Sudan University of Science and Technology
College of Graduate Studies
School of Mechanical Engineering

IMPLEMENTATION OF INTEGRATED SOLAR TRACKING SYSTEMS FOR CONCENTRATING PHOTOVOLTAIC PANELS

تطبيق أنظمة التتبع الشمسية المتكاملة لتركيز الأشعة بمحطات الطاقة الضوئية

Thesis Submitted in Partial fulfillment to the Graduated College, Sudan University of Science & Technology for the degree of Master of Science in Mechanical Engineering (Power)

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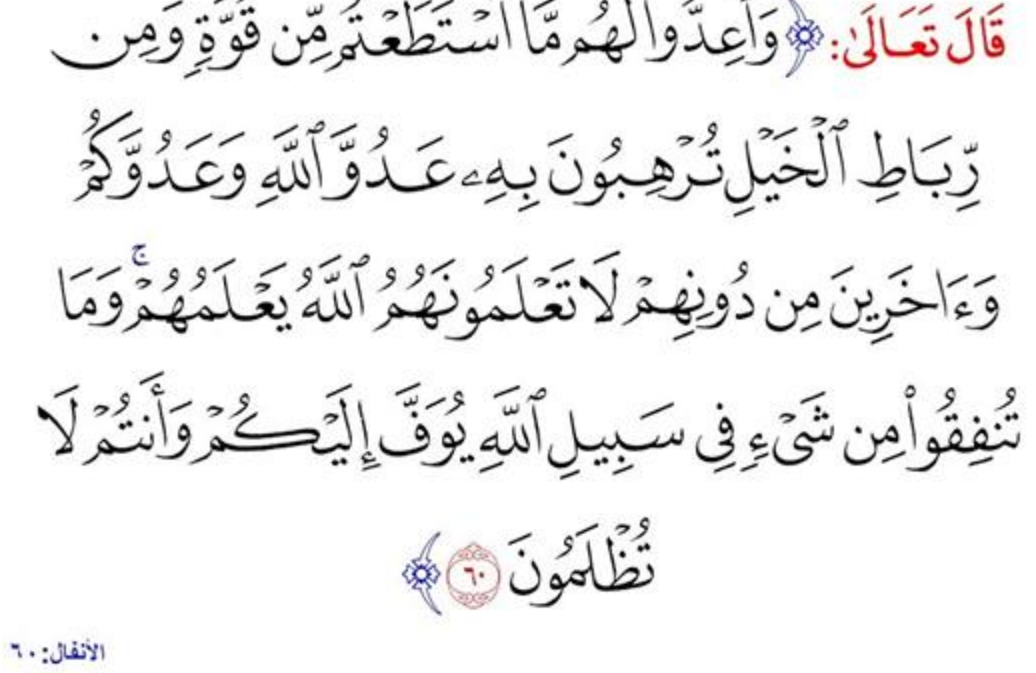
بسم الله الرحمن الرحيم



قَالَ تَعَالَى: ﴿وَأَعِدُّوا۟ لَهُم مَّا ٱسْتَطَعْتُم مِّن قُوَّةٍ وَمِن
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وَءَاخَرِينَ مِن دُونِهِمْ لَا تَعْلَمُونَهُمُ ٱللَّهُ يَعْلَمُهُمْ ۚ وَمَا
تُنفِقُوا۟ مِن شَىْءٍ فِى سَبِيلِ ٱللَّهِ يُوَفَّ إِلَيْكُمْ وَأَنتُمْ لَا
تُظْلَمُونَ ﴿٦٠﴾

الأنفال: ٦٠

Dedication

This is dedicated to:

The spirit of my mother, who never stop giving of herself in countless ways,

My great father, for his continuous support,

My wife, who leads me through the valley of darkness with light of hope and support,

My beloved brother and sisters,

My beloved kids whom I can't force myself to stop loving,

All my family, they symbol of love and giving,

All the people in my life who touch my heart and give me support,

I dedicate this research.

Acknowledgment

I would like to express my deepest gratitude to almighty Allah for giving me the strength and the composure to complete my research within the scheduled time.

I would like to pay gratitude and want to give special thanks to the supervisor **Dr. Abubker Yousif** for helping me in all ways to complete our Project. I highly pleased for giving me such an opportunity.

Finally, thanks to the teaching staff of the Sudan University of Science and Technology, especially to the members of the Mechanical Engineering School.

Abstract

Due to the rotation of the earth in an orbit, direction of the Sun changes relatively. This research represents a setup, which is fabricated to minimize the angle of incidence between incoming light from Sun and a flat photovoltaic (PV) panel to increase the intensity of the light received. It increases the power generated by an installed power generating unit.

The setup consists of a mechanical mechanism to tilt the flat PV panel towards the Sun. This mechanism is derived by DC motors having a high reduction ratio. Voltage supplies to these motors are controlled by the Light Dependent Resistor (LDR) sensors by the means of electronic circuits.

This research aims to analysis and apply a dual axis sun tracker to generate maximum electrical power. The magnitude of energy intensification produced by the SPV panel using a tracker is evaluated by comparing it to the one without a tracker. Efficiency of the PV facility can be improved by 60.22% with a the dual-axis tracking system.

المستخلص

بسبب دوران الأرض في مدارها ، يتغير إتجاه الشمس نسبيًا. هذا البحث يشرح التصميم المستحدث لتقليل زاوية السقوط بين الضوء الوارد من الشمس واللوحة الكهروضوئية المسطحة لزيادة كثافة الضوء المستلم، مما يزيد من الطاقة المولَدة بواسطة وحدة توليد الطاقة المركَبة.

هذا التصميم يتكون من آلية ميكانيكية لإمالة اللوحة الكهروضوئية باتجاه الشمس. هذه الآلية تدار بواسطة موتورات DC ذات نسبة تخفيض عالية. يتم التحكم في الجهد المغذي لهذه الموتورات عن طريق مستشعرات LDR بواسطة الدوائر الإلكترونية.

يهدف هذا البحث إلى تحليل وتطبيق متتبع أشعة الشمس ثنائي المحور لتوليد الطاقة الكهربائية القصوى. يتم تقييم حجم تكثيف الطاقة الذي تنتجه لوحة الطاقة الشمسية الضوئية باستخدام جهاز تعقب من خلال مقارنتها مع تلك التي لا تحتوي على جهاز تعقب. يمكن تحسين كفاءة المنشأة الكهروضوئية بنسبة 60.22% بواسطة استخدام نظام تتبع ثنائي المحور.

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List of symbols:

Symbol	**Description**	**Unit**
S	sunlight vector	
ρ	the tracking angle	rad
i	the cosine of incidence angle	rad
r	the tracking axis	
b	the axis that parallel to the earth surface	
u	the third orthogonal axis	
γ	Azimuth angle	degree
β	tilt angle	degree

List of Abbreviations:

Abbreviations	Description
CSP	Concentrated solar power plants
PV	Photovoltaic
LDR	Light Dependent Resistor
SD	Secure Digital
SPV	Solar Photovoltaic
DC	Direct current
PLC	Programmable Logic Control
NREL	National Renewable Energy Laboratory
SPA	Solar Position Algorithm
MPPT	Maximum Power Point Tracking
FPC	Flat Plate Collector

Chapter 1

Introduction

Chapter 1

Introduction

1.1 Introduction

The solar tracking system plays an important role in solar energy applications where its bents not only exist in the power and efficiency gains, but also in the economic analyses of the large-scale solar energy applications. The systems are oriented with optimal tilt angles towards the equator from the horizon to maximize the solar radiation Absorbs by the solar collectors and panels.

The tracking angles depend on the site latitude and climatic conditions. There are two main solar tracking systems depend on the degree of freedom: are single axis and dual axis solar tracking system. Several sun tracking systems are evaluated and showed to keep the solar panels, solar concentrators, or other solar applications as the studies of single axis, dual axis, single and dual axis tracking with respect to the tracking systems types. Single axis solar tracking system is a technique to track the sun from one side to another using a single pivot point to rotate with: horizontal, vertical and tilted single axis tracking system.

The most popular technology used to convert solar energy to electrical energy is photovoltaics (PV). It is a method of generating electrical power by converting sunlight into direct current electricity using semiconducting materials that exhibit the photovoltaic effect such as Silicon (Si). The efficiency of these photovoltaic systems can be increased through three main ways: The first way is to increase the efficiency of a solar cell through manufacturing such as using selective materials. The second is to maximize the energy conversion from the solar panel by developing method where by maximum power can be obtained from the voltage and current multiplied together. This is known as the maximum power point tracking (MPPT) and there are many developed algorithms that have been deployed to maximize the output power. The third way is by utilizing solar tracking system to maximize the incident power on the solar panel.

1.2 Problem Definition

Electrical energy from PV panels is derived by converting energy from the light of the sun into electrical current. The main challenge is to maximize the capture of the light of the sun fall on the solar panels, which in turn maximize the output of electricity. Practice of achieving this is by positioning the panels such that the light of the sun falls perpendicularly on the solar panels by tracking the movement of the sun using an automatic solar tracker. Automatic solar tracker is an electro-mechanical system that increases power output of solar panel than the stationary system. Therefore, a solar panel receives more sunlight when it is perpendicular to the sun, but the direction of the sunlight changes depends on the movement of the sun in during a day. Mostly of the existed solar panels were installed statically.

1.3 Objectives of Research

The goal of this project is to: -

1. Analysis solar tracker -integrated system that can maximize the utilization of solar energy.
2. Analysis of Approach of Solar Tracking Systems.
3. Implement and compare the efficiencies of solar tracker systems.

1.4 Scope of the Research

This research provides rationales for effective application of a solar tracking system. Efficiency of the PV facility can be improved with a single-axis tracking system. Expected power increase of the dual-axis tracking. The work presents one of the most accurate algorithms for solar tracking NREL SPA, based on the tracking algorithm, Equations of the sun radiation diagram.

1.5 Methodology

This will contain the methods used to reach the object:

- Analysis of Dual Axis Sun Tracker System.
- Efficiency of Dual-Axis Tracking System over Fixed Mount.
- Experimental Approach.
- Conclusion and Recommendations.
- Matlab Program

1.6 Layout of the Project

- Chapter 1: Introduction
- Chapter 2: Literature review
- Chapter 3: Sun Solar Tracker System
- Chapter 4: Analysis of Dual Axis Sun Tracker System
- Chapter 5: Implementation and Results Efficiency of Dual Axis Sun Tracker System
- Chapter 6: Conclusion and recommendations

Chapter 2

Literature Review

Chapter 2

Literature Review

2.1 Introduction

The global warming debate, along with the high oil prices reached, has touched on the discussion related with how to meet the growing demand in power around the world. Thus, renewable energy sources have become more important and more economic resources are being used to finance research activities.

The main power sources used today and their importance in the world's primary energy supply can be seen at Figure 2-1. Fossil fuels are the dominating sources at present [1]. The predicted limited resources of fossil fuels in the world along with a growing demand for power and the high levels of environmental pollution in the world are forcing the politicians and scientists to focus on renewable energy sources. The idea is to decrease the use of fossil fuels such as oil, coal and gas in the future and to increase the use of renewable energy sources like hydropower, biomass, wind, solar power and geothermal. Nuclear power, not being considered as a fossil fuel but also not as a renewable energy source, has an unclear future, since there exist a number of opinions concerning its development.

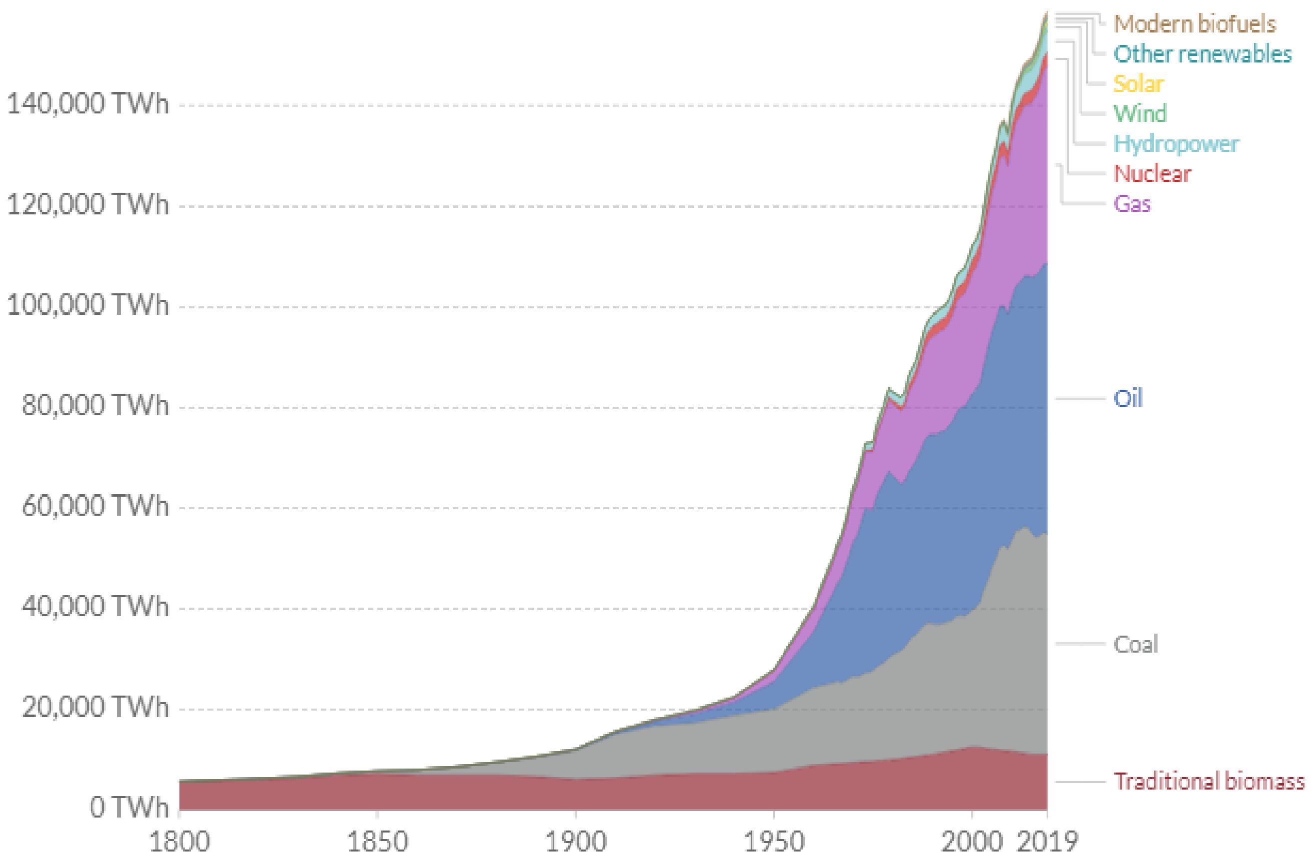

Figure. 2-1 Evolution of world total primary energy consumption

2.2 Historic overview

The first active tracking systems showed in 1975, the system presented by **McZee**, which is an algorithm used to calculate the total power in a central receiver of a solar power system and determine the distribution of flux density in it. The error tolerance of the position of the sun was between 0.5° to 1°. Active tracking system sorted with different control types as microprocessor-based, electric-optical sensor based, date and time methods, and auxiliary PV cells [2].

