DECEMBER 2018 M. Sc. in Mechanical Engineering FAREED ABDULKAREEM ALTAEE

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A STUDY ON THE IMPROVEMENT OF SOLAR PV PANEL EFFICIENCY AND POWER OUTPUT

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IN

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BY

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An experimental study on the improvement of a solar PV panel efficiency

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Supervisor

Prof. Dr. M. Sait SÖYLEMEZ

by

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ABSTRACT

A STUDY ON THE IMPROVEMENT OF SOLAR PV PANEL EFFICIENCY AND POWER OUTPUT

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M. Sc. in Mechanical Engineering
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Solar Tracking System is a unit used in many solar energy systems such as for concentrating a solar lens or reflector or orienting a solar panel in the direction of sun. In photovoltaic (PV) systems, trackers enable to reduce the angle of incidence between the incident sun light and the PV panel, which improve the energy generation of the PV panel. In this thesis, we proposed a dual axis tracking system for a PV panel and investigated several factors that should be put in consideration involves: the level of direct solar irradiation, feed-in tariffs in the location in which the system is set up, and also the cost to maintain and install the trackers. The goal of this thesis is to design two axis trackers in PV panel is to place the solar panels perpendicular towards the sun's rays. For tracking system, a spherical solar cell indicator has been used in order to analyzing electrical energy generation for almost all direction in real time to determine the best position that panel should be directed. It consisted of several solar cell arranged on semi spherical structure. The energy product from each cell will be amylases by specific program in microcontroller that will determine best direction that PV panel should be aligned and control the solar trackers in order to rotate on horizontal and a vertical axis. The result shows the the prposed system got a good acuricy and the reltivaly improvement in power generation.

Keywords: Solar Tracking System, Dual Axis Tracking System, Photovoltaic Panels, PV.

ÖZET

FOTOVOLTAİK GÜNEŞ PANELLERİNİN VERİMLİLİK VE GÜÇ DEĞERLERİNİN GELİŞTİRİLMESİ ÜZERİNE BİR ÇALIŞMA

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Güneşi sürekli takip etme uygulaması bu sistemlerde kullanılabilmektedir. Fotovoltaik sistemlerde enerji üretimini arttırmak için güneşi sürekli takip eden bir sistem üzerinde araştırma yapılarak elde edilen sonuçlar bu çalışmada sunulmaktadır. Sunulan çalışmada çift eksenli olarak kontrol edilen güneş takip sistemi uygulaması güneş ışınımını en yüksek seviyede alabilmektedir. Bu sistemler genellikle maliyet anlamında irdelenmekte ve uygulanabilmektedir. Çalışmanın temel amacı çift eksen kontrollü güneş takip sisteminin maksimum verimde çalışabilecek şekilde dizayn edilmesidir. Bu amaçla, mikro kontrol sistemleri kullanılarak elektronik kontrol ünitesi tesis edilmiştir. Küresel ve düzlemsel iki farklı kontrol paneli kullanılarak elde edilen sonuçlar mukayese edilmiştir. Sonuç olarak, bu sistemin uygulanabilir olması için en düşük maliyetle en yüksek verimi elde edebilmek adına bu araştırma gerçekleştirilmiş ve literatüre yeni birtakım katkılar sağlanmıştır.

Anahtar Kelimeler: Güneş Takip Sistemi, Çift Eksenli Takip Sistemi, Fotovoltaik Güneş Paneli.

This Thesis Is Dedicated To ….

My parents, my brothers, my sisters, my family, and my friends for their continuous support and never-ending love and encouragement ….

WITH GREAT LOVE

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LIST OF SYMBOLS / ABBREVIATIONS

β	Tilt Angle
φ	Latitude Angle
AADAT	Azimuth-Altitude Dual-Axis Trackers
AC	Alternating Current
DC	Direct Current
HSAT	Horizontal Single Axis Tacker
LDRs	Light Dependent Resistors
MCU	Microcontroller Unit
P	Power
P_{max}	The Maximum Power
PASAT	Polar Aligned Single Axis Tacker
PV	Photovoltaic
PWM	Pulse Width Modulation
TF	Thin Film
TFSC	Thin-Film Solar Cells
TSAT	Tilted Single Axis Tacker
TTDAT	Tip-Tilt Dual-Axis Trackers
V	Volt
VSAT	vertical single axis tacker

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Renewable energy is becoming the appropriate alternative approach to generate energy besides prevent the concerns associated with weather conditions change as a result of the emission of green house gases. Solar energy is infinite, close to, free and requires no polluting deposit or exhausts of greenhouse gases [1].

The theory of transformation of solar light to electric power, called PhotoVoltaic (PV) transformation. The PV approach is not too new, even so, the improving of power generation productivity of the PV products is still one of most important focus for many academic and/or commercial study organizations around the world. The PV panel power generation ability is dependent on the sunlight intensity. The sun positioning associated with any world location is variants in a cyclic track during a season. Tracking the sun positioning can be able to enhance a PV panel power production by positioned the PV panel at maximum radiation side at any area and any given time [2].

Solar tackers are the devices which orient the solar panels continually depending on the changing of the sun position and to make sure that at any possible time the positioning of the PV panel is perpendicular towards the sun in order to enhance efficiency. Many tacking system models are readily available that have 1 or 2 degree of freedom. This involves both active and passive systems. A single axis tackers will be classified as: tilted single axis tacker (TSAT), vertical single axis tacker (VSAT); horizontal single axis tacker (HSAT); and polar aligned single axis tacker (PASAT). The HSAT can be utilized in tropical regions in which the days are relativaly short and sun becomes highly at moon time. VSAT can be used at places in which the summer days are lengthy and sun doesn't get highly. The use of one axis tracker provides a good power gain to the system. For more power gain it should be using the dual-axis tacking system. The dual axis solar tackers contain both vertical and horizontal axis and therefore they are able to track the sun's motion intended for placing the PV panel perpendicular towards the sun's ray. The dual axis-passive trackers operate using the concept of materials thermal expansion. A form of memory alloy shape; usually; chloro fluorocarbon is utilized. As the PV panel is perpendicular to the sun; both sides have reached equilibrium. Sun's motion will cause one side being heated while the other side to contact; as a result the solar panel will be rotated [3]. Nevertheless, these systems according to Ref. [4] aren't favorite commercially.

1.2 Solar Power Generation Concept

There are several aspects effected on power generation that should be taken into consideration that can effect on PV power genration, which are in follows.

1.2.1 Photovoltaic System (PV System)

Photovoltaic system is a relatively recent supplier of clean energy. The popular of clean energy resources would have performed a vital role in study and evolution of the PV system. The modern PV systems are a lot more efficient whch can be in between 40% and 45% for some of the technology presently being designed in research laboratories in compartion with the earliest PV systems who was used solar cells based amorphous silicon that got just 6% efficiency. A regular range of efficency for today’s commercial presented modules is in range inbetween 15% to 20% [5]. One another significant factor in PV systems is the charge controller that vary the charging rates depending on the battery’s charge level. It controls the charging of the battery’s nearer to its maximum capacity. In addition, it monitors the battery’s temperature so that avoiding overheating. [6]. The other important PV system parts is the control and stability [7].

1.2.2 Sun’s Path and Solar Position

The path of the sun is the relative earth motion around the sun, by the hour and by the season. The sun position at a given time is varied with seasons or possibly with months. The Sun path over different seasons is illustrated in the Figure 1.1 [8].

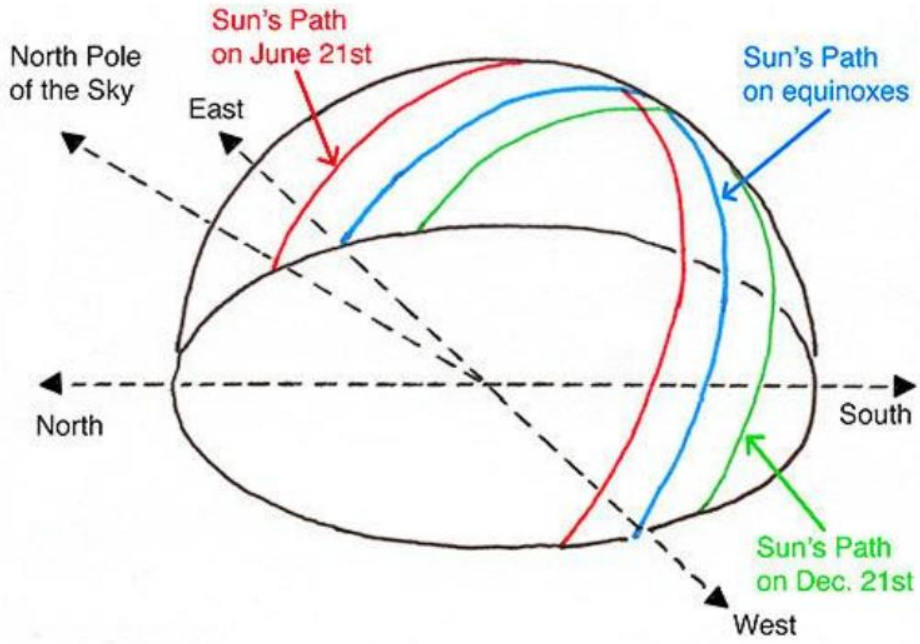

Figure 1.1 Path of the sun over different seasons [8]

Because of that, the incident solar irradiation could not all the time be normal to the PV panel which has a fixed position. As a result, the sunlight falling intensity on the PV panel is significantly reduced. Sun path tracking systems have been used to reposition the PV panel considering the sun movement to ensure that the incident sunlight is constantly normal to the PV panel surface [9].

