomagnetic radiation. These are light sensitive devices or light sensors. LDR works on the principle of photo conductivity i.e. the materials conductivity increases when more light falls on it and resistivity increases when light source moves away from the semiconductor device.

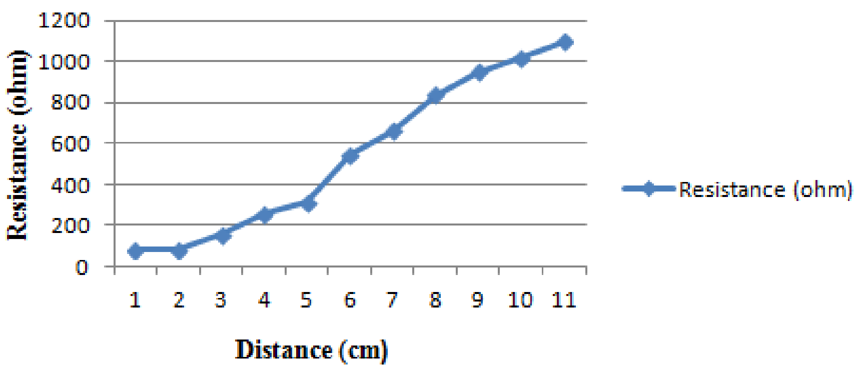

Figure 6.1: LDR Characteristics

The above graph was plotted by taking readings of change in resistance with consecutive change is distance of light source moving towards and away from the LDR.

6.2 Motor driver IC L293D

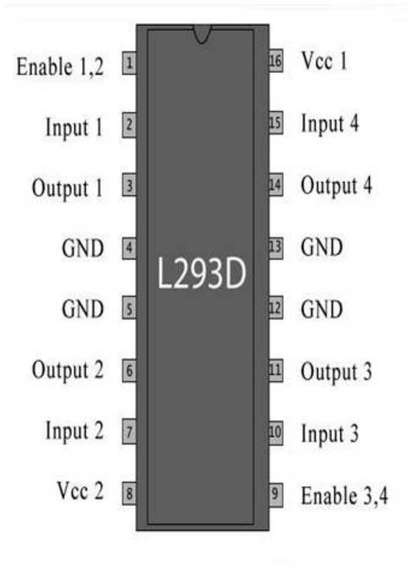

Figure 6.2: Motor driver IC L293D

L293D is a dual H-bridge motor driver IC. By using one IC, we can control two DC motors in both clockwise and counter clockwise directions. The L293D can provide bidirectional drive currents of upto 600 mA at voltages from 4.5 V to 36 V. All the inputs are TTL compatible and output clamp diodes protect the circuit from back emf of DC motor. Drivers are enabled in pairs, with driver 1 and 2 enabled by a high input to enable pin 1. When drivers are enabled, their outputs will be active and in phase with their inputs. When drivers are disabled, their outputs will be off and will be in high impedance state.

Table I: Control signals and Motor status

Input1	**Input2**	**Motor status**
Low	Low	Stops
Low	High	Anti-clockwise
High	Low	Clockwise
High	High	Stops

The input pins 2 and 7 of L293D are used for rotation of one DC motor in both directions. The motor receives 12V supply via output pins 3 and 6.

1. For normal weather condition when LDR1 receives more sunlight than LDR2, logic of high and low are given to input. This will rotate the motor in clockwise direction by sensing the sun's position.

2. Similarly when LDR2 receives more sunlight than LDR1, logic of low and high will be given to input. This will rotate motor in anti-clockwise direction.

3. During noon time, logic of low and low will be given to input which will not rotate the motor.

4. During cloudy weather condition, logic of high and low will be given to input for few miliseconds so that motor rotates by 1 degree every 4 minutes and for the remaining seconds it will receive logic of low and low so that it does not rotate for the remaining time. Again the process is repeated for the next 4 minutes.

