2.1 BACKGROUND

The earth follows a complex motion that consists of the daily motion and the annual motion as seen in the Figure 2.1. The daily motion causes the sun to appear in the east to west direction over the earth whereas the annual motion causes the sun to tilt to the north or south at a particular angle while moving along east to west direction.[17]

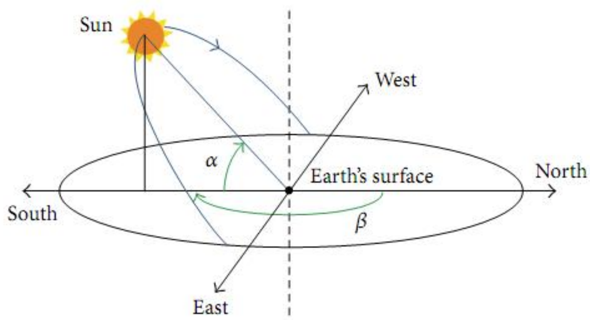

Figure 2.1 The Sun Path

Angle **α** is the angle between the sun's position and the horizontal plane of the earth's surface while angle **β** specifies the angle between a vertical plane containing the solar disk and a line running to the south[17].

2.1.1 Solar Power Fundamentals

Solar panels are formed out of solar cells that are connected in parallel or series. Each individual solar cell is typically made out of crystalline silicon, although other types such as ribbon and thin-film silicone are gaining popularity as shown in Figure 2.2[19]

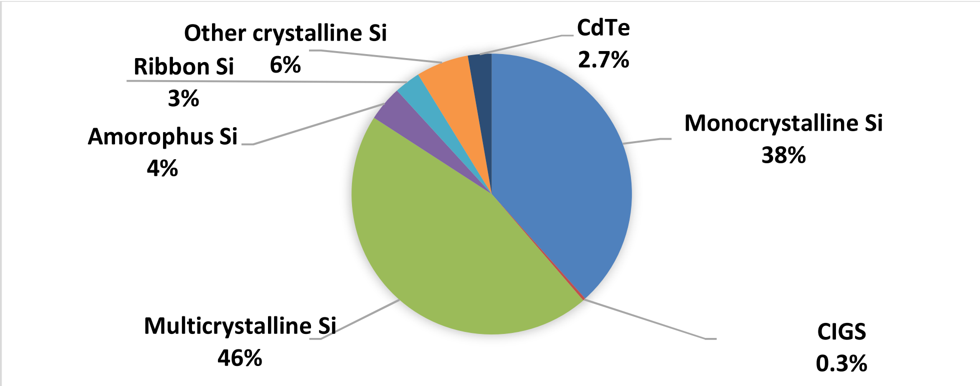

Figure 2.2 Solar Panel Types

PV cells consist of layered silicon that is doped with different elements to form a p-n junction as shown in Figure 2.3. 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 can't 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. [3, 19]

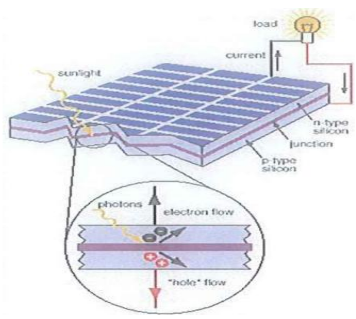

Figure 2.3 PV Cell connected with load

Because the PV cells generate a current, cells/panels can be modeled as Direct Current (DC) current sources. The amount of current a PV panel produces has a direct correlation with the intensity of light the panel is absorbing

The normal to the cell is perpendicular to the cell's exposed face. The sunlight comes in and strikes the panel at an angle as mentioned in Figure 2.4.