One of the popular regular technique used in the present day to track sun location is to comprise of two photo-sensors positioned at couple opposite sides of PV panel [10]. Tracking is made by evaluating the output voltage of two photo-sensors. In case the output of the two sensors differ by a lot more than certain appropriate error amount, in that case the solar panel is shifted in the particular direction. One more interesting approach utilises image processing to keep track of the Sun's current position [11]. It utilises a designed reflecting type Cassegrain telescope to obtain an image. After that it uses image processing to acquire the coordinate of Sun center and then moves the panel toward the Sun's center. The other techniques involve GPS receiver [12], where the GPS receiver output is fed into a microcontroller (MCU) that can calculate the current altitude and elevation of sun, then the solar panel is directed to that particular direction.

1.3 Related Works

The following is a brief description of the thesis that was studied to understand about solar tracker.

1.3.1 Brief Histrory of Solar Cell and Solar Traking System

The development in technologies of solar cell starts with 1839 test done by Antoine-Cesar Becquerel who is the French physicist, from his expriement he noticed the photovoltaic effect with a small electrode in an electrolyte solution. Consequently, he noticed a voltage produced when light dropped upon the electrode [13].

In 1876, the William Grylls Adams, the british natural philosopher, along with his student Richard Evans Day presented the photovoltaic influence in a junction based upon the semiconductor selenium and platinum, even so, with a poor performance. After that, Charles Fritts, the american inventor has managed to try to make a PV-device based on a gold-selenium junction. The efficiency of energy conversion of that device was 1%. In 1887, Heinrich Hertz, the German physicist, had observed the photoelectric effect. In such effect, the electrons will be emitted from a material featuring absorbtion to light that having a wavelength shortest than a material-dependent threshold frequency. During 1905, the Albert Einstein posted a paper that has he described the photoelectric effect with supposing that light energy is having carried with quantised packages of energy, that currently called photons. In 1918 the Jan Czochralski, the Polish chemist developed a method to produce high-quality crystalline materials. This procedure currently is very significant for growing monocrystalline silicon utilized for high-quality silicon solar cells. The evolution of the c-Si technology began in the second half of the 20th century. Dan Trivich, in 1953,was the first one to implement theoretical calculations on the performance of solar cell for materials having different bandgaps. In 1954, the researchers Gerald L. Pearson, Calvin S. Fuller, and Daryl M. Chapin had made a solar cell based silicon with 6% efficiency [14].

More advancement have been achived from that time until the 1980 where the first thin film solar cells has been demonstrated at university of Delaware, which is based upon a junction of copper-sulfide/cadmium-sulfide and it has been achived a 10% conversion efficiency. In 1985, the university of New South Wales in Australiasolar has been demonstrated a cells based crystalline silicon with efficiencies above 20%. In 1991 the first highly efficent Dye-sensitized solar cell had published by Michael Grätzel and coworkers in Switzerland. This type of solar cell is a type of photo-electrochemical system, where a semiconductor material dependent on molecular sensitizers, is positioned between electrolyte and photoanode. In 1994, the National Renewable Energy Laboratory in united state has demonstrated a concentrator solar cell based upon III-V semiconductor materials. Their solar cell is exceeded the 30% conversion limit. From 2000 century, the economic and environmental issues began to become increasingly more important in the public discussion, that renewed the public interests in solar energy [15].

Along with the development of solar cell, the solar trackers have been started in around 50 years. The first tracker type was the passive trackers that is manufactured has started in late of 1970s. In the 1980s, the Array Systems like Zomeworks, is started providing solar trackers that is closedloop and optically controlled which is still made in our day. In 1975, McFee publicized one of the initial automatic solar tracking systems, that has subdivided every plane-mirror into 484 elements, supposing the slope of every element to be associate of the surface slope average at its position, and summing the advantages of all elements and after that the all mirrors in the array [16]

The primary large-scale solar trackers had been built in 1983 in California at the Carrizo Plains, that was the first proposed solar power plants of 750 MW. After some years later, the ARCO constructed dual-axis tracker for PV panel. The modern tracker structure for PV power plants stagnated at the time of most of the Reagan years. As the solar industry began its phoenix-like go up in the 1990s, a few tracker products reached market. Earliest 1990s models lacked the reliability, standardization and, most essentially, the cost structure to be applied on a large scale. Solar economics had been (and still are) operated by the nature of numerous subsidy programs. Common programs in the 1990s had been based upon system peak ratings rather than performance and so the raised financial investment for a tracker design produced less financial sense [17].

Tracker technology continuing to improve as a practical alternative to fixed-tilt for utility-scale solar plants, even though there was very much issue throughout the early

2000s regarding whether it was greater for features to stick with the popular common fixed-tilt solution or switch to a less popular technology to increase production. Among the big concerns about utilizing trackers is about maintenance: How frequently do these moving parts crash? How much its value per watt to work over 30 years? Where various resurches continues to be study to enhancing the solar traking by designed several traking methodes starting from on axis traker to dual axis traker along with lower part requisites and cost, by reducing sensors, motors, and controllers [18].

1.3.2 Recent Solar Traking System Researches

Recently, there are many researches have been achived in area of solar tracking system that can be described as follows:

1. Otieno [19], discussed the model and manufacturing of a prototype for solar tracking system which has a single axis of mobility. He has used the Light Dependent Resistors (LDRs) for detection of sunlight. The controller circuit is depending on ATMega328P MUC. He had programmed to locate sunlight via the LDRs ahead of actuating the servo to positioning the solar panel. The solar panel is positioned in which it is capable to get maximum light. He was utilised servo motors since it able to keep their torque at high speed. Characteristics and Performance of solar panels are analysed experimentally. They proved that the single tracking system is less expensive, not so complex and even so got the expected efficiency in comparison with dual axis tracker system that is extra expensive. The rise in power of their suggested system is significant and as a result worth the tiny increase in cost. Maintenance expense is not likely to be high.

2. Rana [20], designed and constructed a polar single axis tracker. It consists of a fixed vertical axis and a changeable horizontal motor-controlled axis. The tracker attempt to tracks the sun and adjust its position consequently to maximize the energy output. To stop wasting power by operating the motor constantly, the tracker adjusts its position after 2 degrees to 3 degrees of misalignment. The detectors check the intensities of light for each side and move the panels till the tracker recognizes equal light on both sides. Besides

that, it avoids rapid changes in track that might be induced by reflections. A back-sensor circuit is also integrated to help in repositioning the solar panels for the upcoming sunrise. The gear motor has been overturned triggers to protect the panel against rotating 360° and entangling wires. The sensing circuitry and motor control runs on batteries charged by the PV panel. This system utilises three small 10W solar panels of around 15x10 inches to model larger sized panels employed in industry.

3. Vijayalakshmi [21], provided a control system that made better alignment of PV array with sun light and to obtain solar power. The suggested system adjusts its direction in two axes to track the sunlight coordinate by discovering the difference between position of panel and sun. The system has been tested to check the system ability to follow and track the sunlight in an efficient way. They additionally mentioned the brilliance of dual axis solar tracking system beyond the single axis solar tracking system.

4. Morón et al. [22], had designed a new prototype of PV tracker by utilized an Arduino platform. The feedback control system which allows solar tracking with two axes by using a stepper motor and linear actuator had been demonstrated throughout an electronic circuit depending on photodiodes. Furthermore, real structure of the prototype has been carried out, in which the efficiency of the design and its capacity to bring a maximum gain of an incident radiation have been noticed, positioning the panel perpendicularly to the received energy and enhancing its performance for its request in future setting up in housings. The results gained from the comparison between the proposed prototype and the static panel oriented as stated by the latitude of the area, give about 18% energy gain.

1.4 Aim of the Thesis

This thesis is intended to design a dual axis solar tracking system based on real time power cell production analysis that can calculate real cell production from different angle in real time to move panel to the best angle having maximum production. This research work also to makes to design tracker system with relatively lower cost by used low cost component in design.

1.5 Outline of Thesis

This thesis is organized in four chapters besides this chapter and ends with references, each chapter is described as follows:

- **Chapter Two:** explains the solar tracking techniques and the types and methods that has been used in the design of proposed tracker.
- **Chapter Three:** describes the design of the solar tracking system with all hardware and software used in it.
- **Chapter Four**: describes the results and summarizes the main conclusions of the work presented in this work.
- **Chapter Five:** presents the conclusions, and recommendations for future work.

CHAPTER 2

THEORETICAL CONCEPT OF SOLAR TRAKING SYSTEM

2.1 Photovoltaic (PV) Principles

PV is the most widely known as a technique for producing electric power by making use of solar cells packaged in PV modules, generally electrically joined in multiples as solar PV arrays to converts the energy from the sun light directly onto electricity. To basic prinsiple of photovoltaic is that when the sunlight photons hit electrons toward a higher state of energy, thus forming electricity. The photovoltaic (PV) term means the neutral operating function of a photodiode in which the current throughout the device is fully caused by the transduced light energy. Basically all PV units are some kind of photodiode. Physically, a PV panel is consists of a flat surface which have a several p-n junction placed on it that connected with one another by using electronically conducting strips. The PV panel makes sure the change of light radiation to an electrical energy that's characterized that the power output is extremely dependence upon the incident light radiation. Solar cells generets direct current electricity via light that can be utilized to power devices or to charge a battery. The primary practical application of PV was to power orbiting satellites and other spacecraft, but in the present day the most of PV modules are utilized for grid linked power generation. In such a case an inverter is needed to convert the DC to AC.[23]

2.2 Structure of PV System

The PV generator is the significant part in a PV system, however, it requires to affiliate with a number of other types to give a total solution that operates reliably and properly. A PV system involves a number of numerous components and subsystems that are accurately designed and all-together attached to give the preferred power production. Figure 2.1 shows the commonly-found components in a PV system [24].