Zogbi and **Laplaze** [3] constructed dual-axis tracking system with two angles (azimuth and elevation) in 1984 using four electric-optical sensors, which placed in four quadrant formed using two rectangular plans with cross one another in a line. In order to compare the signals received from the sensors in each pair, an amplifier and other electronics components in the tracking control circuit are used. Then operates the two tracking motors using the signal received, and, at the beginning of the night, the system reset to its initial position. The motor is operated by an amplifier when the output of one of the sensors is greater than the threshold set.

Passive tracking system is developed using shape memory alloy (SMA) based on axis actuators by **Poulek** in 1994, where SMA deformed at low operation temperatures range (below 70°C), and when it is heated above a certain specific temperature, SMA return to its original shape and SMA actuator operates as a heat engine during the thermal cycles. In addition, efficiency of SMA actuators is (~2%) compared to bimetallic actuators [4].

Maia et al. developed a mathematical model to predict the absorbed energy, useful energy gains and thermal efficiency of a flat plate solar collector in Brazil. Moreover, several tracking systems were compared to the fixed flat-plate solar collectors. The effect of the inlet water temperature, the number of covers, and the plate emittance was also investigated [5]. Fig. 2-2 shows six types of tracking evaluated through a mathematical model to predict the absorbed energy. The six types of tracking used in evaluation are as following: (R1) The collector rotated over a horizontal east–west axis with continued adjustment to lower the incidence angle, (R2) The collector rotated over a horizontal north–south axis with continued adjustment to lower the incidence angle, (R3) The collector with a constant slope rotated along a vertical axis. The tilt angle was taken equally to the absolute value of the local latitude, (R4) The collector rotated over a north–south axis, parallel to the Earth's axis with continued adjustment to lower the incidence angle, (R5) The collector with continued tracking along dual axes to lower the incidence angle, (R6) a fixed collector slope oriented to north, with 20° tilt angle.

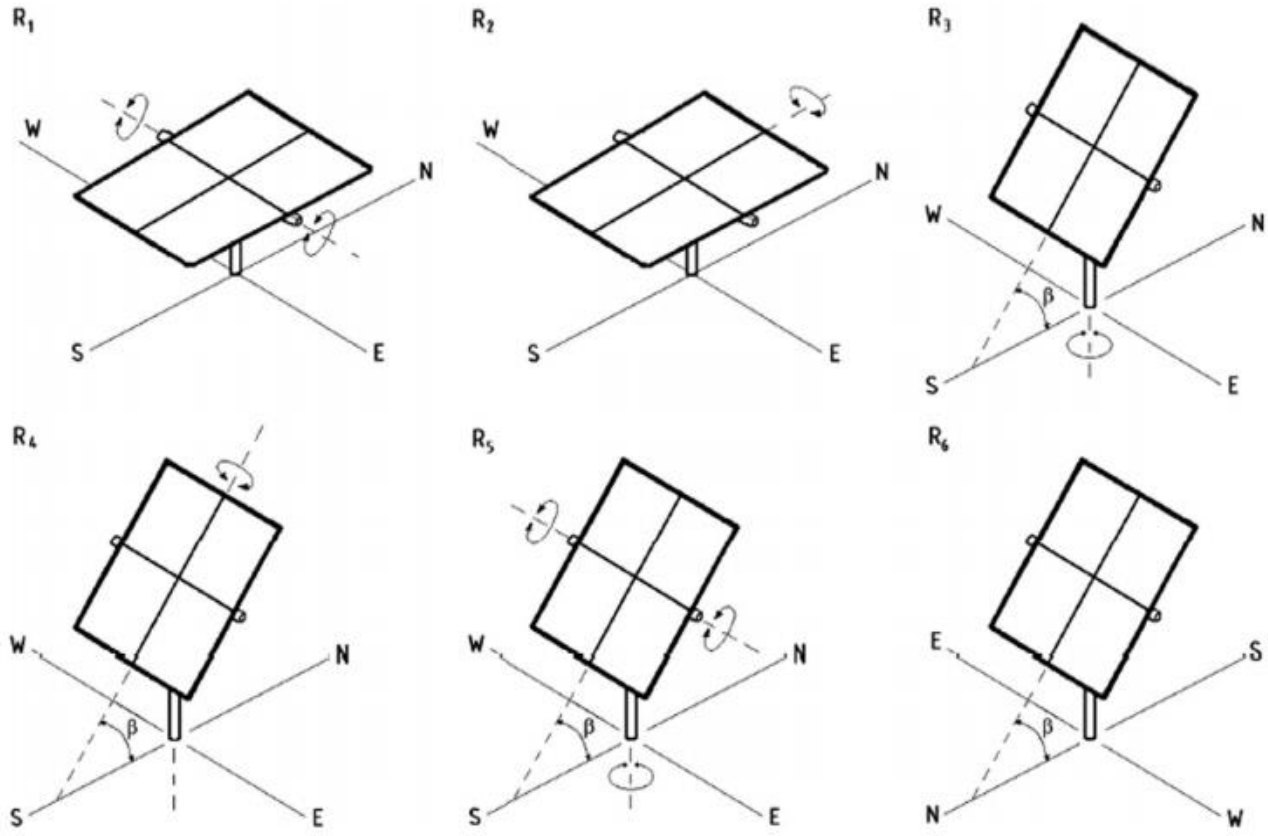

Fig. 2-2 Tracking types of flat plate solar collectors

Chen et al. showed the state space model of dish solar generation tracking servo system with the random disturbances of wind load and system parameter uncertainties [6]. Fig. 2-3 shows one of the types of the solar thermal power generation using of parabolic reflector, dual axis tracking system, receiver, thermoelectric converter, and power converter.

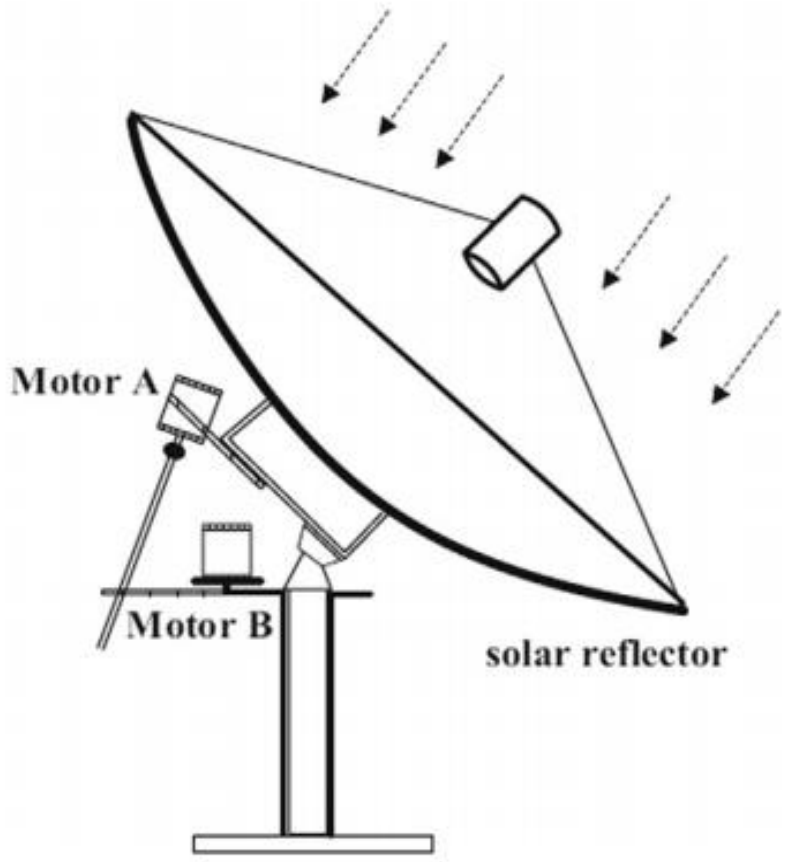

Fig. 2-3. Solar dish using dual axis tracking system

Wang et al. designed automatic sun tracking system for parabolic trough solar concentrator using Programmable Logic Control PLC and hydraulic drive and the tracking error of the system is less than 0.6° [7]. Fig. (2-4. a) shows the rotation of a parabolic trough collector around the single axis tracking. The sunlight vector S follows the tracking axis, ρ is the tracking angle, and i is the cosine of incidence angle. Fig. (2-4. b) shows u-r-b coordinate system, where r is the tracking axis, b is the axis that parallel to the earth surface and u is the third orthogonal axis.

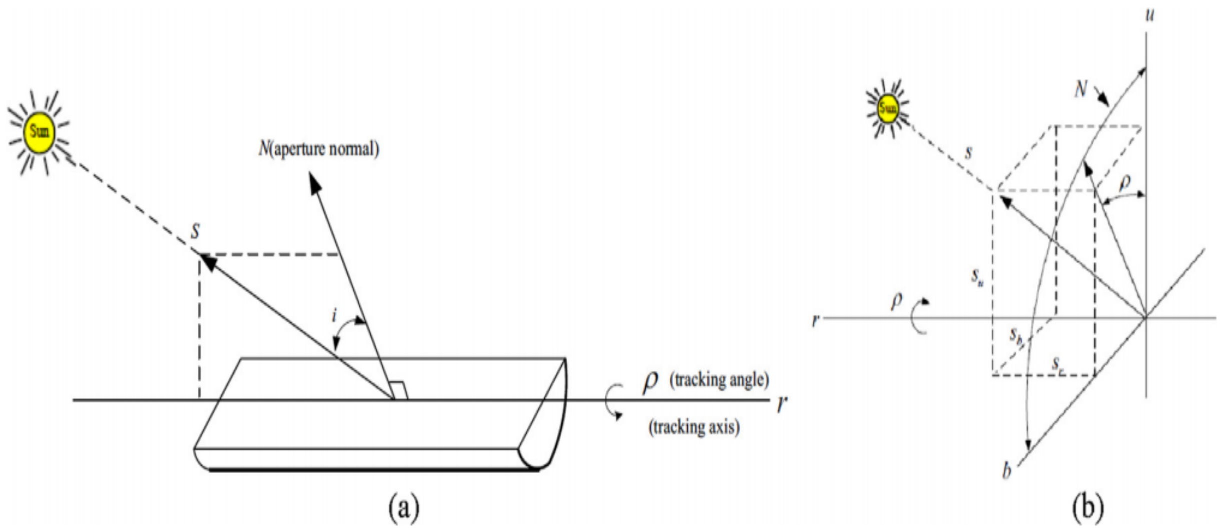

Fig. 2-4. (a) A single-axis tracking to solar parabolic trough (b) The u-r-b coordinate system.

Tomson described the performance of PV modules with daily two-positional tracking around the north–south axis; one in the morning and the other one in the afternoon [8]. It is found that the seasonal energy increased by 10–20% over from a fixed south-facing collector tilted at an optimal angle. In the northern hemisphere, the best performance of fixed Flat Plate Collector FPCs, while facing south with the zero azimuth γ0 = 0, and at the latitude of 60° N, A tilt angle of β0 = 45° used as shown in Fig. (2-5. a). The collector is rotated twice per day with the deflection angles +X to -X where the two positions with the new tilt angle β_X and two new collector azimuth angles + -γ_X to -γ_X as shown in Fig. (2-5. b).