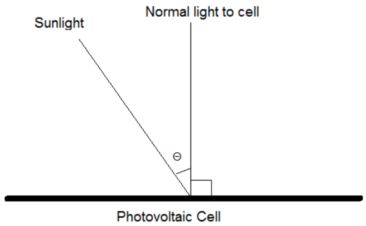

Figure 2.4 PV Cell Power Vs Angle

The angle of the sunlight to the normal is the angle of incidence (Θ). Assuming the sunlight is staying at a constant intensity (λ) the available sunlight to the solar cell for power generation (W) can be calculated as

$$W = A` * \lambda * \cos(\Theta) \qquad 2.1$$

Here, $A`$ represents some limiting conversion factor in the design of the panel because they cannot convert 100% (maximum conversion factor designed is 42%) of the sunlight absorbed into electrical energy. By this calculation, the maximum power generated will be when the sunlight is hitting the PV cell along its normal and no power will be generated when the sunlight is perpendicular to the normal. With a fixed solar panel, there is significant power lost during the day because the panel is not kept perpendicular to the sun’s rays.[8, 27]

2.1.2 The PV Cell Modeling

In order to simulate the solar cell, the simplest equivalent circuit of a solar cell is a current source in parallel with a diode as shown in Figure 2.5. The current source represents the current generated by the PV cell due to the photons received by it, and is constant under constant sun irradiance and temperature. During darkness.[19, 28-30]

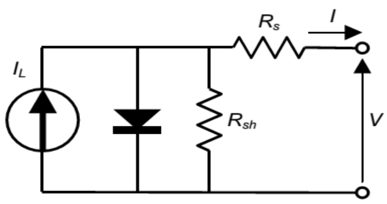

Figure 2.5 PV Cell equivalent circuit

2.1.3 Solar Irradiation effects on I-V Characteristic of a Solar Panel

Highest solar irradiance on the earth ground level is 1000 W/m². If the solar irradiance is decreases due to cloud, the earth movement or any other reason will reduce the output current of the solar panel because it directly proportional to the sun irradiance. While the variation on voltage is much smaller as shown in Figure (2.5).[19, 27-30]

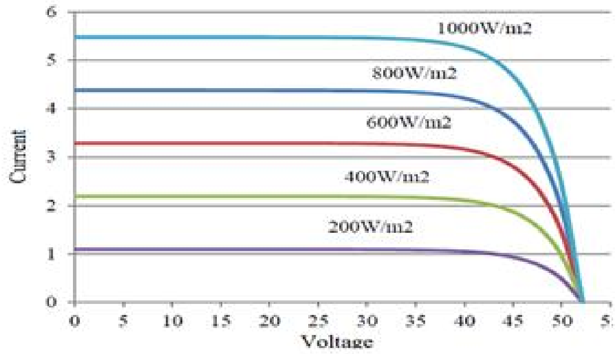

Figure 2.6 Solar Irradiation effects on I-V Characteristic of a Solar Panel

2.1.4 Temperature Effects on I-V Characteristic of a Solar Panel

The operating temperature as shown in Figure 2.7 has a significant effect on the of a solar cell and it can be determined by

- ✓ The ambient air temperature.
- ✓ the characteristics of the module.
- ✓ The intensity of sunlight falling on the module.
- ✓ And by other variables such as wind velocity

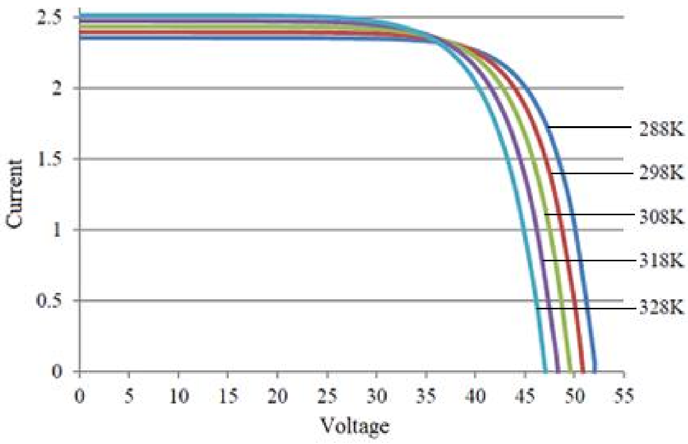

Figure 2.7 Temperature effects on I-V Characteristic of a Solar Panel

2.1.5 Solar collectors

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days.