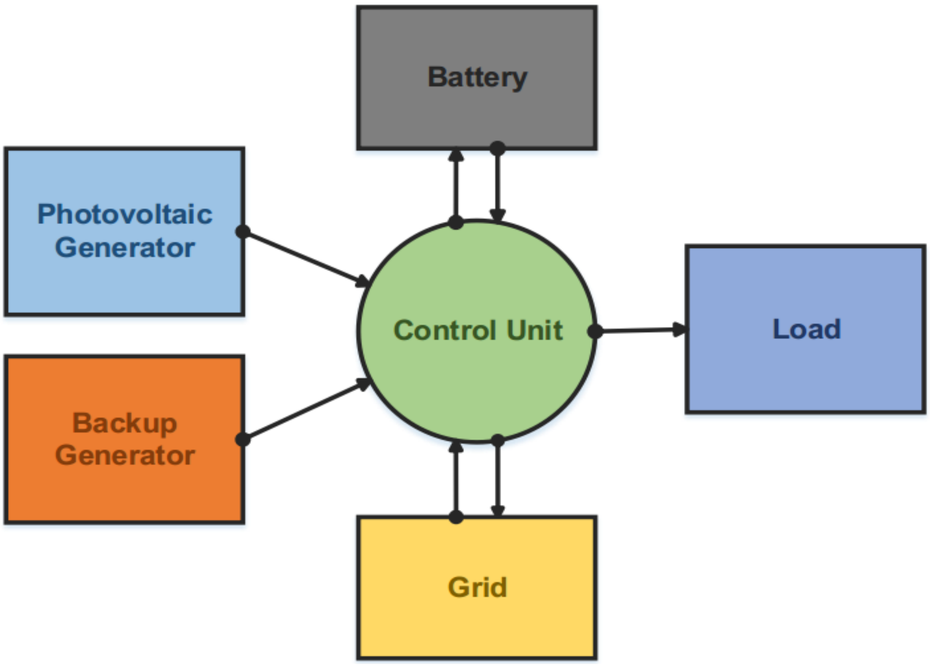

Figure 2.1 Typical components/subsystems of a solar PV system [24]

The PV generator is the most important part of a PV system. It is made by joining multiple PV modules onto solar panels that can be further more connected with each other to make solar array for higher power output. The generator is reinforced by the mechanical element, in whether tracking rotation or fixed position. The PV generator transforms the energy from sunlight to make DC power output that can be used in different ways, according to the application. In compact PV systems, DC output is often consumed by a straight load or charged into a battery for expanded use. For even heavy applications, bigger PV systems also include inverters to give one-phase or three-phase AC output for conventional uses or residential grid systems. For the trusted operation of PV generator, it is necessary to guard individual PV cells in shaded status. Because of the serial interconnection of the cells, the shaded it's possible to act as a load because of forward bias. As a result, the current made from the other cells might warm up the shaded one and burn it up, resulting in system failure. This challenge is avoided by using bypass diodes, to give an alternate path for the PV current if a lot of cell is shaded. Also, in applications used PV generator to charging the battery, a blocking diode is utilized to prevent PV cells from recharging the battery once they are inactive (shaded condition). Energy transformed from the sunlight differs the whole time, so saving that energy is usually a prerequisite. Chemical battery is a common method for energy storage. In order to charge the battery, the PV systems make use of charge regulator for the best functionality and battery protection. The light tracking module, the solar panel protection, charge regulation, along with other regulating modules are all controlled and managed by the control unit, to make certain the proper functionalities of the system. Every one of the components or subsystems in a PV system are supported and physically linked by different mechanical components. They are specially designed to satisfy the application requirements and in adaptation to the working environment. Actual mechanical system, such as tracking system, can highly have an effect on the performance and efficiency of the system, as it can effect how well PV generator can get sunlight energy. [24]

2.3 Solar Panel (PV Panel)

Solar panels are units that converts light directly to electricity. They are also known as "solar panels" since the sun is the most strong source of light existing. Some researchers called them photovoltaic (PV) that means, in short, "light-electricity.” PV is a kind of photoelectric cell, which is the device that its electrical characteristics (voltage, current, or resistance) is change when exposed to light. In cases where the numbers of the photovoltaic cells are collected together, it then make a solar module that can produce electric power from sun light. A solar PV panel is in the combination of multi cells on one plane. Most solar panel has efficiency from 11% to 15%. This efficiency represent the rating measures the sun light percentage that can striking a panel and converted to electricity. The more efficiency, the lesser surface area we will need in our solar panels. There are several types of panel and there are varieties in properties between those panels as well. There are mainly three unique categories of solar panel [25]:

1. Monocrystalline Silicon Solar Cells
2. Amorphous Silicon Solar Cells (Thin-Film Solar Cells (TFSC))
3. Polycrystalline Silicon solar cells

Figure 2.2 shows the three types of PV pane.

Figure 2.2 PV Panels Types (a) Monocrystalline Silicon Solar Cells (b) Polycrystalline Silicon solar cells (c) Thin-Film Solar Cells (TFSC) (Amorphous Silicon Solar Cells) [26]

Mono crystalline PV solar panels are generally the most choice for many years. This because this type of PV panels is most reliable and most efficient methods to production electricity from the sun. Due to the cost efficiency is one of the significant issues to be considered, thus these types is not make it suitable for the system to be designed. A thin film solar cell (TFSC) is a second generation solar cell that is made by dropping one or more tiny layers or thin film (TF) of PV material on a base, for example, ormetal, plastic, glass, etc.. Becouse it produces little electrical power output, then this type of solar panel has commonly used for small-scale applications, such as calculators. However, the latest improvements for these panels make them more attractive for some large-scale uses as well. By making use of amorphous silicon, mass production is convenient but unstable solar panels are often not very useful for maximum commercial sites. These panels are very cheap but at the same time, they as well require enormous space and the efficiency is half polycrystalline and half mono crystalline types. Consequently, this will be not a practical decision to use the amorphous silicon. The current gains that have been offered in polycrystalline solar panel have caused it to be more similarly in efficiency as we get in monocrystalline panels. Among all the positive aspects, it does have one benefit that is something extra ordinary, and that is, it is not influenced by the shades of surrounding buildings and shaded trees [27].

2.4 Solar PV Systems Types

There are different types of PV Systems such as :

A. **Fixed Photovoltaic system:** Fixed Photovoltaic system is adjusted at certain Tilt angle (β). It is the simplest and least expensive type. It will be completely stationary hence, throughout the day, the collected power decreases significantly, and it almost collect all of its energy at noon time where the panel is perpendicular at Solar rays of the Sun. The panel is directed towards the equator (directed towards south in northern hemi-sphere). The Tilt angle (β) is adjusted to be about the latitude angle (φ) so that maximum energy is collected throughout the year [28].

B. **Sun Traker Photovoltaic system:** In photovoltaic systems, trackers help minimize the angle of incidence (the angle that a ray of light makes with a line perpendicular to the surface) between the incoming light and the panel, which increases the amount of energy the installation produces. The use of solar trackers can increase electricity production by around a third, and some claim by as much as 40% in some regions, compared with modules at a fixed angle. In any solar application, the conversion efficiency is improved when the modules are continually adjusted to the optimum angle as the sun traverses the sky. As improved efficiency means improved yield, use of trackers can make quite a difference to the income from a large plant. This is why utility-scale solar installations are increasingly being mounted on tracking systems. However, there are some disadvantages of solar trackers. Adding a solar tracking system means added more equipment, moving parts and gears, that will require regular maintenance and repair or replacement of broken parts. Also, if the solar tracker system breaks down when the solar panels are at an extreme angle, the loss of production until the system is functional again can be substantial. A solar tracker is also more expensive than fixed tracker. Thus these issuses should be take in cosderation in design the efficent solar traker system [29].

2.5 Fundamentals of Solar Tracker

The sun moves over 360 degrees east-west every day, however, the visible portion of sun in any location in any day 180 degrees within a 1-day period. Furthermore, the effects of local horizon will decrease this relatively, making the effective motion around 150 degrees (Sharma, P. et al, 2014). There are many solutions for increasing the PV conversion efficiency such as: new solar cell materials and technologies, optimization of solar cell geometry and configuration, solar tracking, etc. As technologies have developed, the efficiency of the PV panel’s conversion has risen gradually, however it doesn't exceed 13% for the typical ones (Tudor ache et al., 2010). The PV shows a highly nonlinear IV (voltage/current) characteristic and the output power is also nonlinearly dependent upon the insolation of surface. With regards to solar light transformation into electricity, because of the continuing changes in the sun positions, the radiation that incident on the fixed PV panel is consistently changing, achieving an optimum point once the solar radiation direction is perpendicular on the panel surface [30].

A PV in a fixed orientation in between the sunset extremes and dawn will see movement of 75 degrees on each side, and so, based on the table 2.1, will lose about 75% of the energy in the evening and the morning [31].

Table 2.1. Direct Power losses (%) Caused by Misalignment (Angle) [31]

Misalign (angle i)	Direct power lost (0/;= I-co)
0	0
1	.015
3	.14
8	I
23.4	8.3
30	13.4
45	30
60	>50

The significant issue is to increase the capture of the sun rays over the PV panel that will often increase the electricity output. In this context, to increasing the energy-efficiency of the PV panel, it's important to have it geared up with a solar tracking system. An efficient strategy for achieving this is to place the panels in a way that the sun rays fall perpendicularly over the PV panels through the process of tracking the sun movement. This can be carried out through utilizing a PV panel mount that tracks the sun movement during the day. The PV panel motivated using a solar tracker is ensuring to keep it within best achievable insolation for all Sun positions, since the light falls near the geometrical normal incidence angle. Automated solar tracking systems (that used l intensity sensing) could enhance the conversion efficiency consistently f a PV panel, therefore using this method deriving a lot more solar energy. A tracker that rotates in the east-west direction is called a single-axis tracker. Furthermore, the sun is also moving 46 degrees north-south during the period of a year. A similar group of panels set in the midpoint between both local extremes will therefore see the sun move 23 degrees on each side, leading to losses of 8.3%. A tracker that enhances each seasonal daily motion is called a dual axis tracker [31].