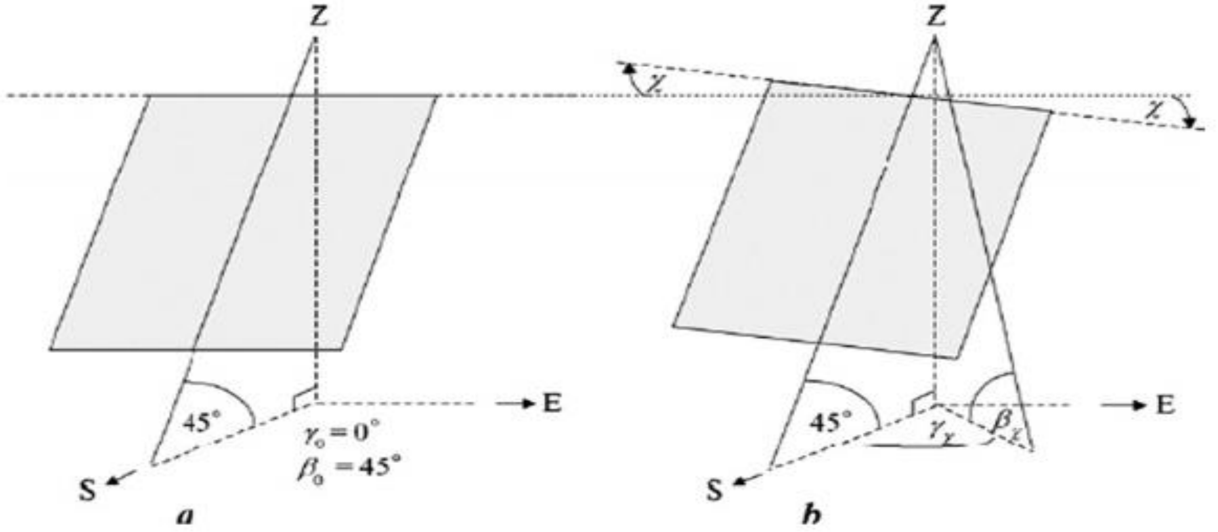

Fig. 2-5. Discrete tracking of a tilted solar collector

Abadi et al. proposed and executed a fuzzy logic controller for a solar tracking system (one input – one output) and implemented on ATMEGA 8353 microcontroller to increase power gain of PV panels which it exceeded 47% compared to the fixed panel. Fig. (2-6. a) shows PV with two LDR sensors to control the tracking system to sense the position of the sun in vertical axis [9]. LDRs are showed with their positions and the principle of working in Fig. (2-6. b).

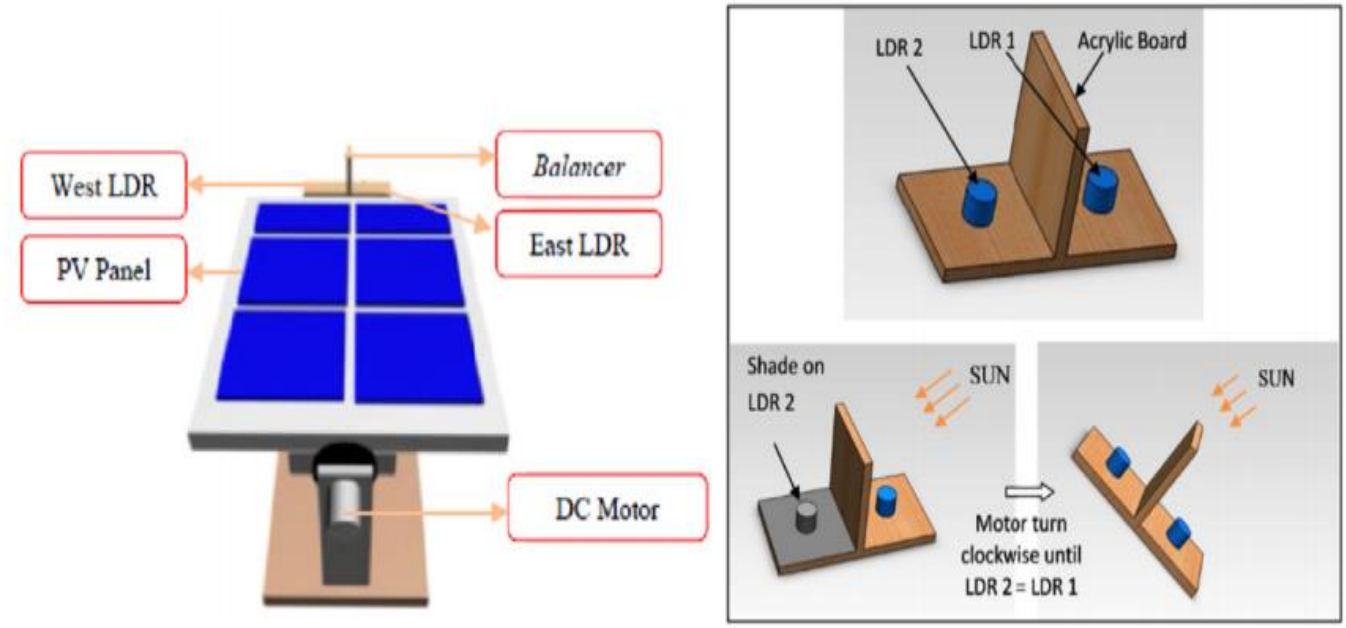

Fig. 2-6. (a) PV panel perspective diagram (b) Tracking system working principle using LDR.

Chapter 3

Sun Solar Tracker System

Chapter 3

Sun Solar Tracker System

3.1 Introduction

The sun, at an estimated temperature of 5800 K, emits high amounts of energy in the form of radiation, which reaches the planes of the solar system. The earth is also reached by the sun's radiation at intensity of 1367 W/m^2 according to the World Radiation Center (Duffie & Beckmann, 2006) [10]. This value known as the Solar Constant Gsc, represents the energy per unit time received from the sun on a unit area of surface perpendicular to the direction of the sun radiation outside the atmosphere. This value however is not constant and changes during the year and over the years. The solar radiation is distributed over a wavelength range, including the visible wavelength range from 0.37 µm up to 0.78 µm. The common wavelength used for the sun's extraterrestrial radiation goes from 0.25 µm to 3 µm, considered as the short wave radiation. The radiation with a wavelength larger than 3 µm is considered as long wave radiation. The short wave radiation can be divided into three groups: The ultraviolet radiation (0.28 – 0.38 µm) with a 7% of the total short wave radiation's energy, the visible wavelength with a 47% of the energy and the infrared radiation (0.78 – 3.00 µm) with a 46% of the energy. Due to the components in the atmosphere, only a part of the extraterrestrial sun's radiation reaches the earth's surface. Once the radiation penetrates the atmosphere, a part of the radiation is absorbed by ozone in the ultraviolet range, by water vapor and carbon dioxide in the infrared range. The entering radiation is also scattered in the atmosphere by air molecules, water vapor and small particles. Thus, the solar radiation that reaches the earth's surface is less than the Solar Constant.

Direct radiation (beam radiation) is the solar radiation of the sun that fall perpendicular while the diffuse radiation is the scattered one. Reflected radiation is the incident radiation (beam and diffuse) that has been reflected by the earth and reaches the surface. The sum of beams, diffuse and reflected radiation is considered as the global radiation on a surface.

Global solar photovoltaic (PV) capacity is estimated to increase significantly from 593.9 gigawatts (GW) in 2019 to 1582.9 GW in 2030 following significant capacity additions by China, India, Germany, the US and Japan, according to Global Data, a leading data and analytics company [11]. Fig. 3-1 shows the irradiance levels around the world, since the available amount of solar energy differs dramatically. The devices can be classified according to the technology used or how the energy is applied.

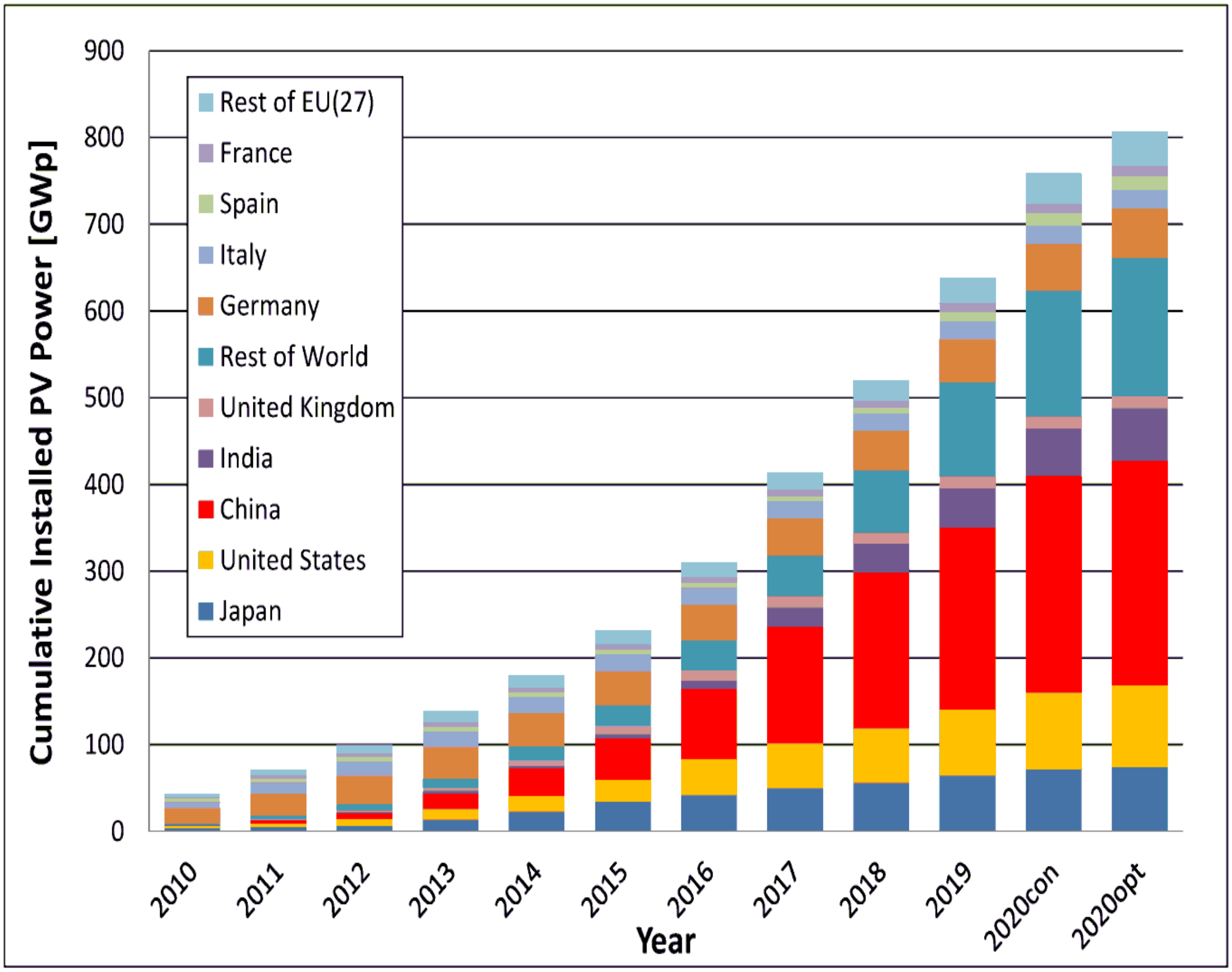

Fig. 3-1: Cumulative Photovoltaic Installations from 2010 to 2020.

3.2 Solar Trackers and Technologies

3.2.1 Solar Tracking Systems

There are two main solar tracking systems types that depend on the movement degree of freedom are: single axis and dual axis solar tracking system. Several sun tracking systems are evaluated and showed to keep the solar panels, solar concentrators, or other solar applications as the studies of single axis tracking, dual axis tracking, single and dual axis tracking with respect to the tracking systems types, the drive mode techniques, and applications [12]. Fig. 3-2 shows there are 42.57% of the studies discussed and presented single axis tracking systems while 41.58% of these studies to the dual axes tracking systems.

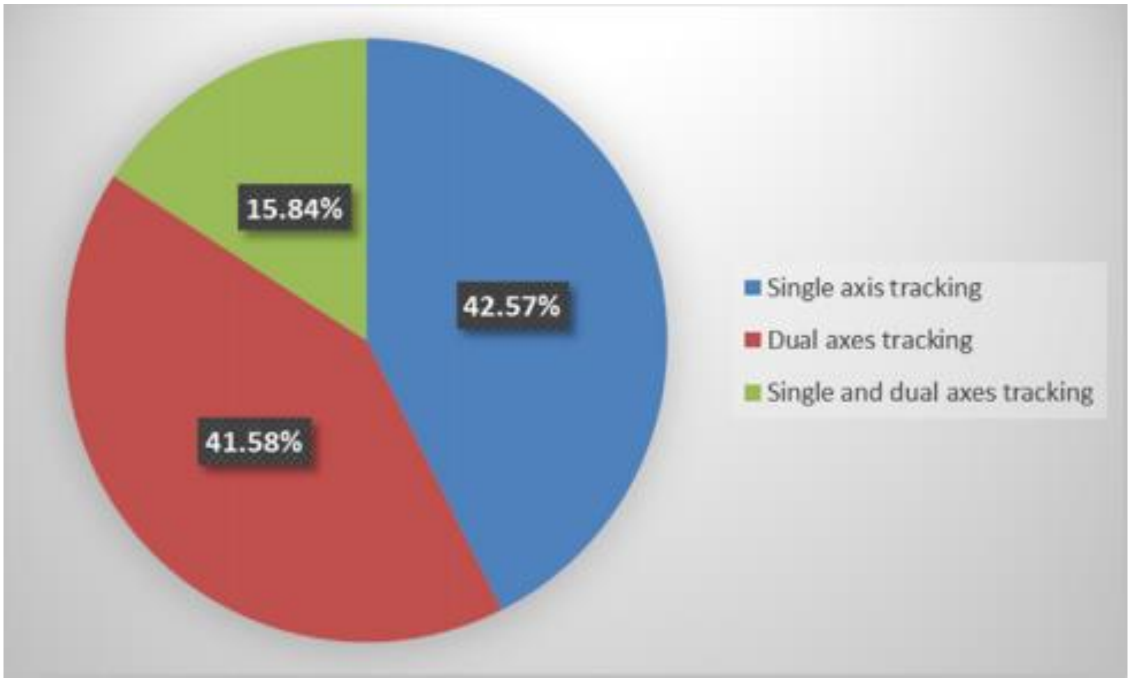

Fig. 3-2. Percentage of usage the solar tracking systems types in the recent studies.