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. Solar Collectors types are summarized in the following Table 2.1 where's Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.[31]

Table (2.1) Solar energy collectors

Motion	Collector type	Absorber type	Concentration ratio	Inicative temperature range (8C)
Stationary				
	Flat plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200

	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking				
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
	Cylindrical trough collector (CTC)	Tubular	10–50	60–300
Two-axes tracking				
	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC) Point	Point	100–1500	150–2000

2.1.6 The solar tracker

The solar tracker, a device that keeps PV or Thermal panels in an optimum position perpendicular to the solar radiation during daylight hours, increases the collected energy. The first tracker introduced by *Finster* in 1962, and it was completely mechanical.[1, 6, 8, 9, 11-13, 16, 18, 20, 22].

The complete integrated system typically includes the following elements and components.[18]

1. Transmission/actuator mechanical drive subsystem Linear actuators, worm gears, linear drives, slew drives, and planetary gear drives form part of the positioning system to move the reflector to face the sun.
2. Electric motors DC or AC electric motors to drive the mechanical drives, through current, frequency or speed control.
3. Battery storage Backup battery system for power storage and start-up power requirements.

4. Motion sensing subsystem devices Linear or rotational shaft encoders, tilt sensors, inclinometers, photodiodes, photosensitive resistors to monitor the present position of the dish while it moves to the desired position.
5. Control unit subsystem Programmable device to coordinate the modes of operation, as well as the control strategy to position the system according to the solar position algorithm or sensor coordinates.
6. Limit switches Devices to prevent mechanical movement beyond predefined limits in order to prevent tracker or cable damage;
7. Environmental or atmospheric ambient sensing devices Light intensity sensing, solar meter, pyranometer, anemometer/wind sensor, ambient temperature sensor, humidity sensor and atmospheric pressure sensors to detect any emergency or threatening environmental risks.
8. Payload The Solar Harvesting System

solar tracking is best achieved when the tilt angle of the solar tracking systems is synchronized with the seasonal changes of the sun's altitude. An ideal tracker would allow the solar modules to point towards the sun, compensating for both changes in the altitude angle of the sun (throughout the day) and latitudinal of set of the sun (during seasonal changes). So the maximum efficiency of the solar panel is not being used by single axis tracking system whereas double axis tracking would ensure a cosine effectiveness of one.[4, 6, 8, 13, 17, 21, 23]

The sun tracker can be categorized in many ways

2.1.7 The Solar Tracker Categorizes

2.1.7.1 According to the driving element

For the design process of the tracking systems, two rotational motions can be considered, the daily motion and the yearly precession motion, resulting in two fundamental ways to track the Sun

A. One axis (mono axis) tracking system

The mono axis tracking -systems spin on their axis to track the Sun, facing east in the morning and west in theater noon; this type of tracker needs a seasonal tilt angle adjustment as shown in Figure 2.8.

The system can be applied in the residential area for alternative electricity generation especially for non-critical and low power appliances [9, 21]

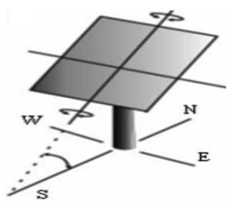

Figure 2.8 One axis tracking system

B. Dual-axis tracking systems

This type follow the Sun more precisely due to the combination of the daily and seasonal/elevation motions; they are more efficient than the mono axis systems but have the disadvantage of a higher price owed to their extra mechanical and electrical parts.[3, 6, 8, 13, 17, 21, 23, 26]

Dual axis can be divided into two types[6]

- Polar (equatorial) tracking there are two independent motions, because the daily motion is made by rotating the PV panel around the fixed polar axis as shown in Figure 2.9.