There are many types of solar trackers, of varying costs, sophistication, and performance. One well-known type of solar tracker is the heliostat, a movable mirror that reflects the moving sun to a fixed location, but many other approaches are used as well. The required accuracy of the solar tracker depends on the application. Concentrators, especially in solar cell applications, require a high degree of accuracy to ensure that the concentrated sunlight is directed precisely to the powered device, which is at (or near) the focal point of the reflector or lens. Typically, concentrator systems will not work at all without tracking, so at least single-axis tracking is mandatory. Very large power plants or high temperature materials research facilities using multiple ground-mounted mirrors and an absorber target require very high precision like that used for solar telescopes. Non-concentrating applications require less accuracy, and many works without any tracking at all. However, tracking can substantially improve both the amount of total power produced by a system and that produced during critical system demand periods (typically late afternoon in hot climates) [32].

The use of trackers in non-concentrating applications is usually an engineering decision based on economics. Compared to photovoltaics, trackers can be inexpensive. This makes them especially effective for photovoltaic systems using high-efficiency (and thus expensive) panels. Although trackers are not a necessary part of a P.V system, their implementation can dramatically improve a systems power output by keeping the sun in focus throughout the day. Efficiency is particularly improved in the morning and afternoon hours where a fixed panel will be facing well away from the sun's rays. Usually, photovoltaic modules are expensive and in most cases the cost of the modules themselves will outweigh the cost of the tracker system. Additionally, a well-designed system which utilizes a tracker will need less panels due to increased efficiency, resulting in a reduction of initial implementation costs [33].

The advantage of solar tracker against fixed tracker can be simulated in Table 2.2 [24]

Table 2.2. Advantages and disadvantages of trackers over fixed mounts [24]

Advantage	Disadvantage
Higher overall efficiency	More complicated design
Higher accuracy	Higher cost
Longer active functioning time	Worse tolerance against weather condition
Better lifetime for solar cells	Consumption of energy (active trackers)
Applicability for different applications	

2.5.1 Solar Panel's Performance by Fixed Mounting

For PV modules that collect solar energy on the Earth's surface level, the incoming solar radiation consists of three main components [34]:

- Direct beam that reaches straight to the Earth's surface without scattering
- Diffuse radiation that scatters when passing through the atmosphere of the Earth
- Albedo radiation that reflect from the Earth's surface

Of the first two components, direct beam holds about 80% to 90% of the solar energy in ideal condition (clear sky). It is the major source of energy for the operation of PV generator. For maximum collection of solar energy, solar panels need to maintain alignment with the Sun's direct beams as long as possible. This concept is quantitatively explained by measuring the incident angle between the direct beams and the panels i. For the same amount of incoming direct beams, the effective area of solar panel that collects this radiation is proportional to the cosine of i. As a result, the power P collected by solar panels can be calculated using equation 1 [24]:

$$P = P_{max} \times Cos(i)$$

(2.1)

Where: P_{max} is the maximum power collected when solar panel is correctly aligned. From equation (2.1) we can calculate the loss of power (P_{loss}) [24]:

$$P_{loss} = \frac{P_{max} - P_{max} \times Cos(i)}{P_{max}} = 1 - \cos(i)$$

(2.2)

Equation 2.2 tells that the more misaligned angle is; the more sunlight energy is lost. This connection is illustrated in figure 2.3 [24].

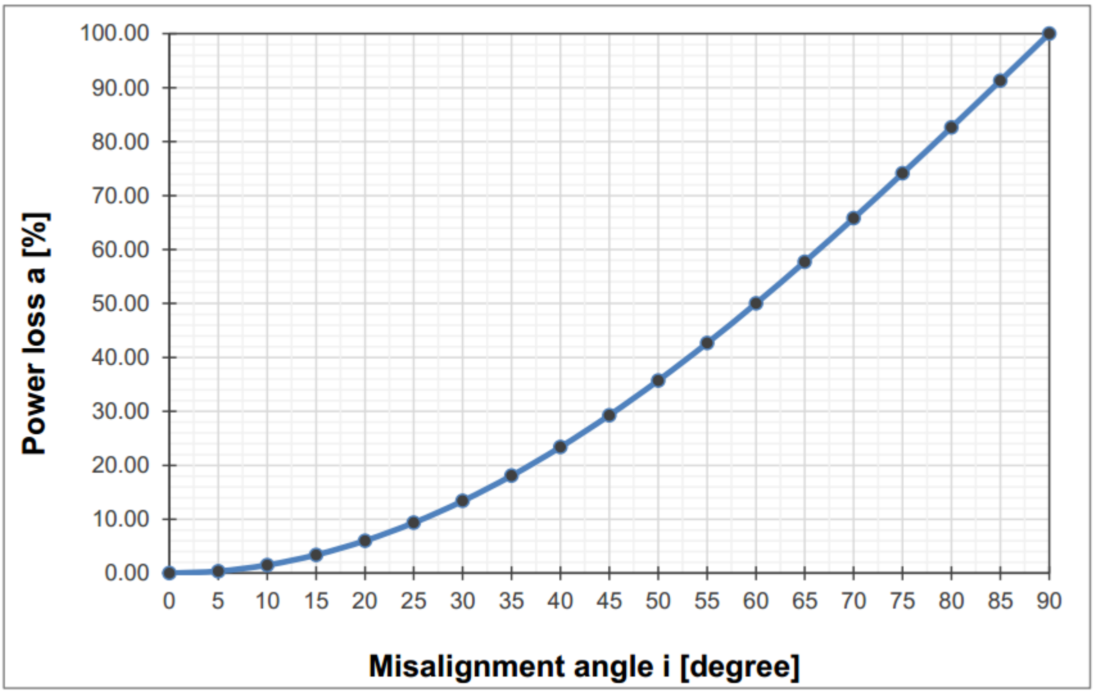

Figure 2.3 Connection between solar panel misalignment and direct power loss [24]

The graph shown in Figure 2.3 provides an illustrative evaluation of how misalignment affects the output power of PV modules. It is easy to observe that the output power drops almost 15% when solar module misaligns 30 degrees from the Sun. The power drops even faster when the misalign angle increases furthermore. By some calculation using solar radiation data from online database, we can evaluate the output power of a fixedmount solar system at some location on the Earth surface. For instance, solar radiation data for Helsinki on the date of May 1st 2016 provides sunrise at 05:20, sunset at 21:20 and solar noon at 13:20. Using these values, we can estimate power output of solar modules for the given time and location, assuming the sky is clear throughout the day [24].

By approximating solar direct beams angle at different time of the day, and calculating power output with equation 2.1, we can plot a graph that compares calculated power values with the maximum power throughout the day, as shown in figure 7 below. It is noticeable that the output power is above 85% only between 11:00 and 16:00, which means the fixed mount panels are efficient in merely 5 hours. For a typical summer day in Helsinki with more than 10 hours of sunlight in average, a PV system operating with this efficiency is certainly not a good solution to gather solar energy [24].

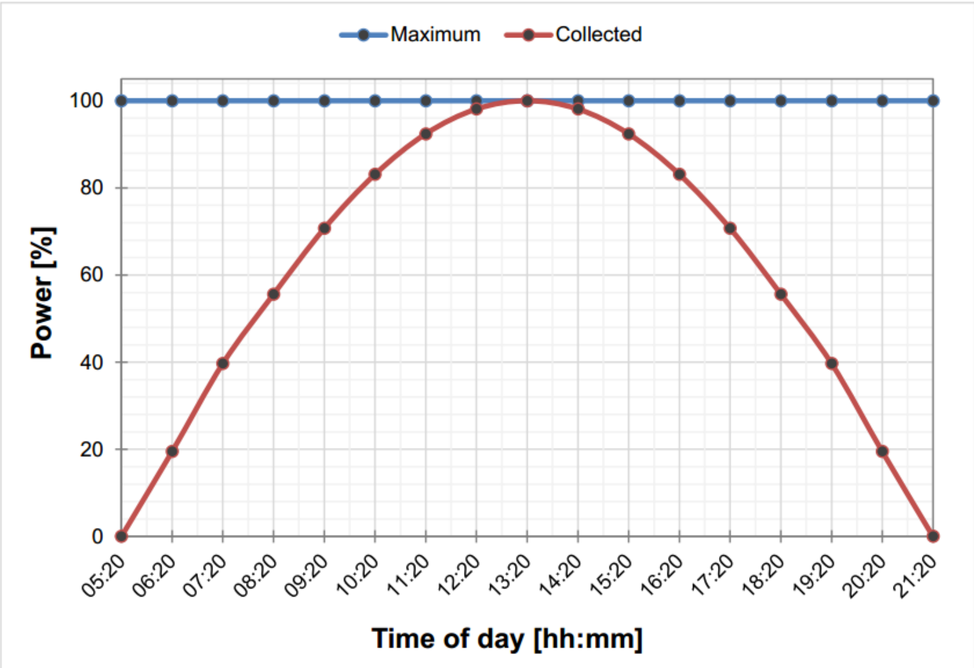

Figure 2.4 Approximation of power output (red line) compared to maximum output (blue line) for a fix mounted solar module. Data gathered from NOAA Solar Calculator [24]

The calculation explained in figure 2.4 is only based on an assumption, and doesn't reflect the whole picture. However, it is apparently pointed out that fixed-mount solar panel is not a solution for maximum efficiency, even in ideal weather condition. In reality, there are much more factors that lessen the production of a PV system (cloud shade, seasonal angle change and limited duration of daylight…). In spite of its mechanical simplicity and stability, fixed mount cannot exploit the most of solar panels' capability, therefore not suitable for higher-capacity and more important projects. There is a need of better solutions for mounting the system. We will be subsequently discussing about current solutions of solar tracker for better harvesting of solar power. This subtopic contains useful information for the design and creation of the solar tracking system in this project [35].

2.5.2 Solar Tracking Geometry

For the surface of a PV array, it is important to know its azimuth and inclination angles, as shown in Figure 2.5. For the position of the sun, it is important to know the solar azimuth and solar elevation angles, as shown in Figure 2.6. Understanding the relationship between these sun angles and the orientation of the solar panels is fundamental to determining tracker accuracy [36].