A. **Single axis solar tracking system**

A single axis solar tracking system is a technique to track the sun from one side to another using a single pivot point to rotate. This system has main three types: horizontal, vertical, and tilted single axis tracking system. The axis of rotation is horizontal with respect to the ground at the horizontal single axis tracking system, where the face of the system collector or module is oriented parallel to the axis or rotation, and this type usually used in tropical regions. The axis of rotation is vertical with respect to the ground at the vertical single axis tracking system, where the face of the system collector or module is oriented at an angle with respect to the axis of rotation, and this type usually used in high latitudes locations. The axis of rotation is between horizontal and vertical axes at the tilted single axis tracking system, where the face of the system collector or module is oriented parallel to the axis of rotation. The main Concentrated solar power plants CSP applications of the single axis tracker are parabolic trough and linear Fresnel solar systems. The main disadvantage of the single axis tracking system is that it can only track the sun during the daily movement and not the yearly movement, and, during the cloudy days, the efficiency of the tracking system is reduced by a large amount due to the rotation around only one-axis.

B. **Dual axis solar tracking system**

Dual axis solar tracking system is a technique that tracks the sun in two different axes using two pivot points to rotate. Solar tracker system in this type usually has both horizontal and vertical axis. One of the most important applications to dual axis tracker are CSP applications and especially solar dish and solar tower systems where the long distance between the heliostat reflectors and the receiver point concentration lead to angle errors in the results. In active systems using dual axis tracking, we usually use four LDRs, two motors and a controller. The four LDRs are placed in different directions of rotation at the system, and each motor rotates the system in one axis when the controller detects the signal from the LDRs.

Dual axis tracking tracks the sun in both two directions, east-west motion and north-south motion, and can be divided to tip-tilt dual-axis tracker and azimuth-altitude tracker. The tip-tilt dual axis tracker presents solar tracking centered both on the rotating axis of the vertical and the horizontal axis.

MATLAB code was developed and validated to experimental data to calculate amount of received radiation, useful energy, heat loss of parabolic collectors, and fresh water production of the desalination plant. Furthermore, the most appropriate tracking system for several altitudes was suggested with respect to the criterion of maximum fresh water production [13]. In Fig. 3-3, Tracking systems for parabolic trough collectors were classified by means of motive modes: single-axis tracking mode rotated over east–west (E-W) or north–south (N-S) orientation or parallel to the earth axis and dual-axis mode through varying parabolic trough collector’s position vertically and horizontally.

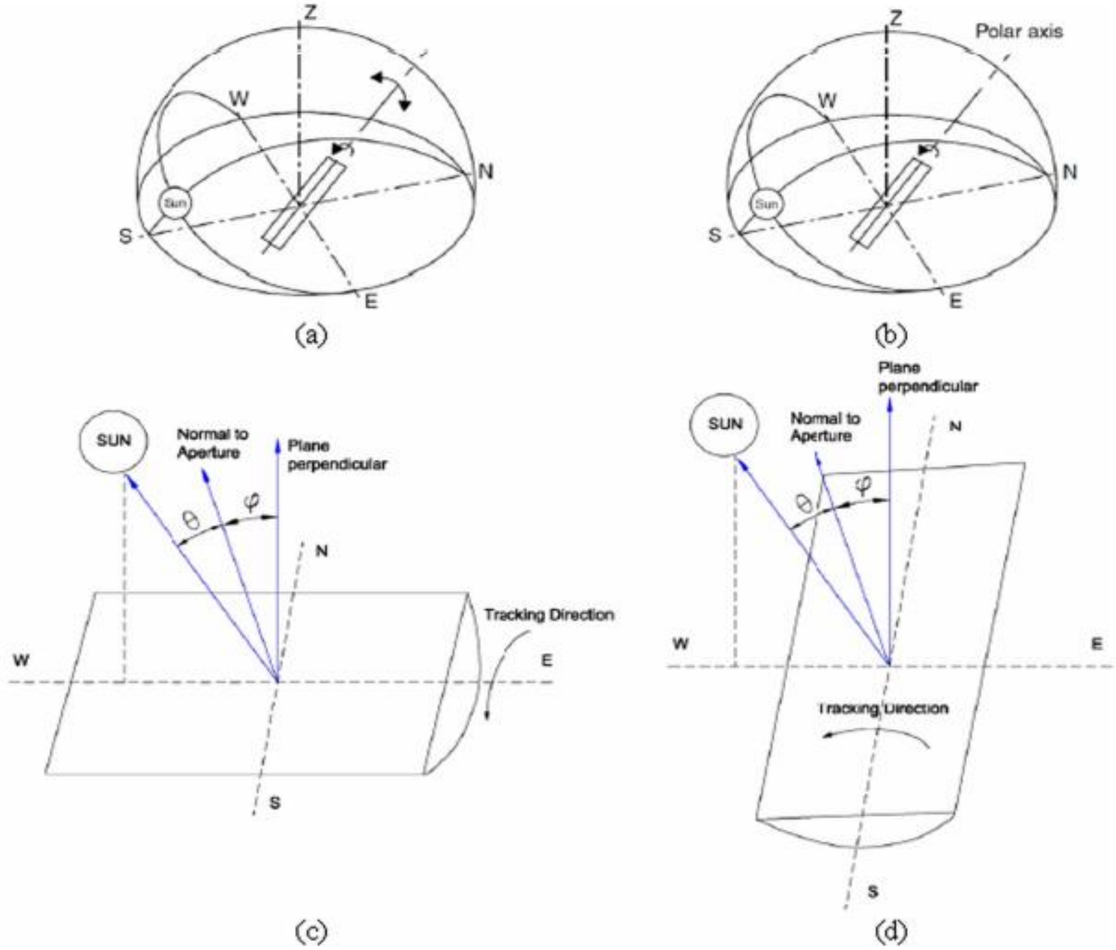

Fig. 3-3. Tracking modes for parabolic trough collector: (a) Full Tracking (b) Polar axis tracking (c) E-W tracking (d) N-S tracking

3.2.2 Solar tracker drive types

The solar tracker drive systems are classified into five types based on their tracking technologies, namely: active tracking, passive tracking, semi-passive tracking, manual tracking, and chronological tracking. The tracker drive types are showed and analyzed in the recent studies: active, chronological, active (normal tracking), manual (daily adjustment on primary axis), active & manual, active & chronological, passive, and semi-passive [14]. Fig. 3-4 shows the most common solar tracker drive type, was active tracker by 76.42% usage in applications while in the second most impact type is the chronological solar tracker by 7.55%.

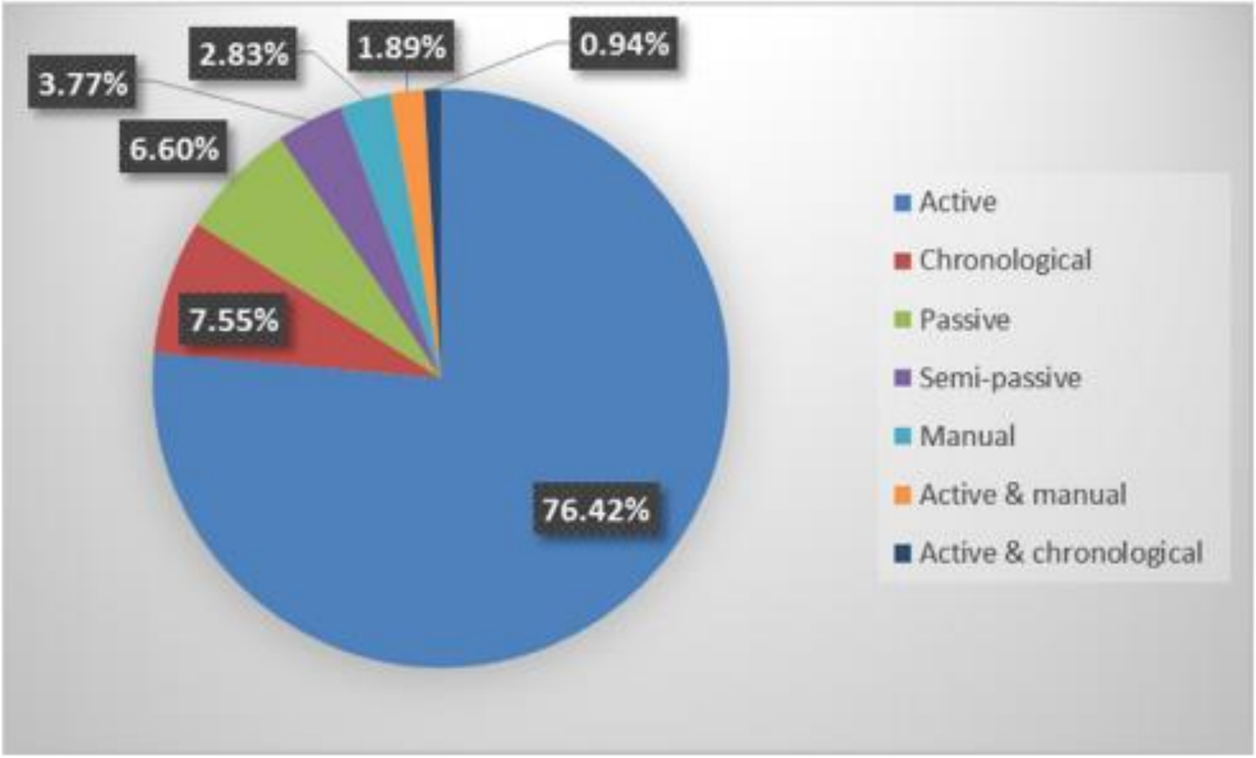

Fig. 3-4. Percentage of usage the solar tracker drive systems types in the recent studies.

A. Active tracker

Active solar tracking system is the system that determines the position of the sun path in the sky during the day with the sensors. These sensors trigger the motor or actuator to move the drive system to the system towards the sun throughout the day. If the solar radiation beams are not perpendicular on the solar tracking system, then this will make a difference in light intensity on one sensor as compared to another leading and this will act the tracking system to be perpendicular on the sunlight beams [15].

Active tracking systems using microprocessor and electric-optical sensors are used at least two photo resistors or PV cells. A comparison between the output signals of the two variables parameters is conducted, and, subsequently, send signal of the difference between them to the drive motor. In solar tracking systems with auxiliary bifacial solar cells, the cells trigger the drive system to move to the desired position. In solar tracking systems that depend on the date and time, mathematical algorithm is calculated by the computer and then generated control signals of the system. At cloudy days, this system is not accurate where the sensors cannot make a decision due to the low solar irradiance intensity difference between the sensors.

B. Passive tracker

Passive tracking system is one of the solar tracking systems which depend on the thermal expansion in materials or an imbalance in pressure between two points at both ends of the tracker, where usually these materials as a fluid. The fluid inserts into two reservoirs, which are opposite to each other, with the specific design in order to vaporize the fluid and change their characteristics with respect to the change in path of the sun with time. The connection between the two tanks made movement in the system by carry the condensate fluid from the highest incidence reservoir to the smaller one. The passive solar tracking system relies on a low boiling point compressed gas fluid, which cause the structure of the tracker to move to an imbalance.

C. Semi-passive tracker

Semi-passive tracking system is a technique where the solar tracking concentrator can track the sun and keep the light’s ray’s perpendicular to the absorber’s cross-sectional area with a minimal mechanical effort and reduced movement for sun tracking. The system is consisted of a micro-heliostat array, a Fresnel lens and a receiver.

D. **Manual tracker**

Manual solar tracker is a method where the system can track the sun angle from season to season with manual tilt angle changing per seasons using a manual gear for ease of the system construction and maintenance. One of the significant advantages of the manual tilt angle axis as the secondary axis in the dual-axis tracking systems is cheaper than used in the previous types by implementing a second motor.

E. **Chronological tracker**

Chronological solar tracking system is a time-based tracking system where the system collector or module moves with a fixed rate and a fixed angle throughout the day as well for different months. The motor or actuator is controlled to rotate at the low rate (15° per hour approx.). One of the main advantages of this system, which is more energy efficient because no energy losses at this tracking calibration due to low tracking error.

Chapter 4

Analysis of Dual Axis Sun Tracker System

Chapter 4

Analysis of Dual Axis Sun Tracker System

4.1 Introduction

Solar energy is the most inexhaustible, renewable source of energy known to humanity. In order to increase the efficiency of solar energy systems, solar tracker is added at the expense of system's complexity and cost. The two basic categories of trackers are single axis and dual axis. Single axis tracker has one axis of freedom, vertical or horizontal. Dual axis tracker has both a vertical and a horizontal axis of freedom, so it able to track the position of the sun precisely.