6.3 Experimental Results

1. **Experimental Setup (Cloudy Weather)**

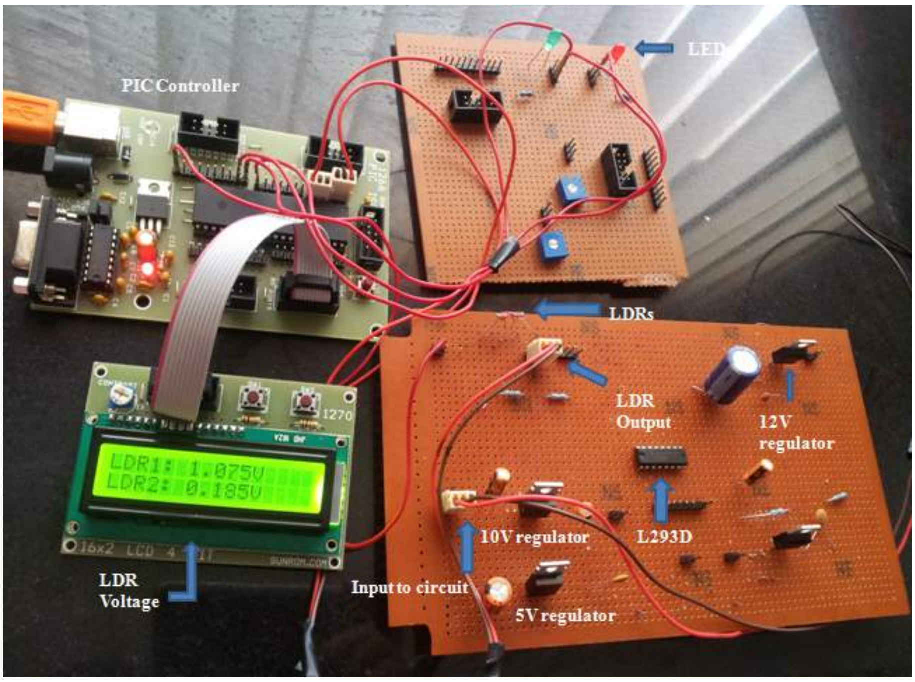

Figure 6.3: Experimental Setup (Cloudy Weather)

In the above Figure 6.3, it can be observed that both the LDR outputs are less which implies it is cloudy weather condition. In this case one of the LEDs will glow for a few miliseconds and for the remaining it will not glow till 4 minutes get completed. This will be reapeated for the next 4 minutes and so on.