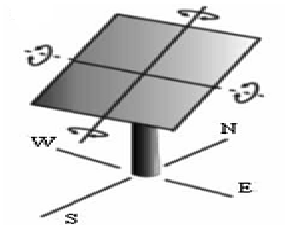

Figure 2.9 Polar tracking system

- Azimuth/elevation (altitude–azimuth) tracking the main motion is made by rotating the PV panel around the vertical axis as shown in Figure 2.10. So it necessary to continuously combine the vertical rotation with an elevation motion around the horizontal axis.[8]

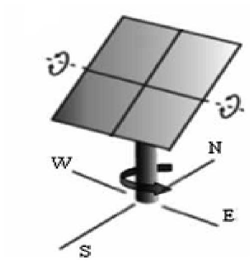

Figure 2.10 Azimuth/elevation (altitude–azimuth) tracking

2.1.7.2 According to the driving mechanism

A. Open looped or Passive (mechanical) sun tracker

This type of tracker are less complex but work in low efficiency and at low temperatures they stop working [3, 6, 9, 25, 30] .Tests have shown that passive trackers are comparable to electrically based systems in terms of performance.

Most of the passive solar trackers are based on

I. The PV panel placed horizontally on a fixed ground and face upwards to the sky If a flat solar panel is mounted on level ground, it is obvious that over the course of the day the sunlight will have an angle of incidence close to 90°in the morning and the evening. At such an angle, the light gathering ability of the cell is essentially zero, resulting in no output. As the day progresses to midday, the angle of incidence approaches 0°, causing steady increase in power until at the point where the light incident on the panel is completely perpendicular, and maximum power is achieved. As the day continues toward dusk, the reverse happens, and the increasing angle causes the power to decrease again toward minimum again.[4]

II. Manual adjustment for the panel manually tracking the sun by adjusting the direction and elevation of the panel [3]

III. Thermal expansion of a shape memory alloys or two bimetallic strips made of aluminum and steel Usually this kind of tracker is composed of couple of actuators working against each other which are, by equal illumination, balanced. By differential illumination of actuators, unbalanced forces are used for orientation of the apparatus in such direction where equal illumination of actuators and balance of forces is restored [3]

IV. Mass imbalance between both ends of the panel This type are based on the thermal expansion of a Freon-based liquid from one edge of the tracker to another because of the heat-sensitive working fluid [6]

B. Active (electrical) sun trackers

The active tracking systems contain mechanisms driven by controlled motors – actuators using sensors to detect the sun position,[9, 15, 27] However, Sensors may introduce errors in the detection of the sun's real position for variable weather conditions. The active sun tracker can be classified into:-

I. Microprocessor base: Once the location is selected, the azimuth elevation range is determined and the angular steps are calculated. In this solar tracker design, sensors were used to determine the sun position.[9]
Such trackers, with high accuracy, are intended mainly for concentrator solar systems. These trackers are complex and, therefore, expensive and also unreliable [3, 12, 15, 16]

II. Computer controlled date and time based: A Personal computer (PC) is used to calculate the sun positions by making use of date and time using algorithms. and create signals for the system control[3] . in some cases, many sensors are used to identify specific positions

III. Auxiliary bifacial solar cell A bifacial auxiliary solar cell (sensor cell) is fixed to the rotary axle of the tracker and is placed perpendicular to the main bifacial solar panel array. The sensor cell is connected directly to a motor, usually a DC electromotor. When the sun moves, the angle of incidence increases on the sensor cell, which eventually produces enough power to move the motor and the solar panel array. the bifacial solar cell senses and drives the system to the desired position. [1, 3]

2.1.8 Microcontroller

An integrated circuit that contains many of the same items that a desktop computer has, such as CPU, memory, etc., but does not include any "human interface" devices like a monitor, keyboard or mouse. [32, 33]

Microcontrollers are designed for machine control applications, rather than human interaction [34]. Microcontrollers are integrated into many appliances we have grown used to, like household appliances (microwave, washing machine , ...) , telecommunication (mobile phones) , automotive industry (fuel injection, ABS, ...) , aerospace industry and industrial automation

The basic internal designs of microcontrollers are pretty similar. Figure 1.11 shows the block diagram of a typical microcontroller. All components are connected via an internal bus and are all integrated on one chip. The modules are connected to the outside world via I/O pins.