A prototype of the automatic two-axis solar tracking system with a new design of sun-position tracker mechanism. Two angle sensors are used to measure the physical angles on both outlet shafts of azimuth and elevation to make sure the desired angles are reached. Set of Four LDR light sensors are used to trim the errors of altitude and azimuth angles, as shown in the in the figure 4-1.

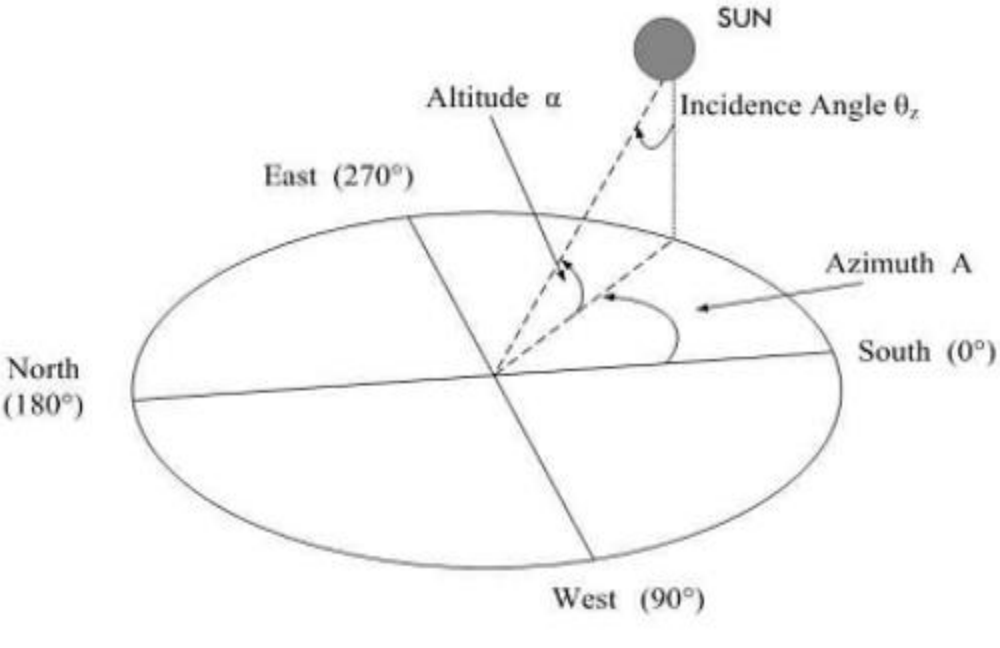

Fig. 4-1. Azimuth and Altitude angles

The theoretical value of altitude and azimuth angles are translated into digital commands for driving DC motors to the corresponding position. Then, the system automatically trims the altitude and azimuth angle of the PV panel according to feedback signal of the proposed LDR sensor module. The sunlight sensor module consists of four LDR sensors. Two angle sensors are placed on outlet shafts of altitude and azimuth angles for measuring the final value of altitude and azimuth angles and transmitting these values to the supervisory computer user interface.

4.2 Principle of the Work

LDR sensors are mounted at the middle of the side edges of the PV panel as shown in Figure 4-2. If there is any intensity difference in between LDR2 & LDR4 or LDR1 & LDR3 then a signal produces. This signal reaches to the control system (circuit1/circuit2) and is evaluated there. Then required instruction signal reaches to the motor (motor2/motor1) which is attached to mechanism and the motor rotates the PV panel. LDR1 and LDR3 send the signals to circuit2 and LDR2 and LDR4 send the signals to circuit1. Circuit1 and circuit2 send the signals to motor2 and motor1 respectively, and also operate them. The panel rotates according to this control signal and the movement of the PV panel stops at the position where it directly faces the Sun.

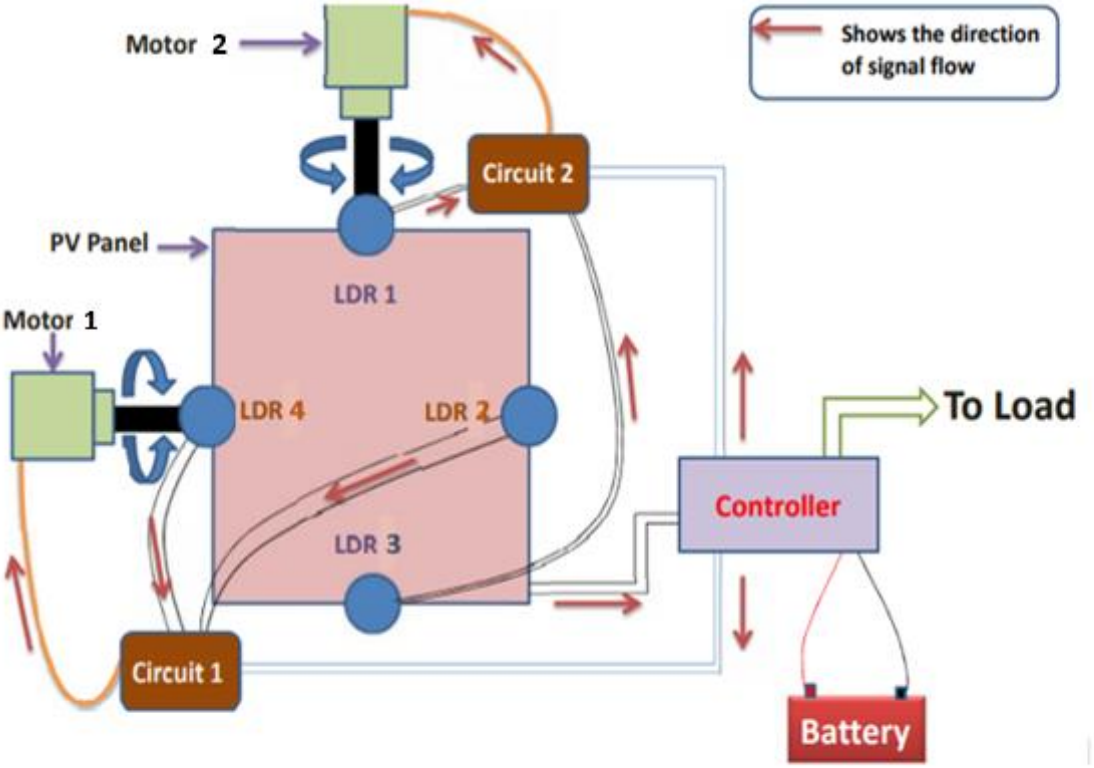

Figure 4-2. Block diagram of the setup

4.3 Analysis of Dual Axis Sun Tracker System

The application of that dual axis sun tracker requires the right components that are corresponding to the design. The fundamental main components are shown in Fig.4-3 below.

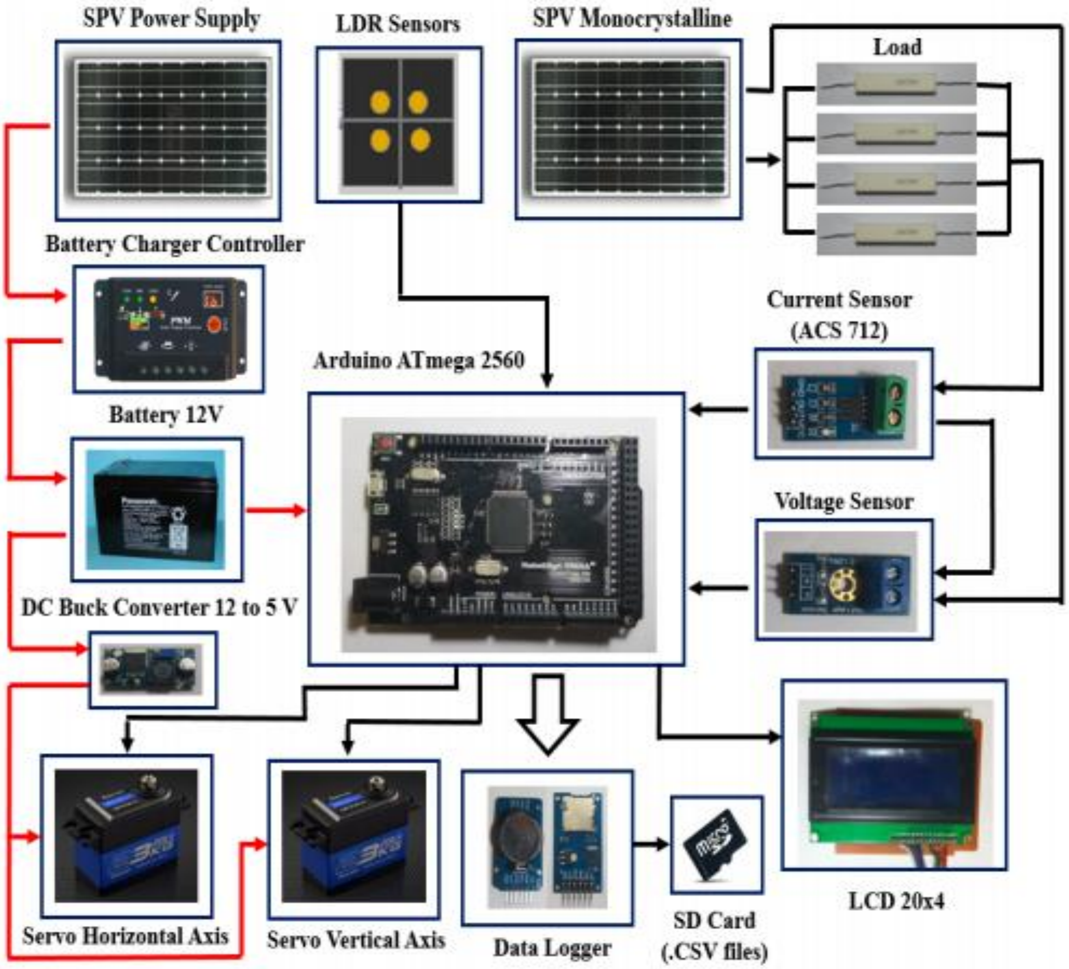

Fig. 4-3. A diagram of dual axis sun tracker system prototype design

To attain the light detection sensor, four blocked LDR sensors are needed. The proportion of signal produced by the sensors is used to activate two servo motor units (horizontal and vertical axis) to be perpendicular towards the sunlight's all the time. The control and measurement energy system created by the SPV panel will be automatically stored by the Data Logger to the SD memory card in the csv format. The next subsections describe the selection of the components such as a light detection sensor, servo motor and actuator, energy monitoring and measurement system.

4.3.1 Light Detection Sensor

LDR, phototransistor and photodiode are the sensors used as the light detecting sensors. In this research the analog LDR sensor is utilized because it is easy to use, simple, and affordable. The light detecting sensor consists of four sensors blocked to four rooms as depicted in Fig. 4-4 below.

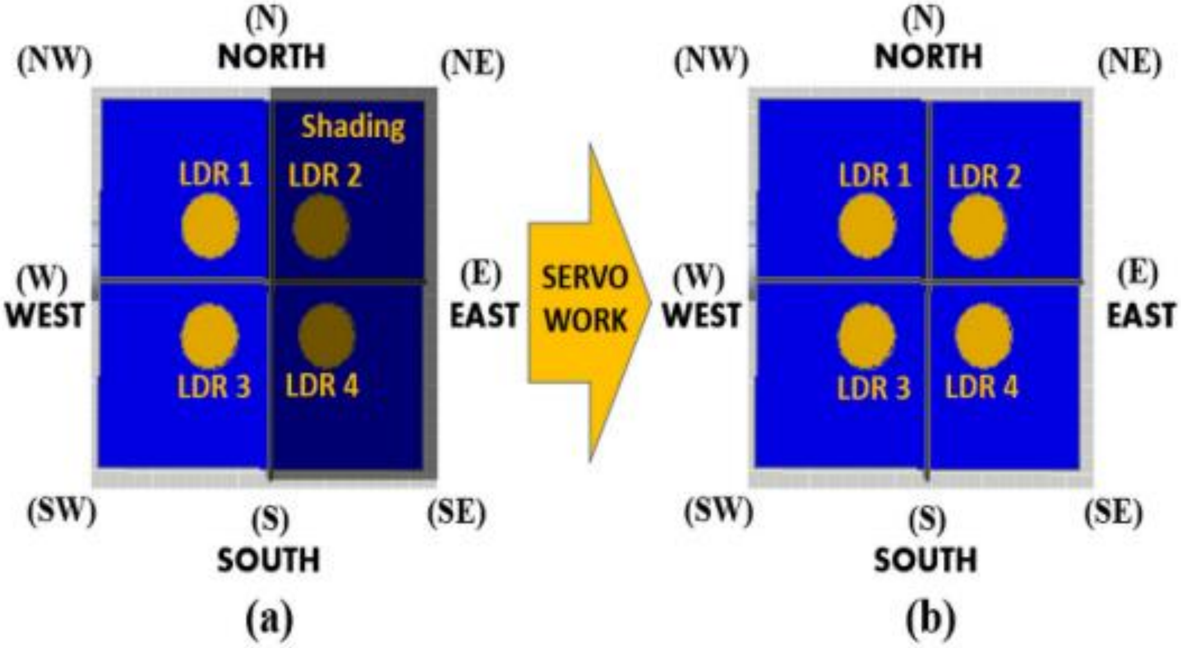

Fig. 4-4. Dual axis sun tracker LDR sensor design

The working system of the light detecting sensor is that each servo movement direction comprises two LDR sensors that are blocked by a partition. When the sun directs to the west, then the sunlight on LDR 2 and LDR 4 are obstructed by the sensor partition. Thus the horizontal servo will move from the east to the west until all sensors gain equal light intensity or that the sensor is at a 90° angle towards the sun light. The light detection sensor for three other directions also uses a similar principle to the previous one.