2. LDR1 receives more insolation than LDR2 (Normal weather)

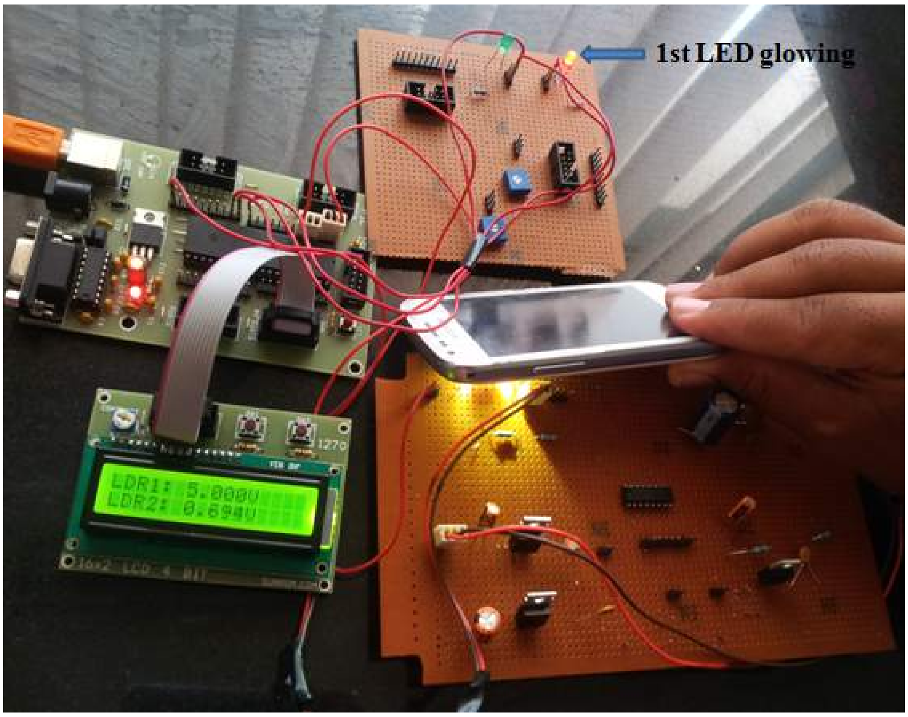

Figure 6.4: LDR1 receives more insolation than LDR2 (Normal weather)

In the above Figure 6.4, LDR1 receives more insolation than LDR2, the L293D will receive a logic of high and low and one of the two LEDs will glow, making the motor rotate in clockwise direction.

3. LDR2 receives more insolation than LDR1 (Normal weather)

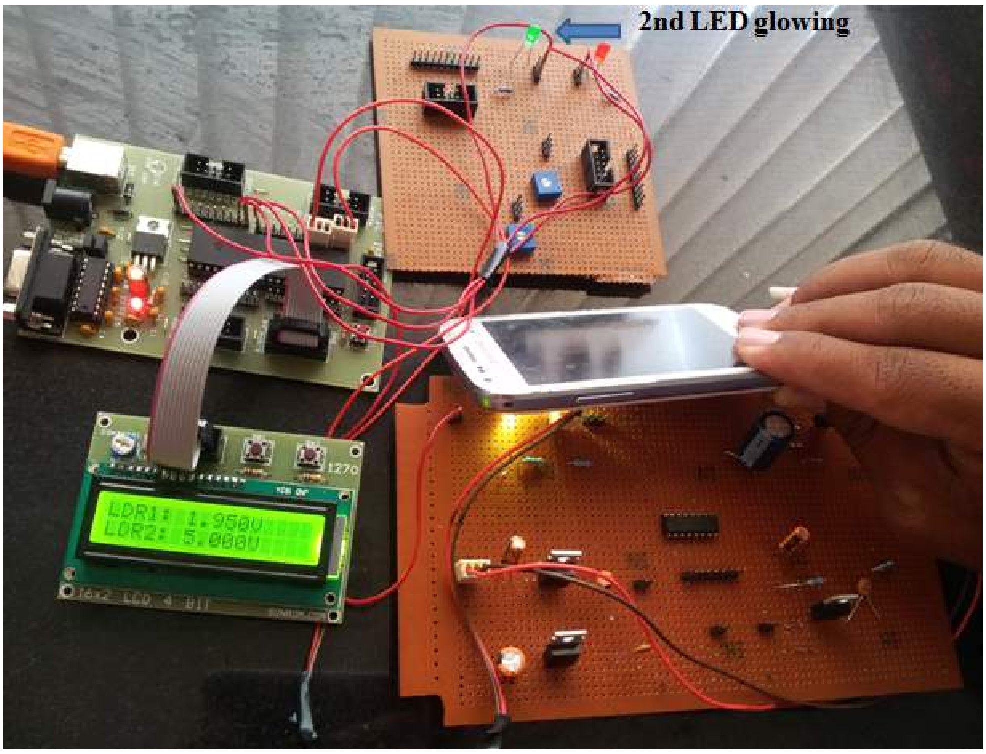

Figure 6.5: LDR2 receives more insolation than LDR1 (Normal weather)

In the above Figure 6.5, LDR2 receives more insolation than LDR1, the L293D will receive a logic of low and high and one of the two LEDs will glow, making the motor rotate in anti-clockwise direction.