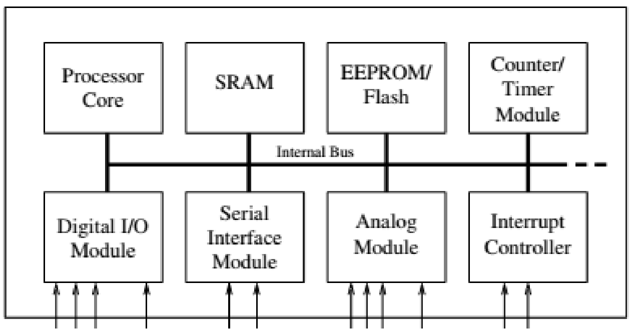

Figure 2.11 Basic layout of a microcontroller.

I. **Processor Core:** The CPU of the controller. It contains the arithmetic logic unit, the control unit, and the registers (stack pointer, program counter, accumulator register, register file, . . .).

II. **Memory:** The memory is sometimes split into program memory and data memory. In larger controllers, a DMA controller handles data transfers between peripheral components and the memory.

III. **Interrupt Controller:** Interrupts are useful for interrupting the normal program flow in case of (important) external or internal events. In conjunction with sleep modes, they help to conserve power.

IV. **Timer/Counter:** Most controllers have at least one and more likely 2-3 Timer/Counters, which can be used to timestamp events, measure intervals, or count events. Many controllers also contain PWM (pulse width modulation) outputs, which can be used to drive motors or for safe breaking (antilock brake system, ABS). Furthermore, the PWM output can, in conjunction with an external filter, be used to realize a cheap digital/analog converter.

V. **Digital I/O:** Parallel digital I/O ports are one of the main features of microcontrollers. The number of I/O pins varies from 3-4 to over 90, depending on the controller family and the controller type.

VI. **Analog I/O:** Apart from a few small controllers, most microcontrollers have integrated analog/digital converters, which differ in the number of channels (2-16) and their resolution (8-12 bits). The analog module also generally features an analog comparator. In some cases, the microcontroller includes digital/analog converters.

VII. **Interfaces:** Controllers generally have at least one serial interface which can be used to download the program and for communication with the development PC in general. Since serial interfaces can also be used to communicate with external peripheral devices, most controllers offer several and varied interfaces like SPI and SCI. Many microcontrollers also contain integrated bus controllers for the most common (field)busses. IIC and CAN controllers lead the field here. Larger microcontrollers may also contain PCI, USB, or Ethernet interfaces.

VIII. **Watchdog Timer:** Since safety-critical systems form a major application area of microcontrollers, it is important to guard against errors in the program and/or the hardware. The watchdog timer is used to reset the controller in case of software "crashes".

IX. **Debugging Unit:** Some controllers are equipped with additional hardware to allow remote debugging of the chip from the PC. So there is no need to download special debugging software, which has the distinct advantage that erroneous application code cannot overwrite the debugger.

2.2 RELATED WORKS

2.2.1 Mechatronics Design of Solar Tracking System [14]

In This patent the author developed a smart solar tracking system, based on mechatronics design approach, such that the solar panel through both day and seasonal changes is accurately perpendicular to sunlight beam (accurately point towards sun)

The conception of light tracking system is quite simple as shown in Figure 2.11, where light detectors detect position of the sun, based on sensors readings, and generated sun tracking error, based on error, the control unit generates the voltage used to command the drive circuit to drive a low- speed motor, that outputs the rotational speed or displacement of electric motor, (to rotate the solar panel via a speed-reduction system) until it perpendicularly faces the sun