4.3.2 Servo motor and Actuator

The electric motor is an activator system commonly used on the sun tracker. Some mostly utilized electric motors are the servo motor, hydraulic pump motor, and stepper motor. In this research uses the servo motor as a driver because it is affordable, has high torque, can save the energy, and easy to control for Clock Wise (CW) and Counter Clock Wise (CCW) direction. The designed system requires two servo motors placed on horizontal and vertical axis as show in Fig. 4.5 below.

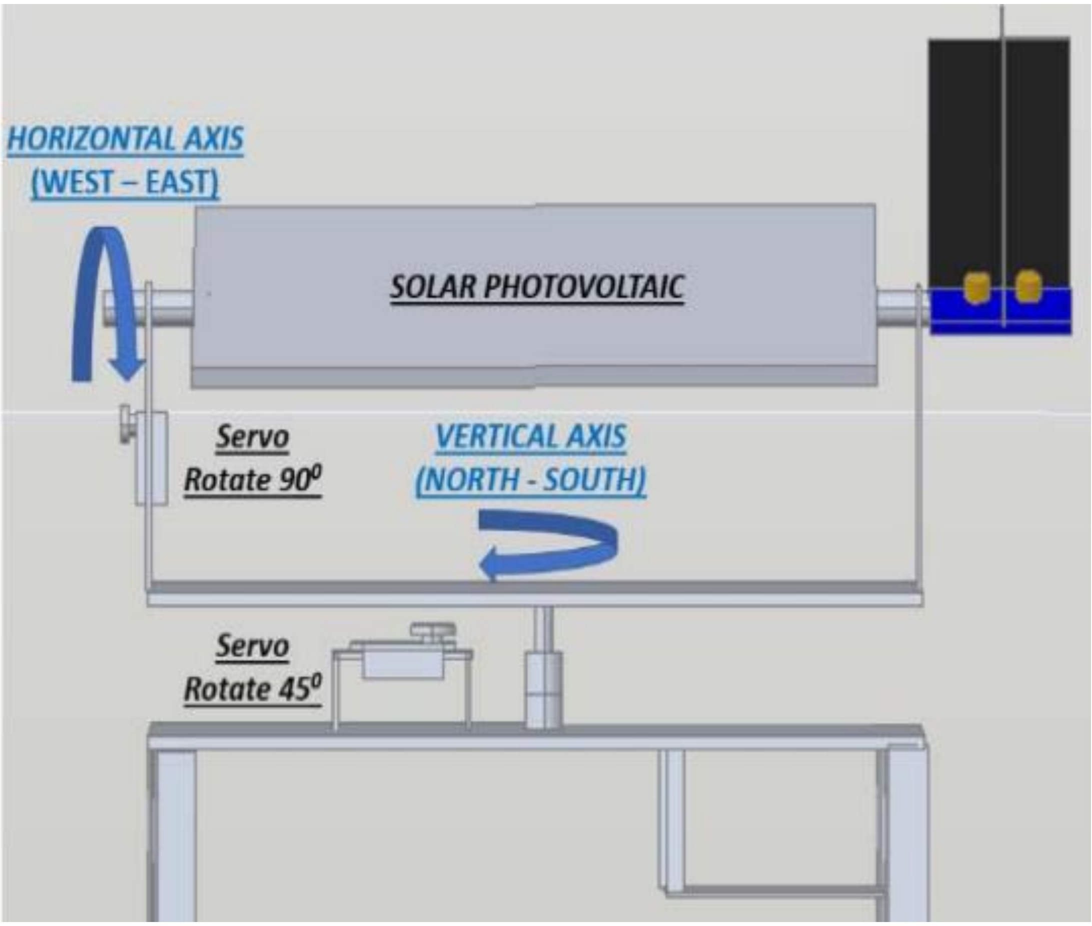

Fig. 4-5 Design of motor actuator for dual axis sun tracker.

The servo motor in this design is capable of driving the SPV panel at 90° CW reference angle and 90°CCW to track the sun movement from the east to the west. Meanwhile, the vertical servo motor could activate the SPV panel with 45° CW reference angle and 45°CCW to track the movement of the sun from the south to the north.

4.3.3 Energy Monitoring and Measurement System

The voltage and current measurement sensor are used to monitor and gauge the energy produced by SPV panel. The voltage sensor used is capable of maximally measuring 25 V DC, containing an array of Voltage divider with a very precise measuring output. Furthermore. For the load from the dual axis sun track demo, there are four power resistors with 47 ohm 20 W connected in parallel. The Data Logger is used to save the measurement outcome on the basis of the time programmed on Arduino. The result is then stored to an SD card in csv format. The procedure applied to realize the monitoring system, measurement, and Data Logger can be seen in flowchart in Fig. 4-7.

4.3.4 Software operation

Working of the proposed smart tracking system is based on the automatic rotation of photovoltaic (PV) panel depending on the intensity of sun light. It will help in maintaining the alignment of PV panels with the Sunlight to obtain maximum solar power at any instance. Intensity of sunlight on a particular alignment of solar PV panel varies throughout the day. As the intensity of light on PV panel decreases the proposed smart tracking system has the intelligence to automatically redirect the panel alignment to get maximum intensity of light. Four Light Dependent Resistor LDR sensors are placed on the surface of the PV panel to detect the intensity of light. Two servomotors are employed in the back side of PV panel system to align the panel with maximum light intensity.

LDRs were used as light sensors: Two for the East-West and two for the North-South orientation. Light intensity was measured by using a resistor in series with each LDR making a voltage dividing circuit as shown in Fig. 4-6. Whenever the intensity of light on LDR changes, its resistance and hence the output voltage are changed; change in intensity is translated into a change in voltage. Under the following four conditions, tracker decides the direction to be moved:

- If light intensity on both LDRs is same, it means their resistance would be equal and hence the same voltage to the controller; solar tracker will maintain its present position.

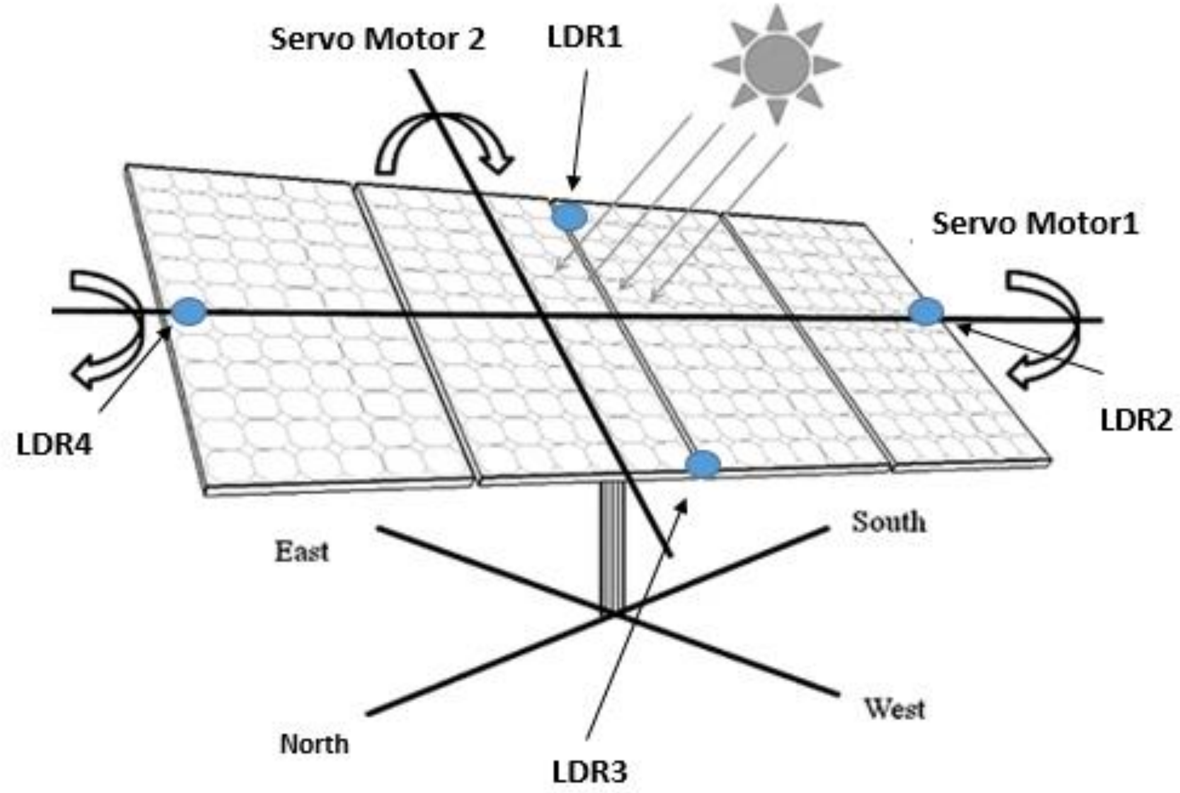

Fig. 4-6 Dual Axis Active Solar Tracker.

- If intensity on LDR2 is larger than intensity on LDR4, the resistance of LDR2 will be lower than the resistance of LDR4 resulting in V2 > V4; servo motor2 will move rightward; solar tracker will move toward the east.
- If intensity on LDR4 is larger than intensity on LDR2, the resistance of LDR4 will be lower than the resistance of LDR2 resulting in V4 > V2; servo motor2 will move leftward; solar tracker will move toward the west.
- If intensity on LDR1is larger than intensity on LDR3, the resistance of LDR1 will be lower than the resistance of LDR3 resulting in V1 > V3; servo motor1 will move upward; solar tracker will move toward the north.
- If intensity on LDR3 is larger than intensity on LDR1, the resistance of LDR3 will be lower than the resistance of LDR1 resulting in V3 > V1; servo motor1 will move downward; solar tracker will move toward the south.

Each time the position of the sun is changed, the controller repeats the same flowchart algorithm and orients the panel in the sun’s direction, solar tracker flowchart is shown in Fig. 4-7. Appendix A have been processed in this way.

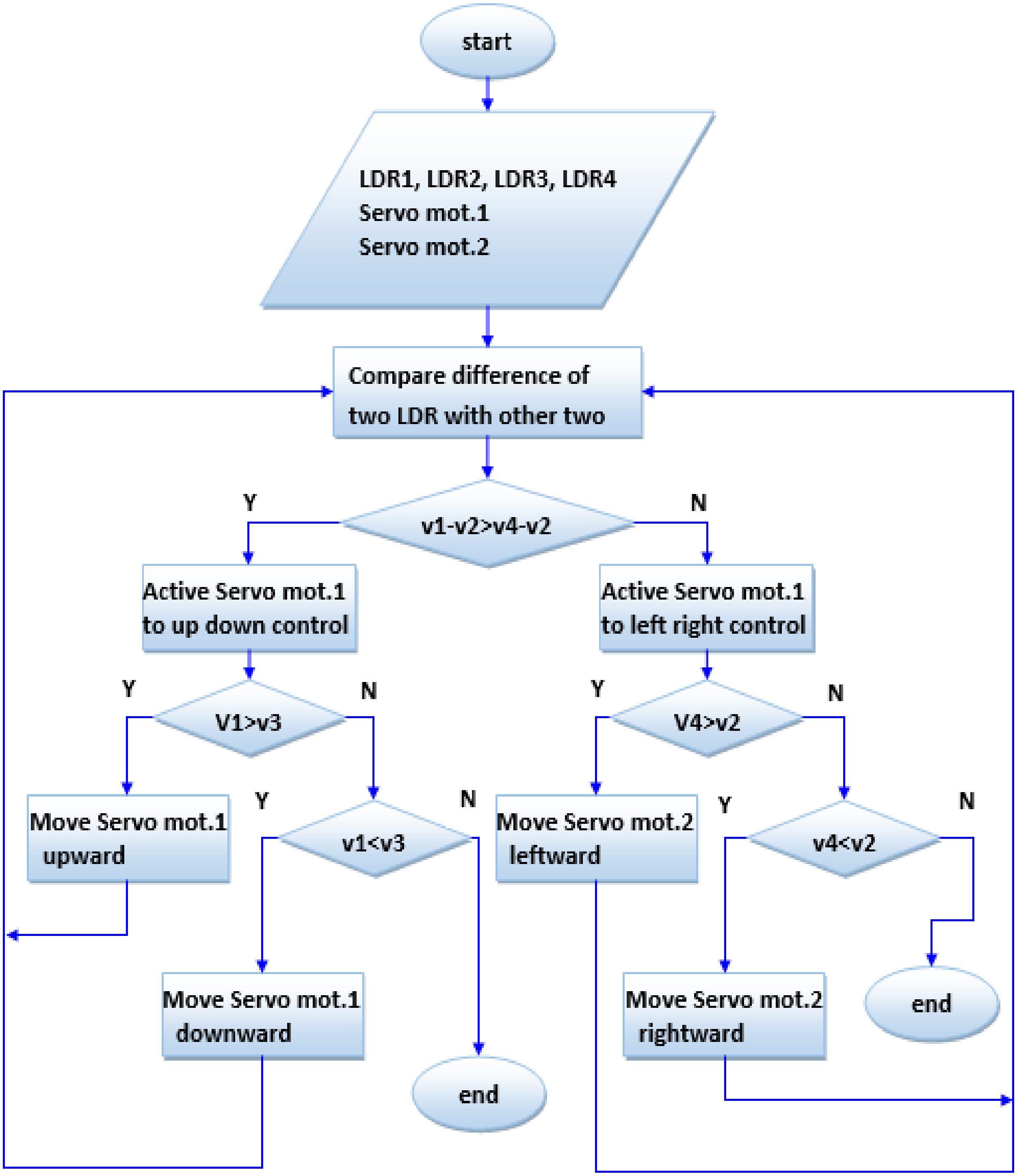

Fig. 4-7. Flowchart of smart dual-axis Tracker.