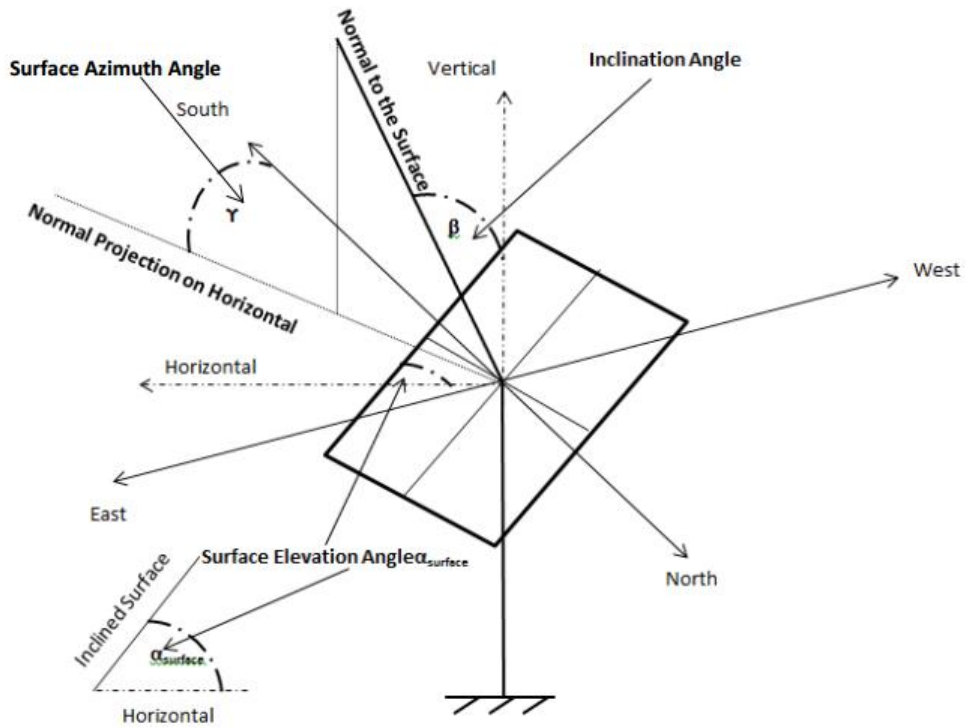

Figure 2.5 Surface azimuth and surface elevation angles [37]

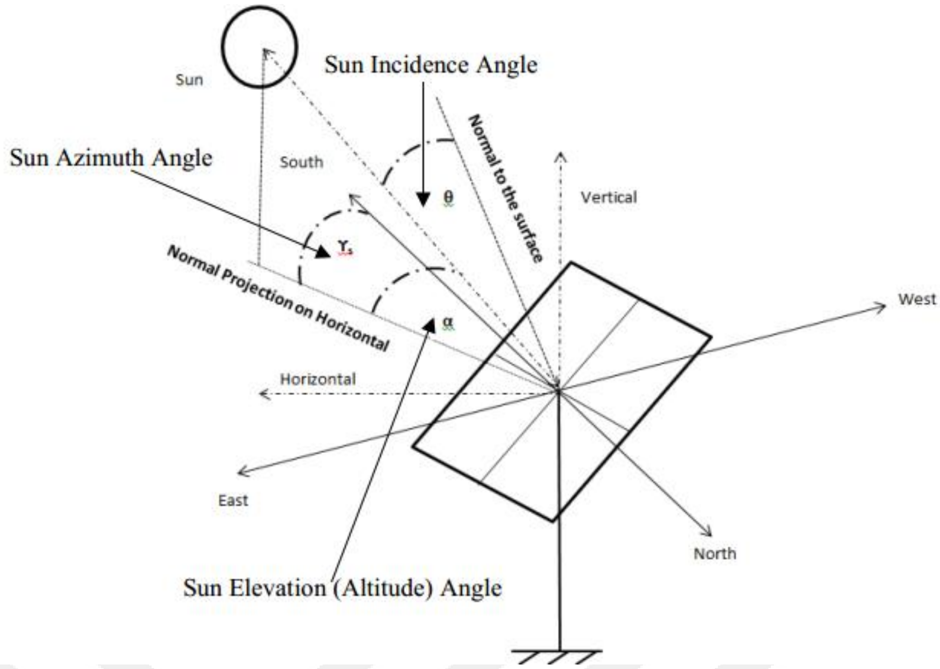

Figure 2.6 Solar azimuth, solar elevation, and solar incident angles while the direct solar radiation is not normal to a surface (general condition). [37]

In order to have an optimum tracking orientation of the solar tracker and insure that the surface of the PV array is always normal to the incident solar radiation as shown in Figure 2.7, the inclination angle and the solar elevation angle should be complementary angles (their sum is equal to 90°) and the surface azimuth angle should be equal to the sun azimuth angle [37].

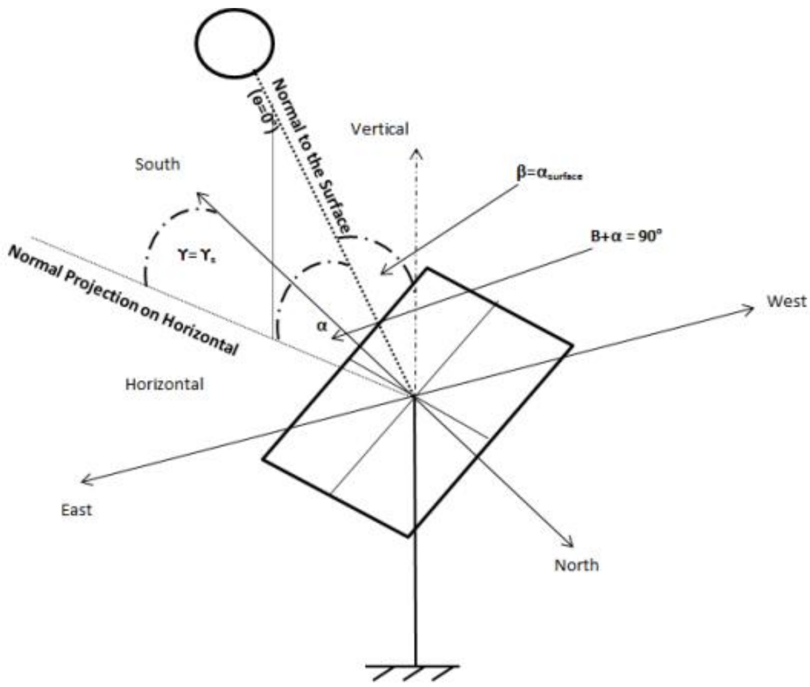

Figure 2.7 Optimum tracking orientation; that is, direct radiation normal to the surface. [37]

2.6 Solar Tracker Types and Mechanisms

Solar trackers may be active or passive and may be single axis or dual axis. Single axis trackers usually use a polar mount for maximum solar efficiency. Single axis trackers will usually have a manual elevation (axis tilt) adjustment on a second axis which is adjusted on regular intervals throughout the year. Compared to a fixed mount, a single axis tracker increases annual output by approximately 30%, and a dual axis tracker an additional 6% [38].

There are several ways to oriented the PV Panel towards the sun path. Some of them are [38]:

1. Fixed modules installed at an tilted angle (β)
2. Seasonal adjustment of the tilt angle β (few adjustments per year)

A. Azimuth tracking: Modules mounted inclined on a single tracking vertical axis (at constant tilt angle β). Figure 2.8 A

3. Polar tracking: Modules mounted on an inclined tracking axis oriented NorthSouth (axis with a tilted angle β). Figure 2.8 B
4. Double axis tracking (Figure 2.8 C)

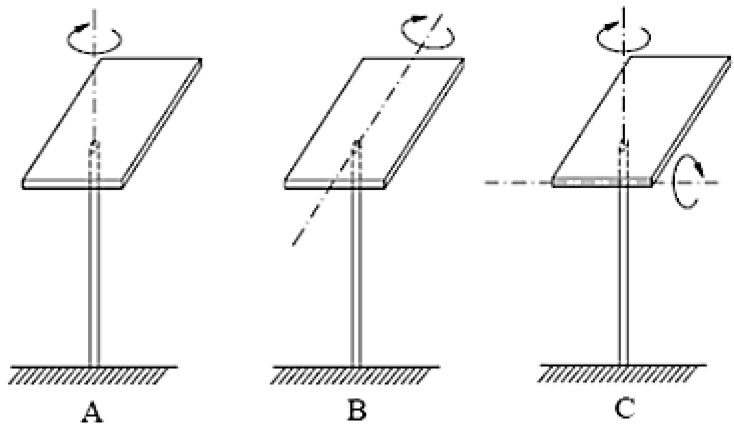

Figure 2.8 Solar Tracking modules [38]

Solar traking types can be classified depened on two main types depending on the positioning system, type of drive or sensing.

2.6.1 Solar Tracker Types Depending on Axes

There are two types of Axis traker, Single-Axis Solar and and Dual-Axis Solar Trackers. Each type has also classified to another types dependes on it is mothion and implementations. Figure 2.9 explain the types of 1 solar tracker that dependent on Axes [39].