4. Both LDRs receive same insolation (noon)

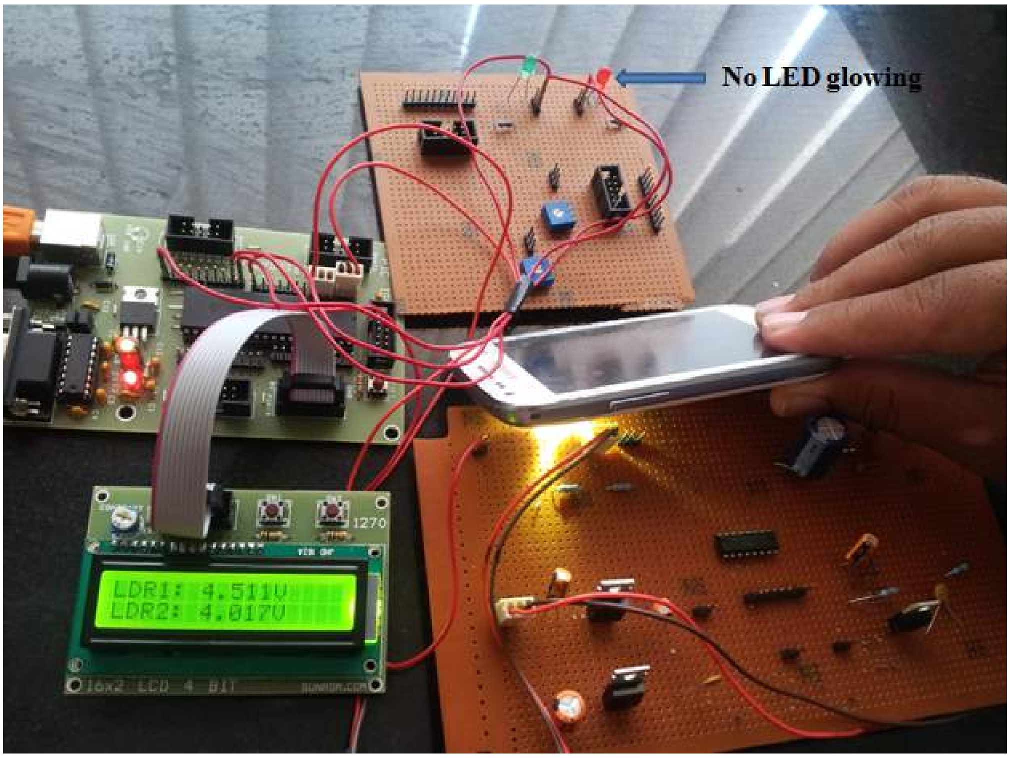

Figure 6.6: Both LDRs receive same insolation (noon)

In the above Figure 6.6, both LDR1 and LDR2 receive same insolation, the L293D will receive a logic of low and low and none of the two LEDs will glow which will not rotate the motor.