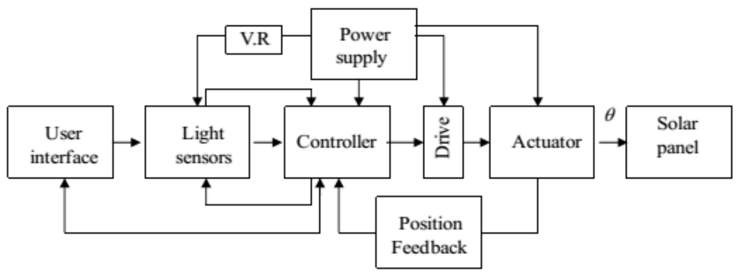

Figure 2.12 Mechatronics Design of Solar Tracking System

2.2.2 The Design and Implementation of a Solar Tracking Generating Power [5]

In this work the author presents a solar tracking power generation system fig (2,12). The tracking controller based on the fuzzy algorithm which designed and implemented on FPGA with a NiosII embedded system. Set up on the solar tracking system, the CdS light sensitivity resistors are used to determine the solar light intensity. The proposed solar tracking power generation system can track the sun light automatically. Thus, the efficiency of solar energy generation can be increased.

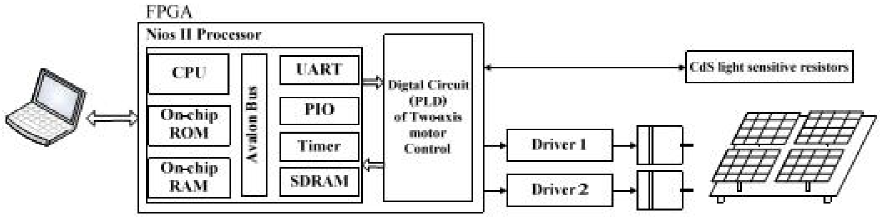

Figure 2.13 The Design and Implementation of a Solar Tracking

2.2.3 Microcontroller based automatic solar power tracking system [15]

The proposed sun tracker automatically tracks the sun capturing maximum solar power as shown in Figure 2.13 with help of microcontroller. The system tracks the sun both in normal and bad weather condition. The tracker can initialize the starting position itself which reduce the need of any more photo resistor. Summer solstice and winter solstice problem is solved manually by tilting the panel with the help of fine screw arrangement.

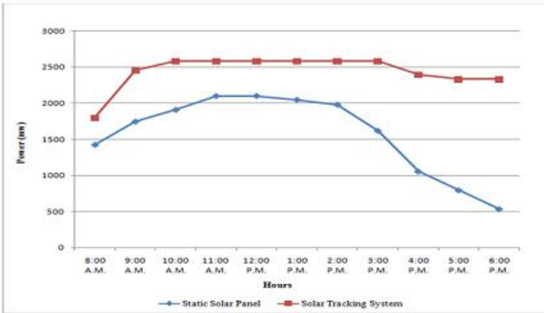

Figure 2.14 Microcontroller based automatic solar power tracking system

2.2.4 Intensity based dual axis solar tracking system [21]

In this patent the author proposed dual axis solar tracking system hardware design and implementation. The system is completely automatic and ensures minimum maintenance at low cost, the system produced an encouraging result as shown in the performance curve in Figure 2,14.

The installation and implementation of dual axis tracking system can be placed anywhere It can be used in many applications such as automobiles, residential areas, industries, institutions etc.

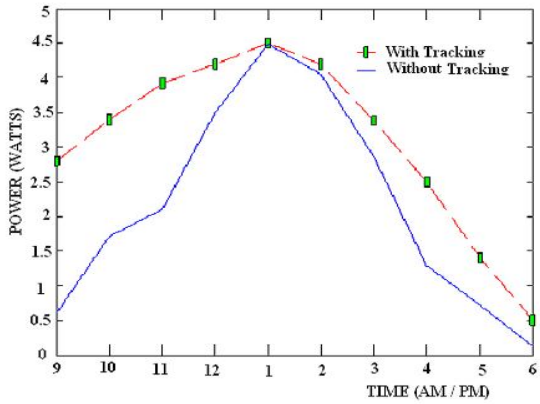

Figure 2.15 Intensity based dual axis solar tracking system

2.2.5 Design and Implementation of Microcontroller Based Automatic Solar Radiation Tracker [16]

In this project, the sun tracking system is developed based on microcontroller. The microcontroller based circuit is used in this system with a minimum number of components and the use of DC servo motors enables accurate tracking of the sun.