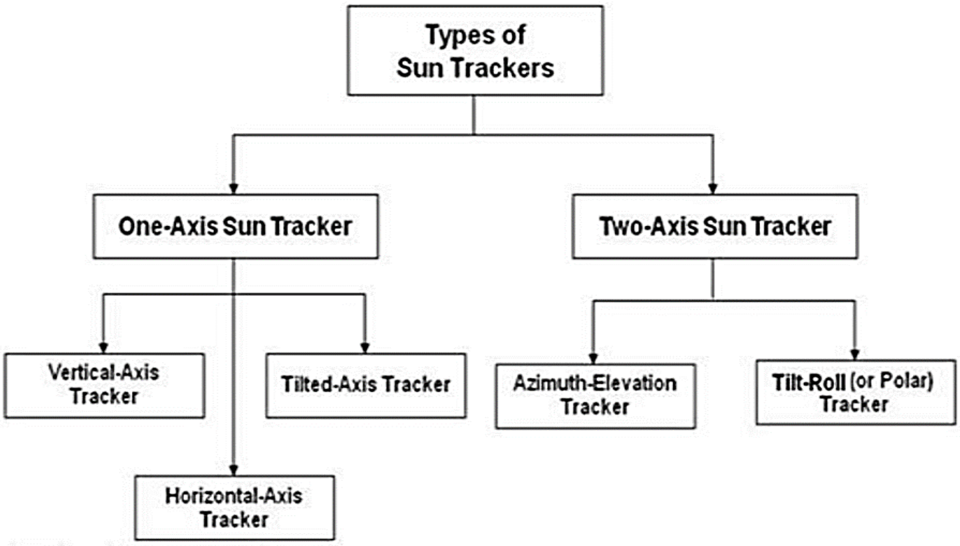

Figure 2.9 Sun Tracker Types [39]

A. Single Axis Solar Trackers

These type of trackers have only one degree of freedom, and can rotate only in one direction. It usually rotates to follow the Sun's elevation only. The axis of rotation is generally north-south axis. There are three types of one-axis sun tracker [40]:

1- **Horizontal-Axis Tracker:** The tracking axis is to remain parallel to the surface of the earth and it is always oriented along East-West or North-South direction. Figure 2.10 (a) illustrated the horizontal type single-axis trackers.
2- **Tilted-Axis Tracker**: The tracking axis is tilted from the horizon by an angle oriented along North-South direction, e.g. Latitude-tilted-axis sun tracker. Figure 2.10 (b) shows the schematic diagram of a tilted single axis tracker.
3- **Vertical-Axis Tracker**: The tracking axis is collinear with the zenith axis and it is known as azimuth sun tracker.
4- **Polar Tracker**: Polar trackers have one axis aligned to be roughly parallel to the axis of rotation of the earth around the north and south poles-- hence the name polar. The polar axis should be angled towards due north, and the angle between this axis and the vertical should be equal to your latitude. Figure 2.10 (c) illustrated the polar type single-axis trackers.

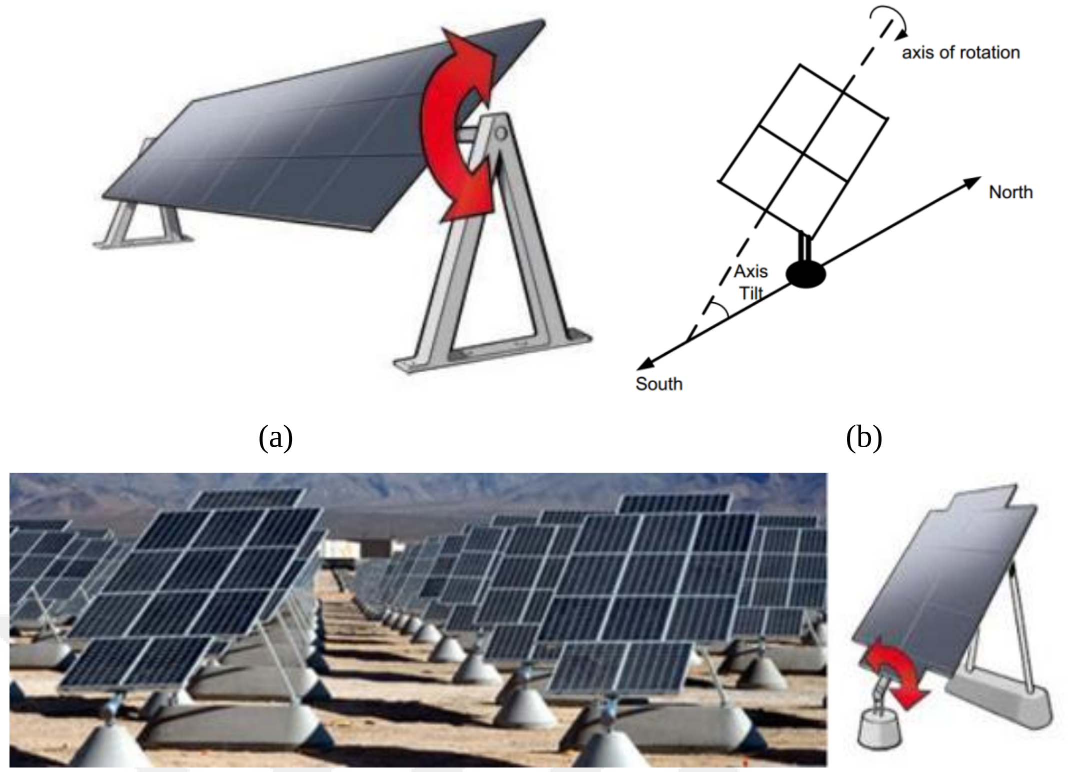

Figure 2.10 Single-axis solar trackers [41], (a) Horizontal type , (b) Tilted type , (c) Polar type

B. Dual Axis Solar Trackers

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. Two-axis tracker tracks the daily east to west movement of the sun and the daily declination movement of the sun. There are several common implementations of dual axis trackers whic are classified by the orientation of their primary axes with respect to the ground. Generally, there are two common implementations of dual axis trackers, which are [42]:

1- **Tip-Tilt Dual-Axis Trackers (TTDAT):** In this type of dual-axis solar tracker configuration the PV panel is mounted at the top of the pole. The east-west movement is performed by rotating around the pole. The vertical rotation of PV panel is governed by a T- or H-shaped mechanism placed at the top of the pole. A typical tip-tilt dual-axis solar tracker looks like Figure 2.11.

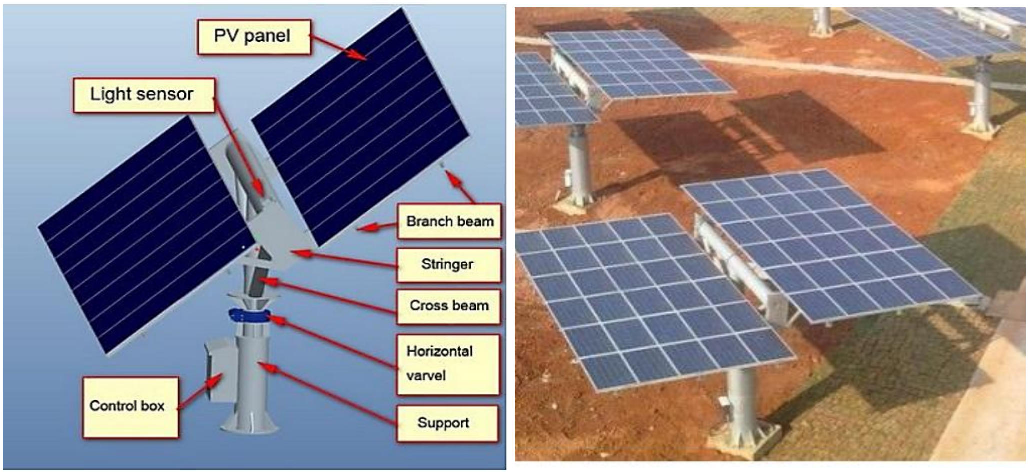

Figure 2.11 Tip-Tilt Dual-Axis Solar Trackers, (a) System Structure, (b) Real Image of Tip-Tilt Dual-Axis Solar Trackers [41]

2- **Azimuth-Altitude Dual-Axis Trackers (AADAT)**: Azimuth axis is considered as primary axis and is vertical to the ground. The secondary axis is considered as elevation axis and is normal to the primary axis. As opposed to the tilt-tip dual axis solar trackers it uses a large ring mounted on the ground with the PV panel mounted on a series of rollers. This type of arrangement is suitable for the large and heavy PV panels. A typical azimuth-altitude dual-axis solar tracker is shown in Figure 2.12 [41].

Figure 2.12 Azimuth-Altitude Dual Axis Tracker, Toledo, Spain [41]

2.6.2 Solar Tracker Types Depending on Driver Type

Solar trackers can be divided into three main types depending on the type of drive and sensing system that they incorporate. Passive trackers use the suns radiation to heat gasses that move the tracker across the sky. Active trackers use electric or hydraulic drives and some type of gearing or actuator to move the tracker. Open loop trackers use no sensing but instead determine the position of the sun through pre recorded data for a particular site [41].

A. Passive Trackers (Gas Trackers)

Passive trackers use a compressed gas fluid as a means of tilting the panel. A canister on the sun side of the tracker is heated causing gas pressure to increase and liquid to be pushed from one side of the tracker to the other. This affects the balance of the tracker and caused it to tilt. This system is very reliable and needs little maintenance. Although reliable and almost maintenance free, the passive gas tracker will very rarely point the solar modules directly towards the sun. This is due to the fact that temperature varies from day to day and the system can not take into account this variable. Overcast days are also a problem when the sun appears and disappears behind clouds causing the gas in the liquid in the holding cylinders to expand and contract resulting in erratic movement of the device. Passive trackers are however an effective and relatively low cost way of increasing the power output of a solar array. The tracker begins the day facing west. As the sun rises in the east, it heats the unshaded west-side canister, forcing liquid into the shaded east-side canister. The liquid that is forced into the east side canister changes the balance of the tracker and it swings to the east. It can take over an hour to accomplish the move from west to east. The heating of the liquid is controlled by the aluminum shadow plates. When one canister is exposed to the sun more than the other, its vapor pressure increases, forcing liquid to the cooler, shaded side. The shifting weight of the liquid causes the rack to rotate until the canisters are equally shaded. The rack completes its daily cycle facing west. It remains in this position overnight until it is "awakened" by the rising sun the following morning. [42]. Figure 2.13 illustrated the passive tracker operation.