5. Experimental Setup with dummy DC Motor

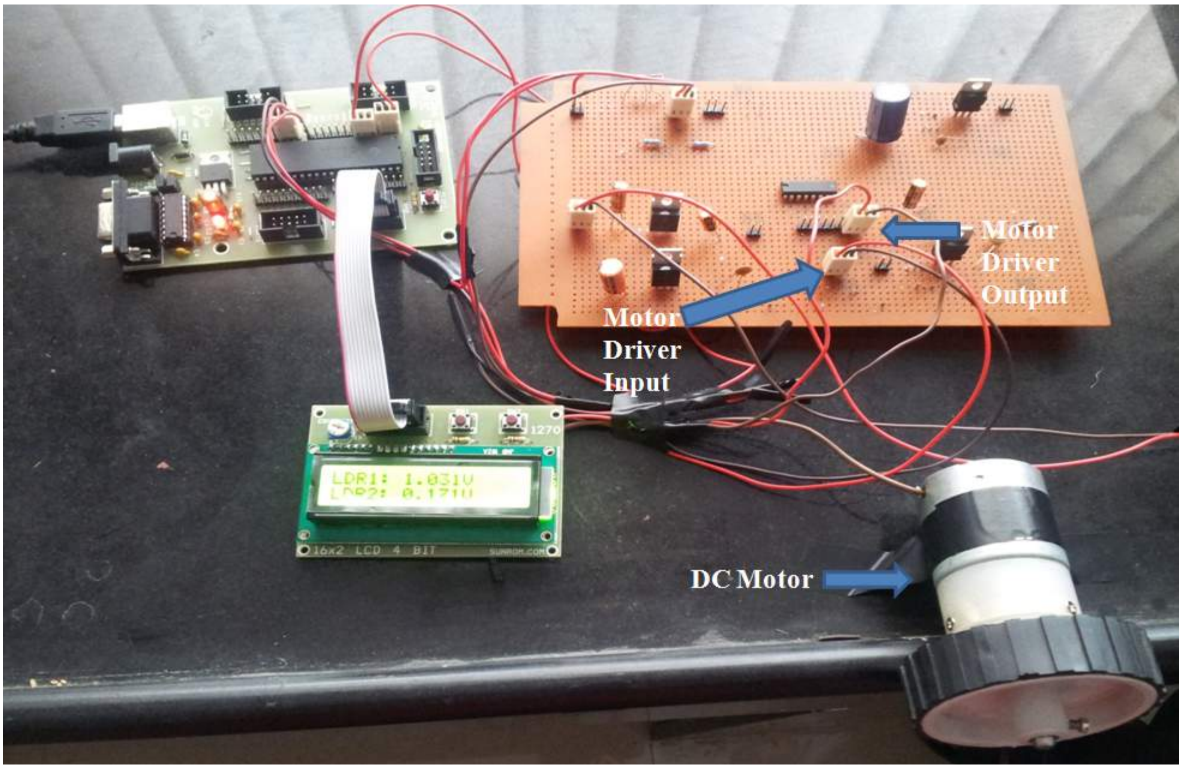

Figure 6.7: Experimental Setup with dummy DC Motor

Hardware results were observed on CRO and the DC motor rotation was checked by connecting a dummy DC gear motor at the output pins 3 and 6 of motor driver IC L293D. The results were checked for all four cases of solar irradiance and DC motor rotaion was checked for both clockwise and anti-clockwise direction.

6.4 Hardware Results

1. **LDR1 receives more insolation than LDR2 (Normal weather)**

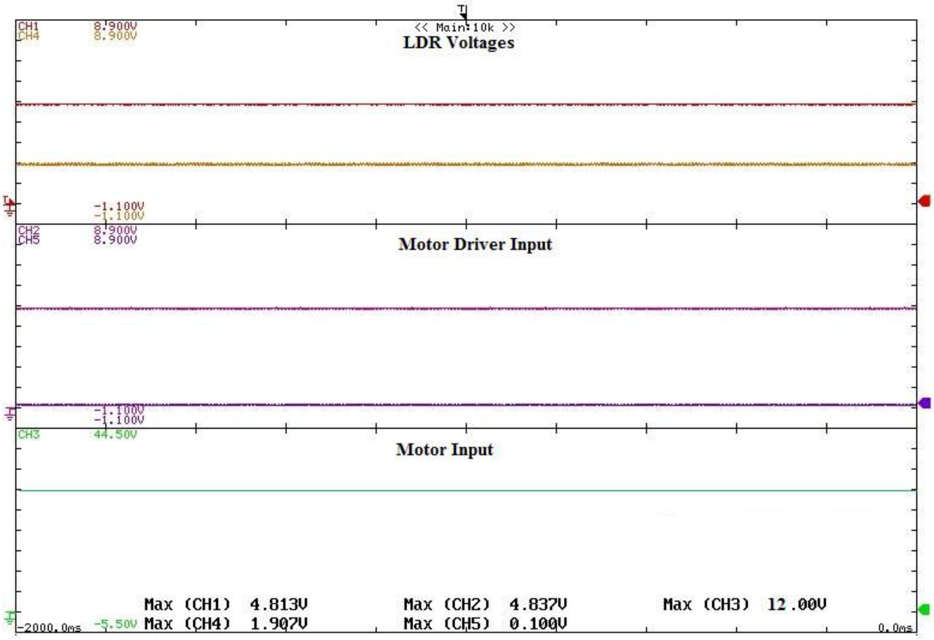

Figure 6.8: LDR1 receives more insolation than LDR2 (Normal weather)