The prototype in Figure 2.15 is designed around a programmed microcontroller which controls the system by communicating with the sensors and motor driver based on the movement of the sun. Automatic Sun Tracking

System is a hybrid hardware/software prototype, which automatically provides best alignment of solar panel with the sun, to get maximum output (electricity). By doing this, the efficiency of the panel can be increased by as much as 15 – 25%.

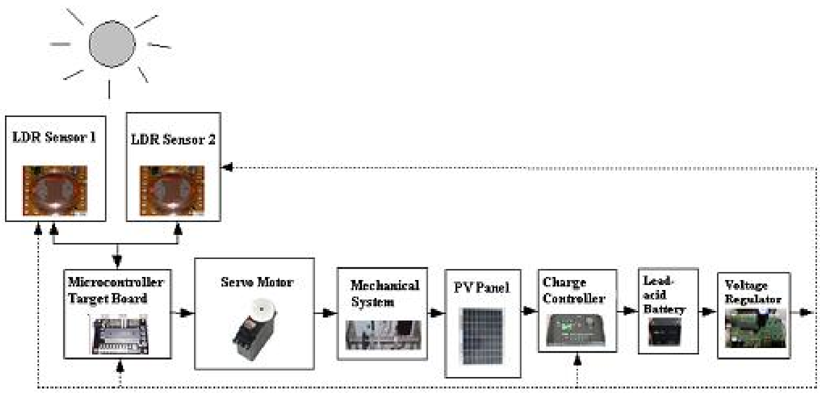

Figure 2.16 Actual solar tracker design

2.2.6 Design, Construction and Performance Evaluation of an Automatic Solar Tracker [22]

An automatic solar tracker has been designed and implemented successfully and it is claimed that this research is successful in increasing the output from the solar panel up to 15% through the day as shown in Figure 2.16. Extra power extracted from the panel with tracker is 182W. It is to be noted that in the summer season, this percentage of extra power will increase up to 30%.

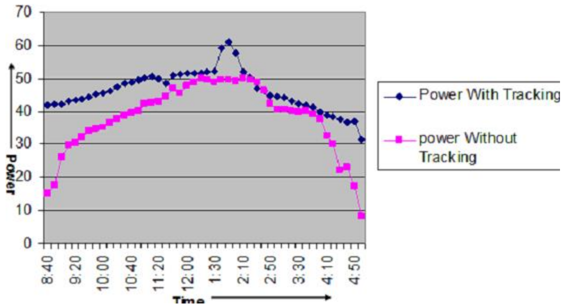

Figure 2.17 Output power

2.2.7 Two Ways of Rotating Freedom Solar Tracker by Using ADC of Microcontroller [12]

In this work the author presents a simple method, low cost microcontroller based solar tracker of two ways of rotating freedom in order to achieve the right positioning of photovoltaic solar cell to get the much sunlight during the day light session and as a result produce more electricity. This tracking system is developed with two direct current motor operated by a PIC16F72 microcontroller which processes the sensors (LDR) information by its internal analog to digital converter (ADC) with Fuzzy logic and send correct information to motor controller IC-LM392D by which motor is operated. The motor is so operated that the panel can rotates two ways such as horizontally and vertically of its direction. A comparison has been made on a conventional solar follower plant and trucking system. From analysis of data we get tracking panel 37 % higher efficiency then stationary panel. Although tracking system is costly than the stationary system but for long time use it will be superior to meet the future energy demand.