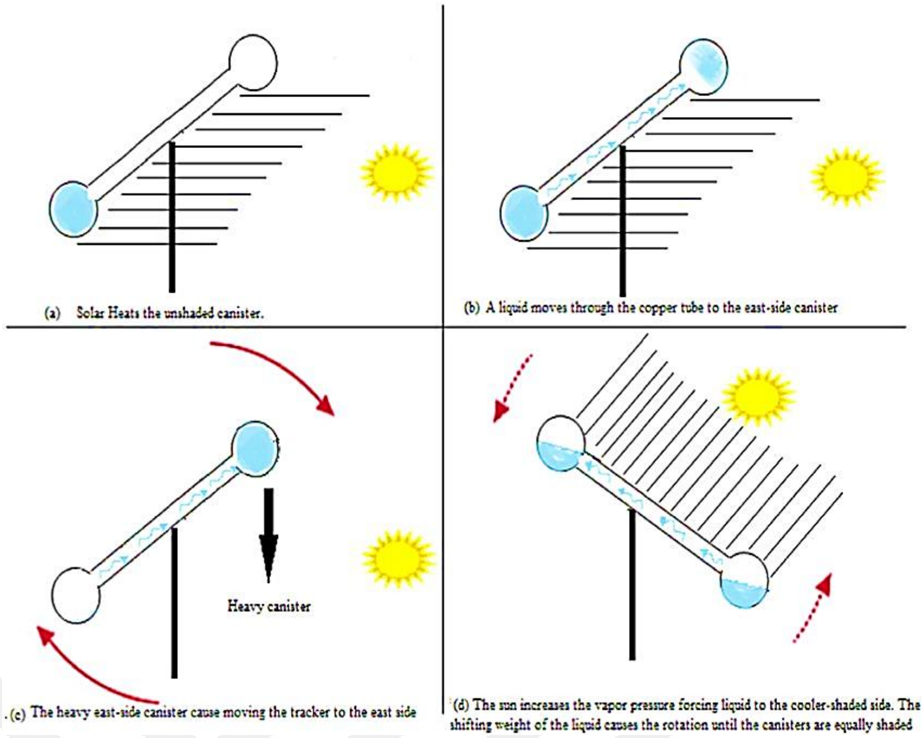

Figure 2.13 Passive Tracker Operation

B. Closed Loop Sensor (Active Trackers)

Active trackers measure the light intensity from the sun to determine where the solar modules should be pointing. The solar tracker actively takes dynamic feedback from the sun using sensors to orient the collector orthogonally towards the sun. Light sensors are positioned on the tracker at various locations or in specially shaped holders. If the sun is not facing the tracker directly there will be a difference in light intensity on one light sensor compared to another and this difference can be used to determine in which direction the tracker has to tilt in order to be facing the sun. Figure 2.14 represents block diagram of an LDR (Light Dependant Resistor) sensor based closed loop solar tracking system which is designed by Wang and Lu. [40]

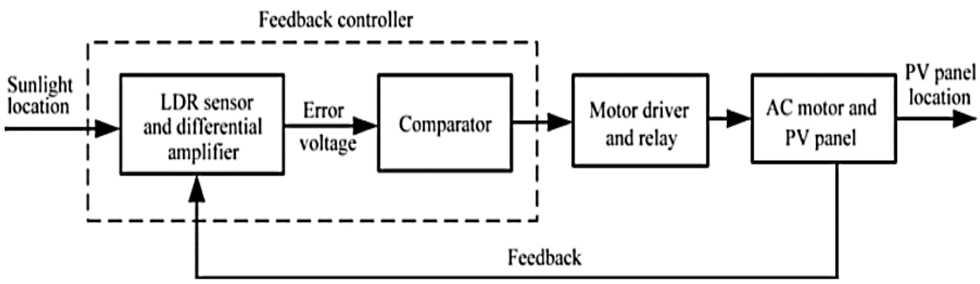

Figure 2.14 An LDR sensor based closed loop solar tracking block diagram [40]

As shown from figure 2.14, the feedback controller consists of LDR sensors, differential amplifier and comparator. The LDR sensors generate voltages by absorbing sunlight. The unbalance in LDR voltages generate an error voltage which is then compared by the comparator with respect to a specified threshold. If the comparator goes HIGH logic, the motor driver and relay will be turned on and rotate the panel. During this rotation, the feedback controller will calculate the error voltage. When the error voltage is less than the specified threshold, the comparator will go LOW logic and turn off the motor driver and delay and the rotation stops orienting the collector towards the sun orthogonally [40].

C. Open Loop Solar Tracking

Open loop trackers determine the position of the sun using computer controlled algorithms or simple timing systems. There is no sensor based solar position feedback in open loop solar tracking, the open loop solar tracker system calculates the sun position based on location, time, date using solar position equation or look-up table of solar position. Then it determines and implements the appropriate tracker rotation depending on the pre-calculated solar position and known tracker position. Incremental movement throughout the day keeps the solar modules facing the general direction of the sun. Trackers of this type can utilize one or two axes depending on their application and the price that the buyer is willing to pay. The main disadvantage of timed systems is that their movement does not take into account the seasonal variation in sun position. Unless measures are taken to adjust the tracker position seasonally there will be a noticeable difference in efficiency depending on the season [42]. Figure 2.15 summarizes this operation with the help of block diagram.

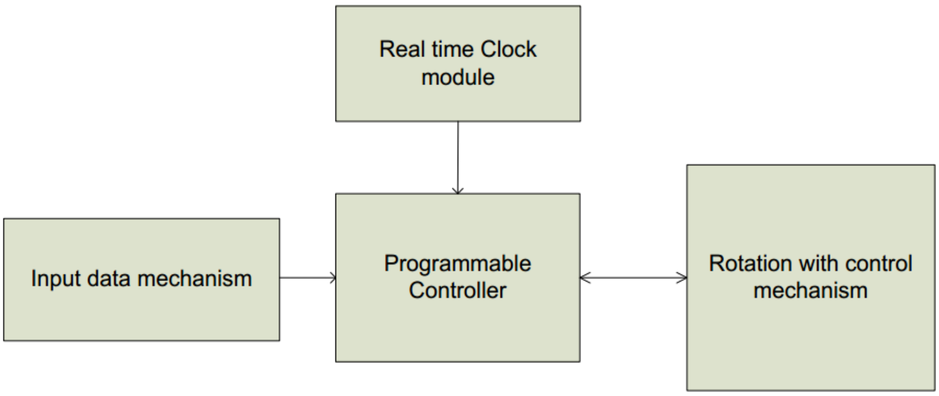

Figure 2.15 An LDR sensor based open loop solar tracking block diagram [42]

There are some other types of solar tracker includes [43]:

1. **Multi-mirror reflective unit:** this device uses multiple mirrors in a horizontal plane to reflect sunlight upward to a high temperature photovoltaic or other system requiring concentrated solar power. Only two drive systems are required for each device. Because of the configuration of the device it is especially suited for use on flat roofs and at low altitudes.

2. **Chronological tracker:** it counteracts the earth's rotation at an equal rate as the earth, but in the opposite direction. These trackers are very simple but yet potentially very accurate solar trackers specifically for use with a polar mount. The drive method may be as simple as a gear motor that rotates at a very slow average rate of one revolution per day (15 degrees per hour).

2.6.3 Compartion between Solar Tracker Types

In follows the most signifient diffrence between tracking systems [44]:

A. **Comparison of Single Axis and Dual Axis Tracker:**
   Single axis tracker, with one degree of freedom uses a relatively simple one dimensional mechanical configuration and control system. It has only one motor driver and motor. Energy loss associated with mechanical movement is minimum in single axis trackers. Besides with respect to dual axis tracker it costs relatively less for simple construction and fewer components. However, single axis tracker has relatively lower accuracy in solar tracking compared to that of dual axes tracker. Also single axis tracker cannot account for seasonal changes. So the improvement in energy extraction through tracking is slightly lower compared to that of dual axes tracker. The accuracy of single axis solar tracking can be slightly improved by tilt angle optimization and manual adjustment of the optimum tilt angle on monthly or seasonal basis, depending on convenience. On the other hand, dual axes tracker is relatively accurate in solar tracking with its two degrees of freedom, it can account for seasonal changes. So the improvement in energy extraction through tracking is slightly more than the single axis tracker but at the compensation of increased cost and complexity of mechanical structure and control system. Dual axes tracker uses a two dimensional control system with two motor drivers and two

motors. The improvement in energy harvesting by a dual axes tracker with respect to a single axis tracker in a particular region needs to be considered relative to its added cost and complexity before dual axes tracker installment in that region [45].

B. Comparison of Closed Loop (Active) And Open Loop Solar Tracking Systems:

Closed loop tracking system is sensitive to disturbances like reflection and shading. In case of such disturbances it may fail to track the sun. On the other hand, open loop tracking system is immune to disturbances like shading or reflection and so it will track the sun successfully. Closed loop tracking system uses a relatively complex circuit structure whereas open loop tracking system uses a much simpler circuit configuration. Closed loop tracking system is based on dynamic feedback from the sun. Light dependent resistor or photo transistor, operational amplifier are used for its low cost implementation. It does not require complex mounting. As it tries to track the sun from any given position, small errors in mounting or small disruption in position of the tracker due to shock will not affect its performance. However open loop tracking system requires a computing hardware, calibrated linear position sensor, a data input mechanism with user interface which can increase the cost. It also tracks the sun position with respect to the tracker position. If errors of small magnitude occur in tracker mounting or tracker positioning, performance of the system may be affected. Thus such system requires more complex and rigid mounting of the tracker with respect to that of the tracker closed loop tracking system [46].

CHAPTER 3

PROPOSED SOLAR TRACKER DESIGN

This chapter presents an experimental setup of 2-axis solar tracking system which includes system hardware and software design in addition to specify the hardware component used and the program operation and its algorithm.

3.1 Proposed Pedometer Design

The proposed solar tracker is consisted from two main parts: power production analyzer and the tracker.

3.1.1 PV Panel

In order to test the accuracy of Solar Tracker we have used a commercial 5-watt solar panel type (Polycrystalline Silicon solar cells), of 5-watt maximum power, 240 milliampere per hour, and 21volts. Figure 3.1 shows the PV panel used in with proposed tracker.