In the above Figure 6.8, LDR1 receives more sunlight than LDR2, the motor driver IC L293D will receive a logic of high and low. The DC motor will get 12V as input and motor will rotate in clockwise direction.

2. LDR2 receives more insolation than LDR1 (Normal weather)

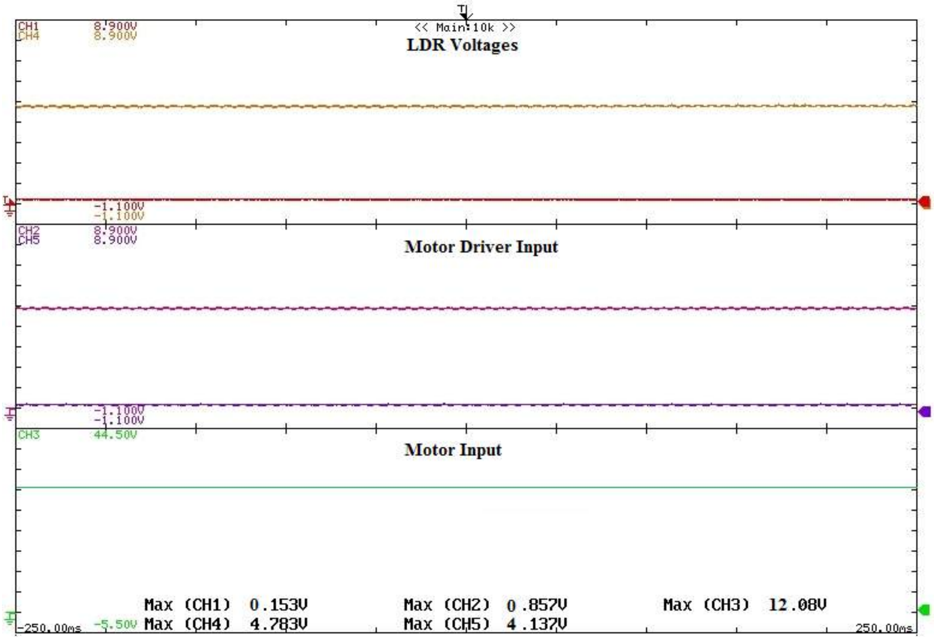

Figure 6.9: LDR2 receives more insolation than LDR1 (Normal weather)

In the above Figure 6.9, LDR2 receives more sunlight than LDR1, the motor driver IC L293D will receive a logic of low and high. The DC motor will get 12V as input and motor will rotate in anti-clockwise direction.