Chapter 5

Implementation and Results Efficiency of Dual Axis Sun Tracker System

Chapter 5

Implementation and Results Efficiency of Dual Axis Sun Tracker System

5.1 Introduction

Dual axis tracking system uses the solar panel to track the sun from east to west and north to south using two pivot points to rotate. The dual axis tracking system uses four LDR’s, two motors and a controller. The four LDR’s are placed at four different directions. One set of sensors and one motor is used to tilt the tracker in sun’s east – west direction and the other set of sensors and the other motor which is fixed at the bottom of the tracker is used to tilt the tracker in the sun’s north-south direction. The controller detects the signal from the LDR’s and commands the motor to rotate the panel in respective direction.

5.2 Efficiency of Dual-Axis Tracking System over Fixed Mount

The readings for both the static panel and dual-axis tracker are taken for from morning 7 Am to evening 6 Pm for every one hour. PV panels were get Solar radiation database from an open place in Khartoum International Airport (15° 35′ 22.19″ N, 32° 33′ 11.38″ E) [16]. The following readings are tabulated and a graph was generated using MATLAB as follows:

Table. I Fixed Vs Dual-Axis

Hours	**Fixed Panel** (W)				**Solar Tracking (Dual Axis)** (W)			
	14th August	**15th August**	**16th August**	**Average**	**14th August**	**15th August**	**16th August**	**Average**
07:00 AM	2.31	7.39	7.55	5.75	1.18	10.7	10.82	7.56
08:00 AM	98.44	101.5	102.07	100.67	183.97	237.53	253.2	224.9
09:00 AM	173.74	260.24	258.19	230.72	205.38	637.42	609.1	483.96
10:00 AM	160.26	407.77	404.04	324.02	166.2	692.34	674.24	510.92
11:00 AM	505.73	514.76	508.38	509.62	698.71	718.81	700.7	706.07
12:00 AM	554.82	572.14	566.24	564.4	693.56	724.4	710.65	709.53
01:00 PM	126.7	582.82	573.08	427.53	146.23	723.31	703.35	524.29
02:00 PM	75.78	545.81	523.16	381.58	86.34	713.91	667.42	489.22
03:00 PM	80.24	422.92	443.43	315.53	86.57	615.46	642.06	448.03
04:00 PM	253.79	330.95	323.62	302.78	341.63	633.89	595.35	523.62
05:00 PM	176	174.65	173.53	174.72	567.41	506.96	501.9	525.42
06:00 PM	45.14	47.09	47.24	46.49	344.54	281.78	177.85	268.05
Average Power	**187.74**	**330.67**	**327.54**	**281.98**	**293.47**	**541.37**	**520.55**	**451.80**

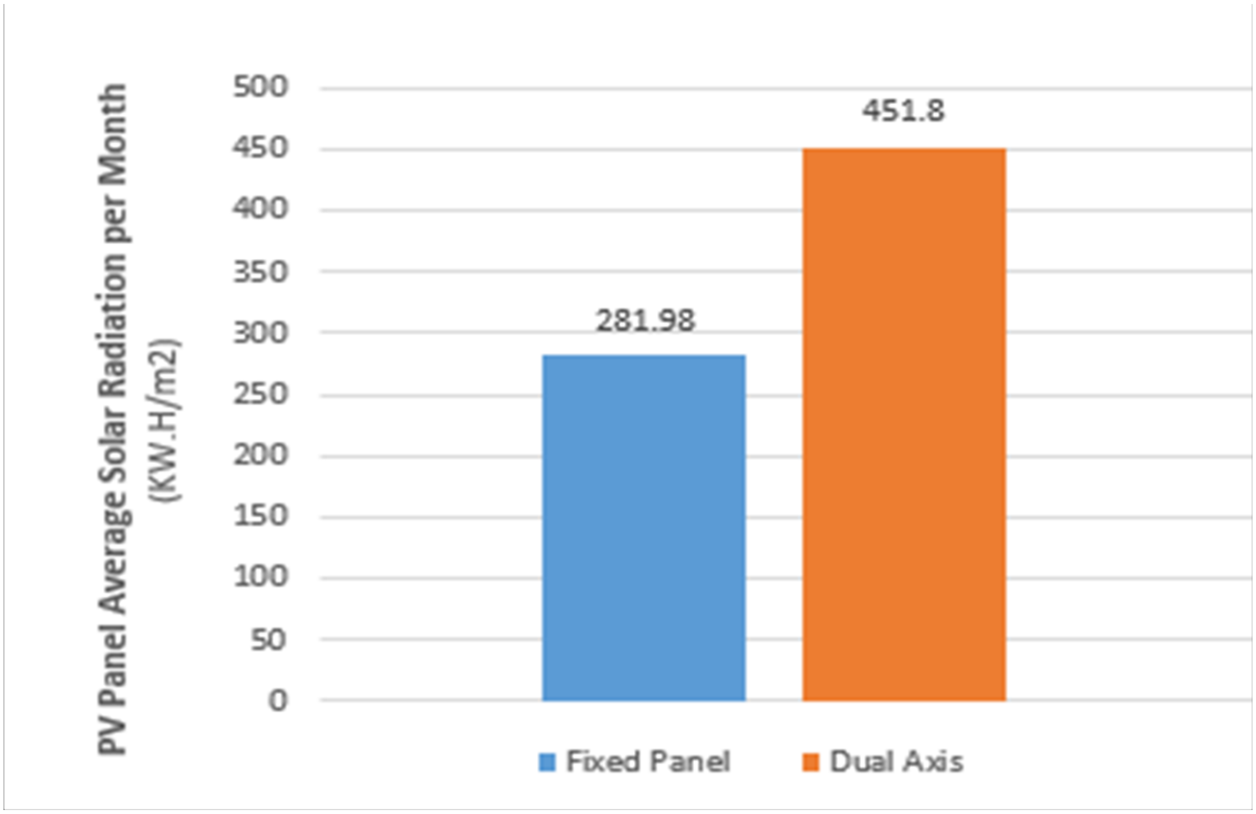

Fig. 5-1. Efficiency of Dual-Axis Tracking System over Fixed panel.

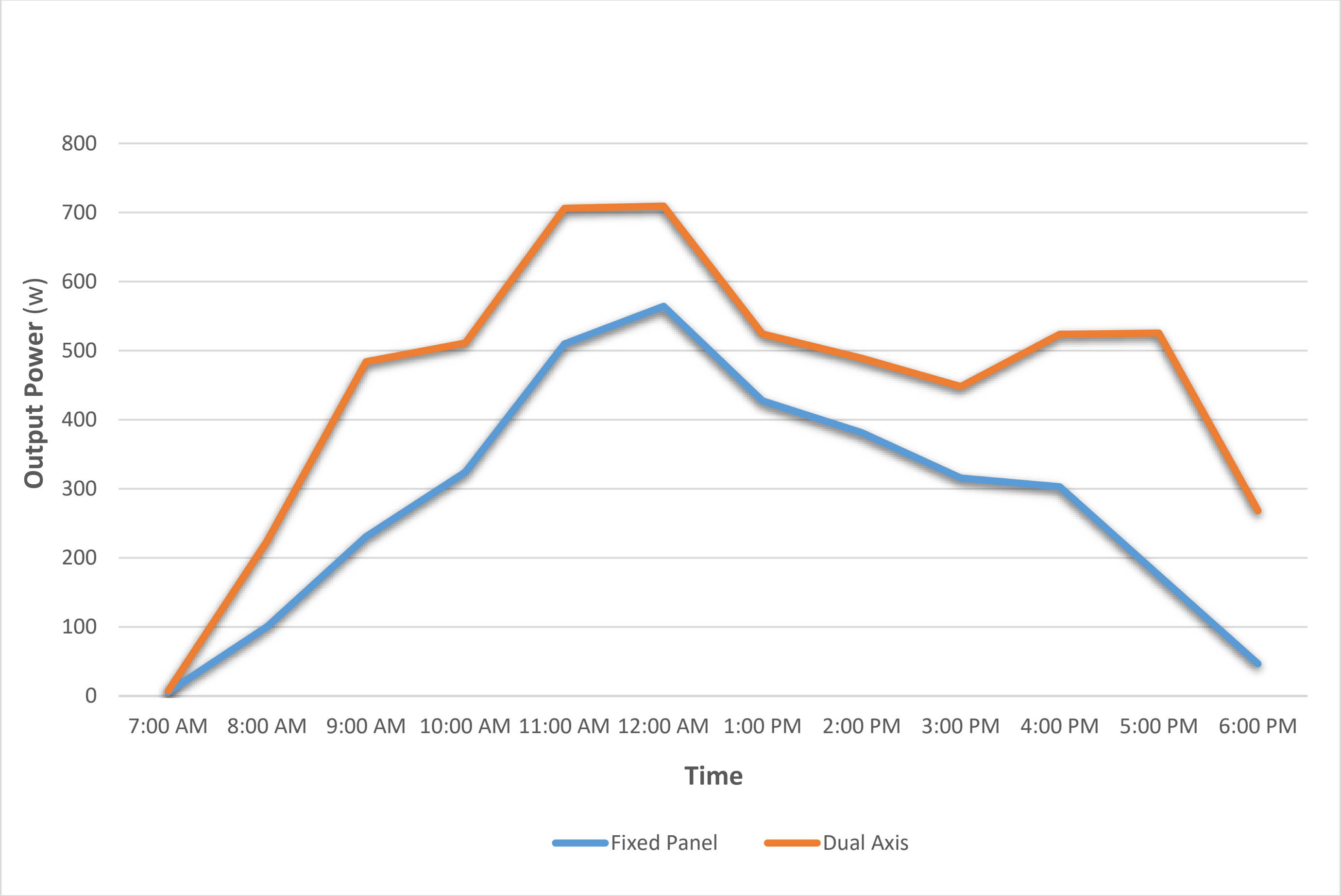

Fig. 5-2. Simulation Result for Comparison of Fixed Mount and Dual Axis Tracker System.

Dual axis sun tracker has proved to be effective in optimizing the energy production generated by SPV panel. There was a great deal of energy produced in comparison to the panel without sun tracker. According to the measured readings the efficiency of the dual axis tracker is found to be 60.22% higher than that of fixed panel. this is calculated from MATLAB code to Simulation Result for Comparison of Fixed Mount and Dual Axis Tracker System as shown in Appendix B.

5.3 Experimental Approach

Total solar radiation from the installed PV panels was measured during 12 months during year. Fig.5-3 shows one of the fixed panels. The tests were also conducted for the south oriented panels at the different angles of inclination to earth surface: a) a horizontal position (0°); b) a vertical position (90°); c) at an angle of 45°. Fig.5-3 shows different methods of the installation of the PV panels. Fig. 5-4 presents the results of measurements for comparison. In conformity with results of the tests, installation of PVs oriented to horizontal position maximizes total solar radiation comparing to other fixed panel's orientations. Besides, Dual-axis sun tracking increases power to 18.71% over the optimum angle of inclination mounted PV. MATLAB code was developed and validated to analysis amount of received radiation database as shown in Appendix C.

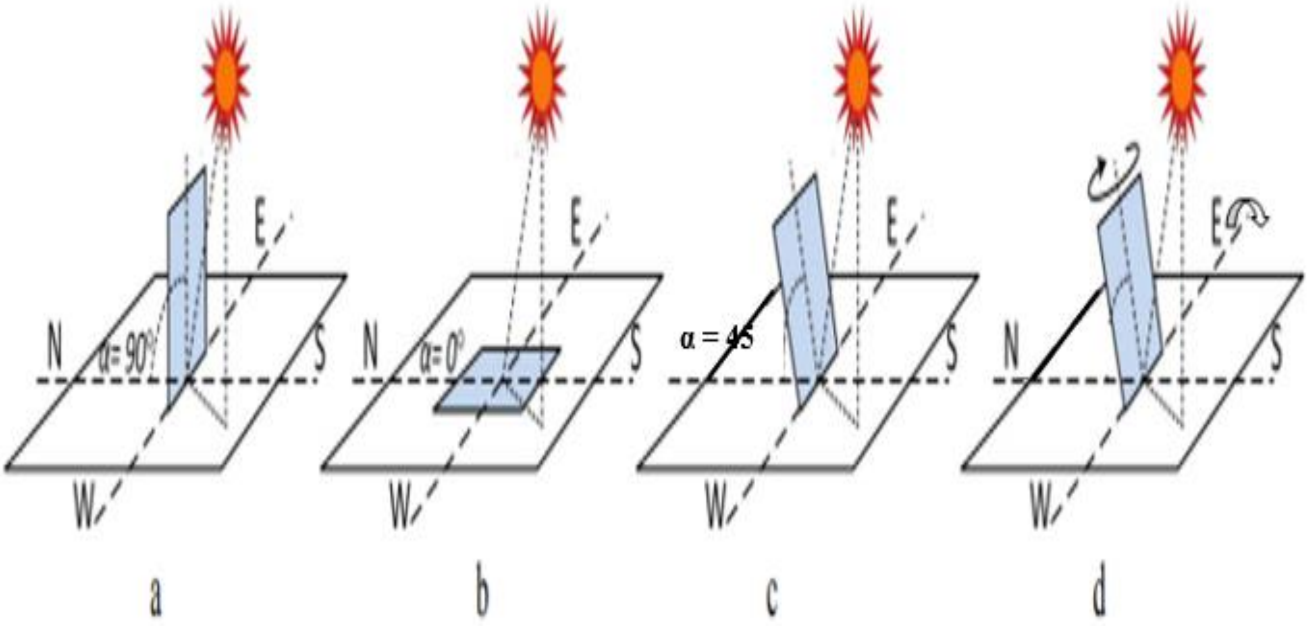

Fig. 5-3. PV panel's different orientations a - vertical position (α = 90°); b - horizontal position (α = 0°); c - optimum angle of inclination (α = 45°); d - Dual-axis sun tracking.