3. Both LDRs receive same insolation (Noon)

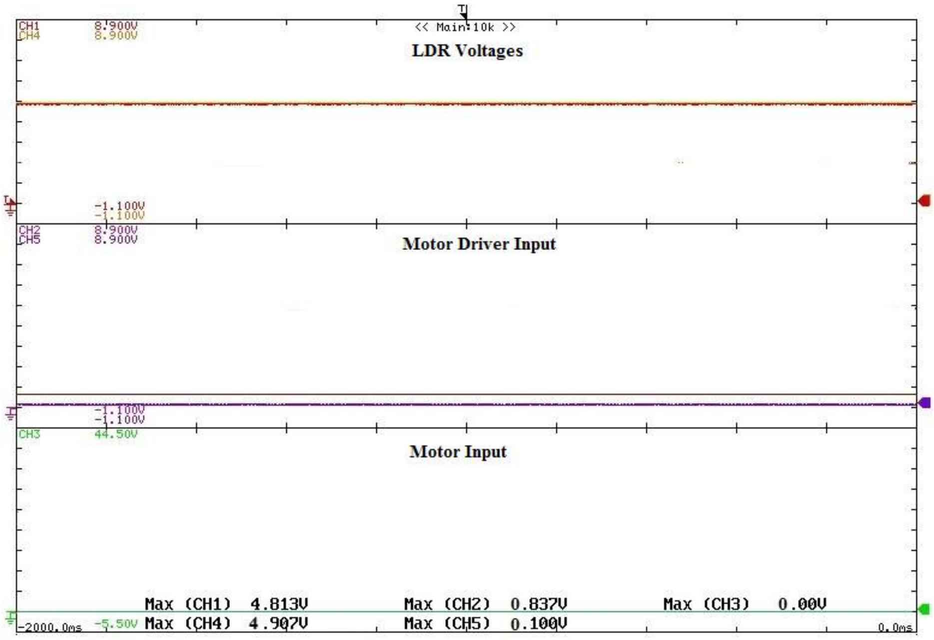

Figure 6.10: Both LDRs receive same insolation (Noon)

In the above Figure 6.10, both LDRs will receive same sunlight, the motor driver IC L293D will receive a logic of low and low. The motor will not get supply voltage of 12V and it will not rotate.

4. Both LDRs receive less insolation (cloudy weather)

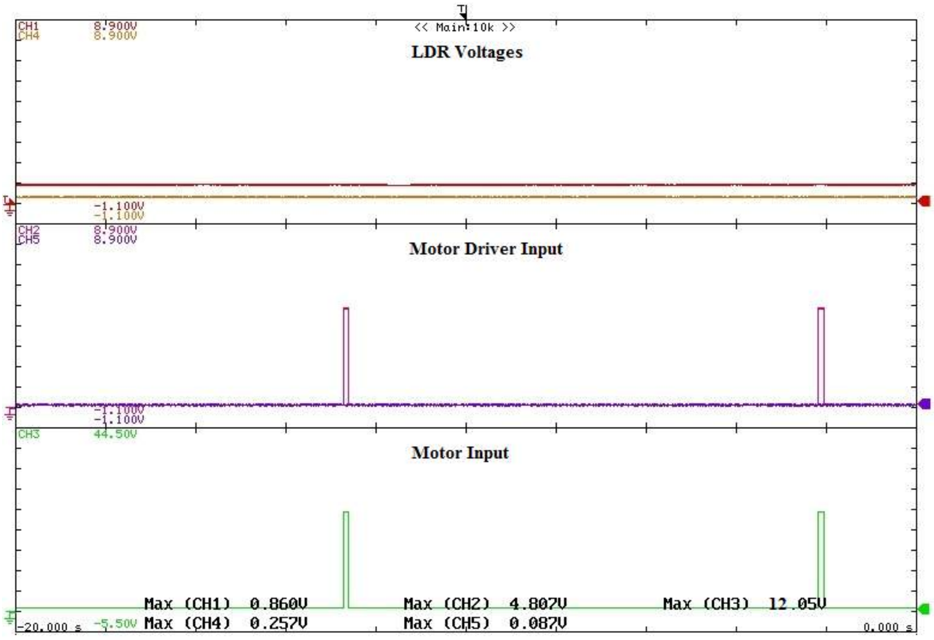

Figure 6.11: Both LDRs receive less insolation (cloudy weather)

In the above Figure 6.11, both LDR1 and LDR2 receive less insolation, the motor driver IC L293D will receive a logic of high and low for few miliseconds and motor will rotate in clockwise direction. For the remaining time period L293D will receive a logic of low and low and motor will not rotate. This is repeated for every 4 minutes.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

Optimization of solar PV panel output can be obtained by using solar tracking technique leading to enhancement of efficiency and output power of solar PV panel. The control circuit was designed, simulated and fabricated. The proposed control circuit will lead to cost effective and reliable operation of solar tracker as it uses LDRs, low cost PIC18F4550 microcontroller and DC gear motor. The control circuit was checked and tested. The hardware results of the setup using available DC gear motor were captured on CRO. Furthermore, MPPT simulation was also carried out and a brief difference between both the tracking techniques is highlighted.

7.2 Future Work

1. **Procurement Work**: Procurement of solar panels, solar panel structure and DC motor.
2. **Trial of Prototype**: The solar tracker prototype will undergo trial after it is ready.

Appendix A

List of Publications

1. Parita .H. Gandhi, Asheesh Dhaneria and Vagish Shrinet, "Economical Feasibility of PV Panel Tracking System For Solar Power Plant", in International Conference on Energy and Infrastructure (ICEA) - 2014, School of Petroleum Management, Pandit Deendayal Petroleum University, Raisan, Gandhinagar.

References

[1] Solar Tracker - Wikipedia

[2] Kenichi Hashizume, Solar Tracking Mechanisms, US Patent US4628142, Dec. 9, 1986

[3] Y .J. Huang, IAENG .B. C. Wu, C. Y. Chen, C. H. Chang and T .C. Kuo, Member, IAENG, Solar tracking fuzzy control system design using FPGA, Proceedings of the World Congress on Engineering 2009 Vol I, WCE 2009, July 1 - 3, 2009, London, U.K.

[4] Robert .D. Lundahl, Robert Wesley Cutlip, Micheal Selzle, Solar Tracking Control System for Solar Collection Devices, US Patent 20120227729, Sep. 13, 2013

[5] Gene .A. Zerlaut, Robert .F. Heiskell, Solar Tracking Device, US patent 4031385, June 21, 1977

[6] Daniel .S. Thompson, Monty Mullins, Craig Stager, Anthony Zante, Solar panel array sun tracking system, US patent 8273978, Sep.25, 2012

[7] Robert .P. Stromberg, Electromechanical solar tracking apparatus, US patent 4274374, Jun. 23, 1981

[8] Glenn .E. Eiden, Solar tracking control system, US patent 4794909, Jan. 3, 1989

[9] Brad .A. Mattson, Solar Energy and tracking system, US patent 5512742, Apr. 30, 1996

[10] David .A. Baker, Portable self contained tracking unit and GPS tracking system, US patent 6339397, Jan. 15, 2002

[11] Gordon Robert Winders, Solar sensor and tracker apparatus, US patent 4107521, Aug. 15, 1978

[12] J. Beltran A., J .L. Gonzalez Rubio S. y C. D. Garcia-Beltran, Design, Manufacturing and Performance Test of a Solar Tracker Made by a Embedded Control, Fourth Congress of Electronics, Robotics and Automotive Mechanics

[13] Introduction to gears, Lecture by Prof. K.Gopinath Prof. M.M.Mayuram, Machine Design II

[14] DC motor - Wikipedia

[15] Motion control made easy, gearbox guide, Anaheim Automation

[16] PIC16F87XA Data Sheet, 2003 Microchip Technology Inc.

[17] Creating the first project in microC PRO for PIC, MicroElektronika, Software and Hardware Solutions for Embedded world.

[18] Introduction to PIC16F877 Microcontrollers, 2006 Pantech Solutions Pvt Ltd.

[19] Introduction to PIC Microcontroller, Dr Abd Rahman Tamuri, Dr Yaacob Mat Daud, Physics Department, Faculty of Science, Universiti Teknologi Malaysia, 81310, JB.

[20] Maximum Power Point Tracking - Wikipedia

[21] Maximum Power Point Tracking Algorithms for Photovoltaic Applications, David Sanz Morales, Faculty of Electronics, Communications and Automation.

[22] Practical Guide to Implementing Solar Panel MPPT Algorithms, Microchip