Table.2 PV panel’s different orientations Vs Dual-Axis

Month	**Solar Radiation** (KW.H/m2/mo)			
	α=90°	**α=0°**	**α=45°**	**Dual-Axis**
January	188.72	184.45	251.11	257.52
February	142.83	187.76	221.34	248.40
March	108.57	228.92	222.85	267.62
April	54.35	230.75	183.6	245.23
May	32.72	222.07	154.24	228.52
June	34.93	213.98	139.89	216.53
July	36.98	200.06	138.53	189.48
August	48.1	194.37	151.24	179.21
September	80.37	187.57	170.96	192.72
October	32.11	199.52	218.56	215.11
November	165.15	182.19	232.86	299.99
December	193.17	176.34	249.21	230.90
Average	**93.17**	**200.67**	**194.53**	**230.94**

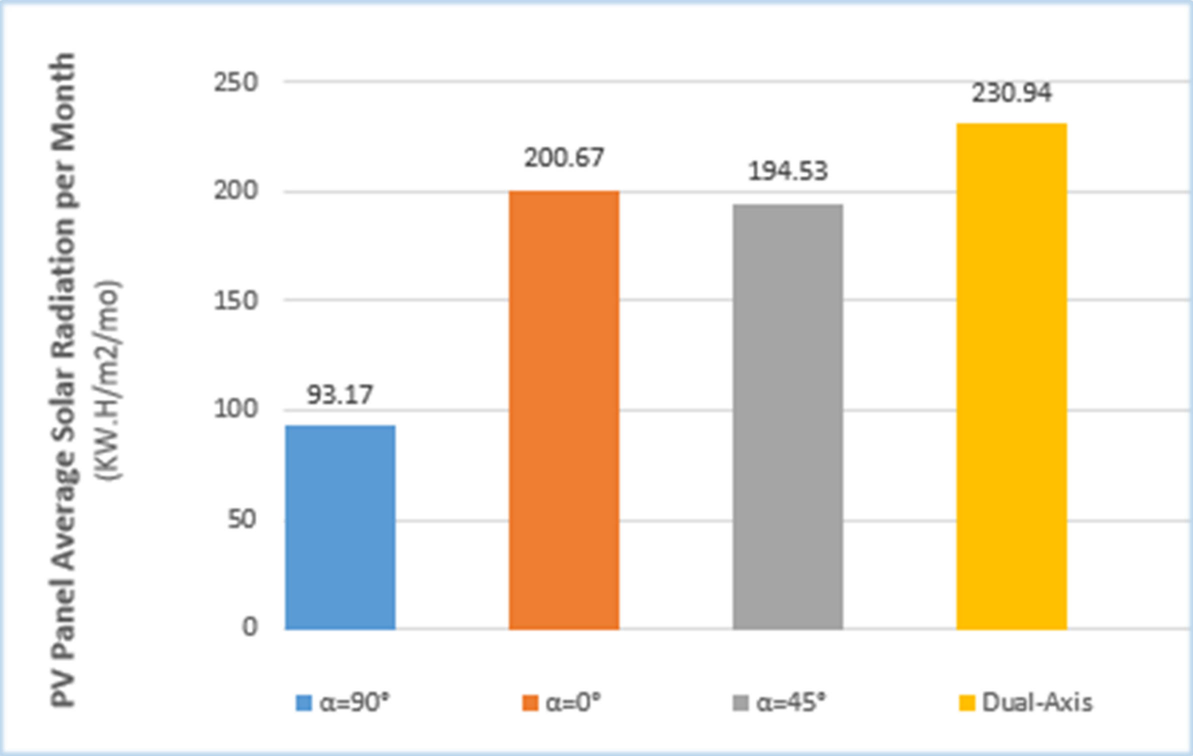

Fig. 5-4. Efficiency of solar radiation during year of differently orientated PV panels.

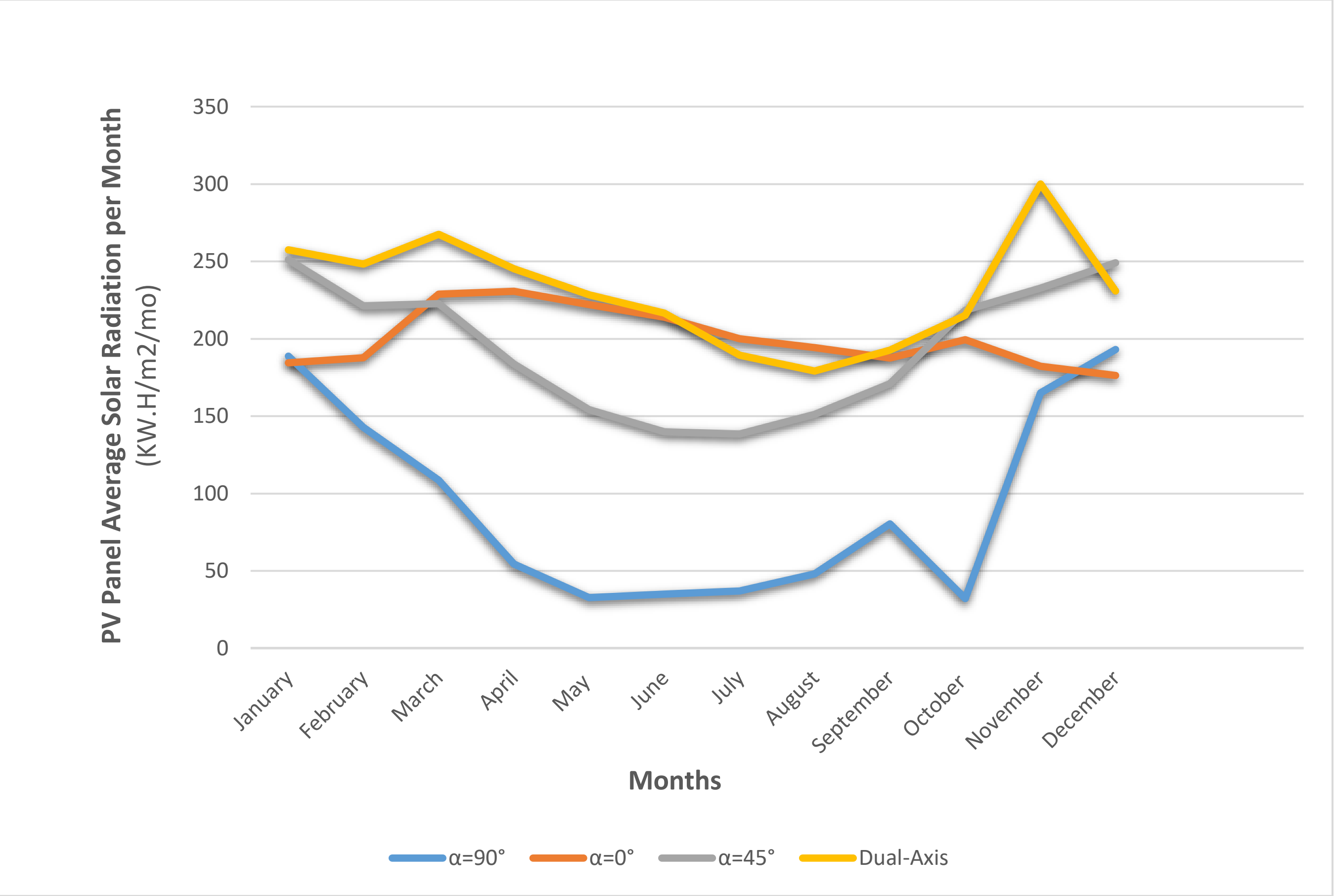

Fig. 5-5. Average monthly solar radiation during year of differently orientated PV panels.

Chapter 6

Conclusion and Recommendations

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

The significant objective of this research is the simplest and cheap mechanical design system included the solar dual axis tracking system if compared with other technical solar systems. Good quality of control unit design that can operate more one technique in the same instant. Overall efficiency of the solar system is advanced along the day time of four seasons.

The proposed model of the dual axis solar tracker is capable of tracking the sun throughout the year. The dual axis tracker provides higher output power when compared to single axis tracker and fixed panel. According to the measured readings the efficiency of the dual axis tracker is found to be 60.22% higher than that of fixed panel.

6.2 Recommendations

In further research, it is suggested that to perform a detailed calculation of the mechanical parts and joints of the system, and make selection of specific actuators based on a calculation of mass dimensional characteristics of the construction.

The efficiency of the dual-axis tracking system can be increased even more by placing a mirror or concave lens on top of the panel. The use of lens or mirror increases the tracker's efficiency since large amount of sunlight is concentrated on the panel and large power is generated. It can also reduce the size of the solar cell required to generate large power. It also has high optical efficiency

Dust particles present in the atmosphere in a large quantity. They cover the panel. This becomes an interruption in the direct contact between Sun light and PV cells. It may decrease the efficiency of the solar power plant. Hence an automatic system can be designed and fabricated for the cleaning of the panel.

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Appendixes

Appendix A: MATLAB Code of the Proposed Smart Tracking System.

Appendix B: MATLAB Code to Simulation Result for Comparison of Fixed Mount and Dual Axis Tracker System.

Appendix C: MATLAB Code to Analysis Amount of Received Radiation Database of PV Panel’s in Different Orientations.

Appendix A: MATLAB Code of the Proposed Smart Tracking System.

```
%clc
clear
v1=input('inter v1: ');
v2=input('inter v2: ');
v3=input('inter v3: ');
v4=input('inter v4: ');
if v1>v3&v2>v4
    disp('servo motor1 will move rightward ;servo motor2
will move uptward ;panel will move north & est.');
    elseif v1>v3&v2<v4
    disp('servo motor1 will move leftward ;servo motor2
will move uptward ;panel will move north & west.');
    elseif v1>v3&v2==v4
    disp('servo motor1 will not move ;servo motor2 will
move uptward ;move toward the north.');
    elseif v1<v3&v2>v4
    disp('servo motor1 will move rightward ;servo motor2
will move downward ;panel will move south & est.');
    elseif v1<v3&v2<v4
    disp('servo motor1 will move lefttward ;servo motor2
will move downward ;panel will move south & west.');
    elseif v1<v3&v2==v4
    disp('servo motor1 will not move ;servo motor2 will
move downward ;panel will move south.');
    elseif v1==v3&v2>v4
    disp('servo motor1 will move rightward ;servo motor2
will not move ;panel will move est.');
    elseif v1==v3&v2<v4
    disp('servo motor1 will move leftward ;servo motor2
will not move ;panel will move west.');
 else
    disp('servo motor1 will not move ;servo motor2 will
not move ;panel maintain its present position.');
end
```

Appendix B: MATLAB Code to Simulation Result for Comparison of Fixed Mount and Dual Axis Tracker System

```
clc
clear
x=[7 8 9 10 11 12 13 14 15 16 17 18];
y=[5.75 100.67 230.72 324.02 509.62 564.4 427.53 381.58
   315.53 302.78 174.72 46.49];
z=[7.56 224.9 483.96 510.92 706.07 709.53 524.29 489.22
   448.03 523.62 525.42 268.05];
axis([6,20,10,800]);
hold on
plot(x,y,'b-o','linewidth',1)
plot(x,z,'r-*','linewidth',1)
hold off
xlabel('Time(sec)')
ylabel('Output Power(W)')
legend('Fixed','Dual Axis')
```

Appendix C: MATLAB Code to Analysis Amount of Receive Radiation Database of PV Panel’s in Different Orientations

```
%clc
clear
x=[1 2 3 4 5 6 7 8 9 10 11 12];
y=[184.45 187.76 228.92 230.75 222.07 213.98 200.06
   194.37 187.57 199.52 182.19 176.34];
z=[251.11 221.34 222.85 183.6 154.24 139.89 138.53
   151.24 170.96 218.56 232.86 249.21];
n=[188.72 142.83 108.57 54.35 32.72 34.93 36.98 48.1
   80.37 32.11 165.15 193.17];
h=[257.52 248.40 267.62 245.23 228.52 216.53 189.48
   179.21 192.72 215.11 299.99 230.90];
hold on
plot(x,n,'b--o','linewidth',1.5)
plot(x,y,'m--x','linewidth',1.5)
plot(x,z,'g-.','linewidth',1.5)
plot(x,h,'r--*','linewidth',1.5)
hold off
xlabel('Month')
ylabel('PV panels Average Solar radiation per
       Month(kW/m2/mo)')
legend(' α=90','α=0','α=45','Dual Axis')
```