Figure 3.1 Polycrystalline Silicon PV panel

3.1.2 Power Production Analyzer

This part is responsible on analyzing the power production of solar cell from different direction to determine the best angle that solar panel should be redirect in order to getting the maximum power generation. The power analyzer is detected part consist of following component:

1. **Microcontroller:** is utilized to store and got the sun position angles through utilized an algorithm for calculation the solar angles in order to evaluating power generation from light sensors or solar cell, and after that control the two servo motors through producing the PWM signals equivalent to the required angle. In this work we used Arduino MEGA 2560 has been used and programed in order to store and got the sun position angles through utilized an algorithm for calculation the solar angles in order to evaluating power generation from light sensors or solar cell, and after that control the two servo motors through producing the PWM signals equivalent to the required angle. Arduino MEGA 2560 has been used that 14 digital pins and 16 analog pins, and can handle a large range of sensors, motors and actuators; that is what we need in our design. The ports from A0 to A11 has been used to got signals from light sensors. Figure 3.2 shows the Arduino MEGA 2560 microcontroller used in this work.

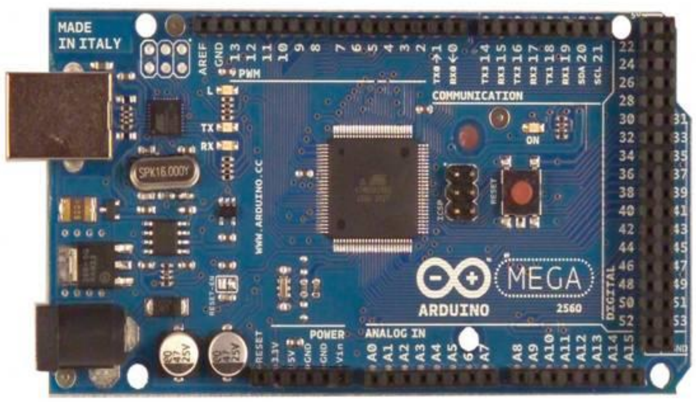

Figure 3.2 Arduino MEGA 2560 Microcontroller

2. **Light Intensity Sensor:** this kind of sensors utilized to detect changes in light intensity. One of this type is Light Dependent Resistor (LDR) which is a variable resistor where itis value decrease with raising incident light intensity. The LDR is manufactured from a higher resistance semiconductor, usually cadmium-supplied. In this work, the photo sensors have been used for sensing

the sun light. We have used four types of trackers that classified based on numbers of LDR and its arrangement, these types are: 4 LDR tracker, 8 LDR on panel tracker, 8 LDR Matrix Tracker, and 12 LDR Matrix Tracker.

For on panel LDR tracker the photo sensors have been positioned on solar panel where for 4 LDR tracker it positioned in + shaped container where positioned upper, lower, right and left sides. Figures 3.3 (a) illustrated the position of LDR and figure 3.3 (b) shows the 4 LDR tracker system.

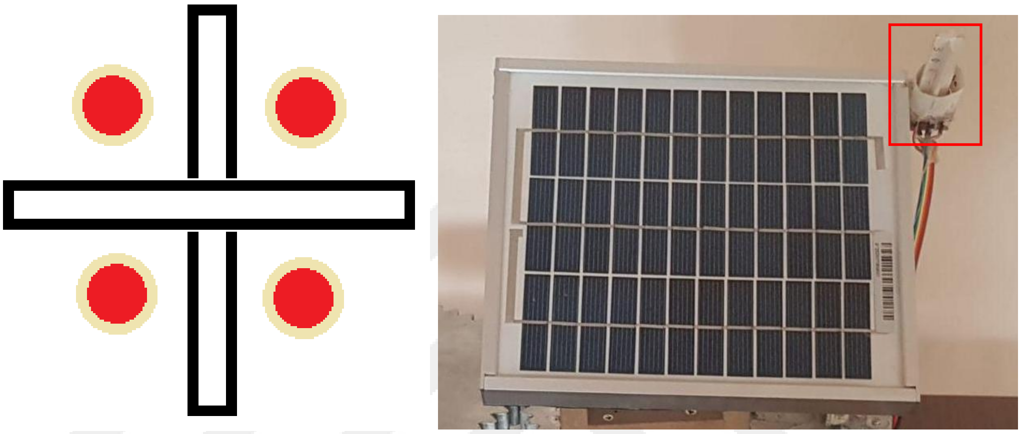

Figure 3.3 4 LDR Tracking system. (a) LDR arrangment in continer (Red circule represent LDR), (b) Proposed system with 4 LDR

For 8 on panel LDR, positioned in center side of upper, lower, right and left sides, in addition to four corners of panel. Figures 3.4 (a) illustrated the position of LDR on panel and figure 3.4 (b) shows the 8 LDR tracker system.

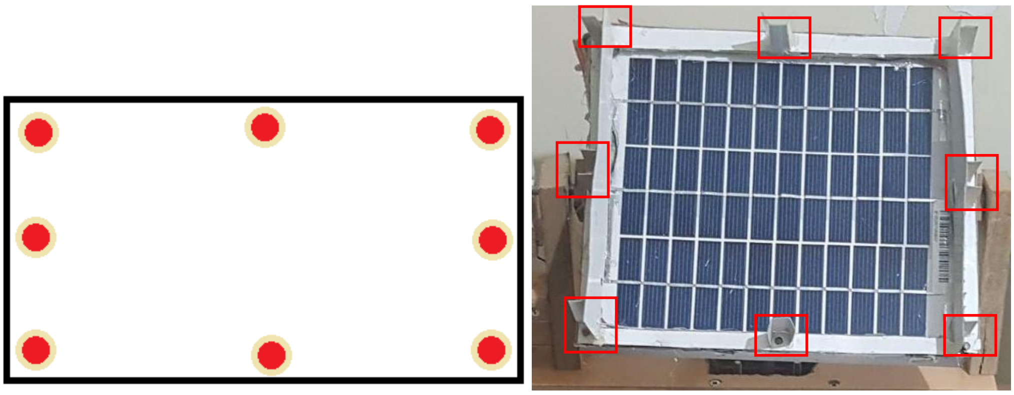

Figure 3.4 4 LDR Tracking system. (a) LDR arrangment on panel (Red circule represent LDR and black rectangule represent the solar panel), (b) Proposed system with 8 LDR Tracker (8 LDR in red box)

For 8 and 12 Matrix LDR, the LDRs have been mounted on the spherical surface in arrange of 4 rows 4 columns in 8 Matrix LDR and 3 rows 4 columns in 12 matrix LDR as shown in figure 3.5.

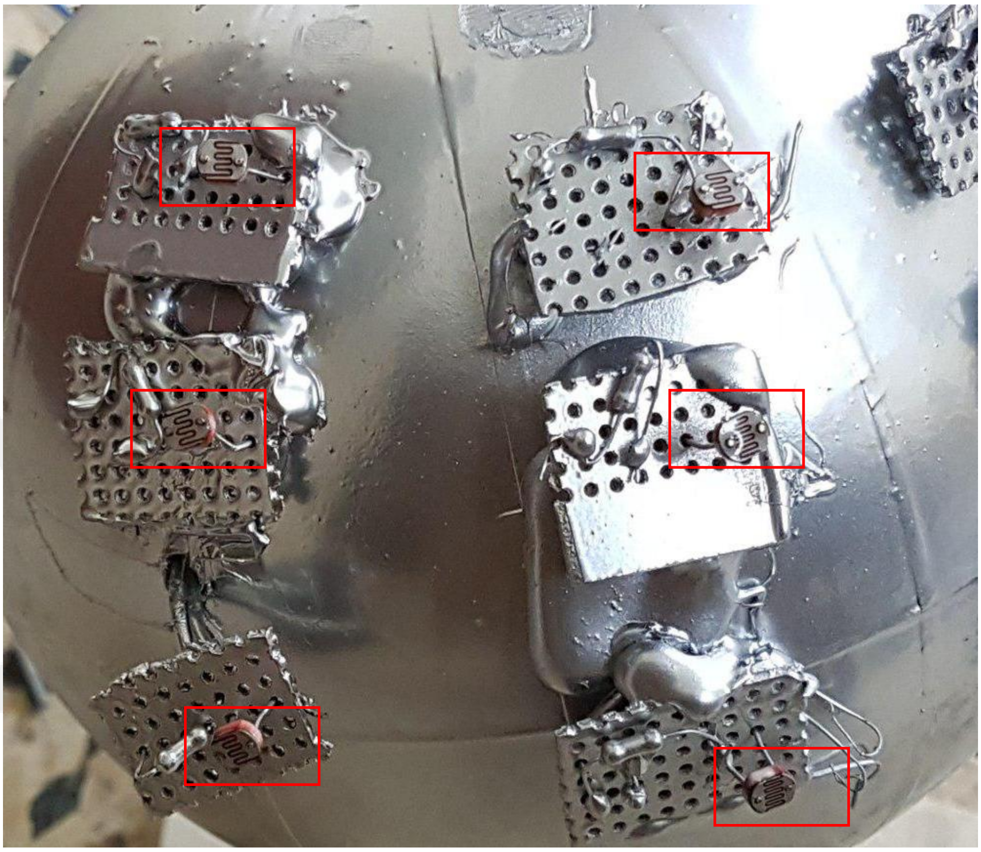

Figure 3.5 LDR photo sensors on Matrix LDR tracker, which arranged on spherical surface of power analyzer

The connection of LDR sensors to Arduino MEGA 2560 pins as follows:

- Sensor a is connected to the A0 input pin of the Arduino.
- Sensitive b is connected to the A1 input pin of the Arduino.
- Sensor c is connected to the the A2 input pin of the Arduino.
- Sensor d is connected to the A3 input pin of the.
- Sensor e is connected to the A4 input pin of the.
- Sensor f is connected to the A5 input pin of the.
- Sensor g is connected to the A6 input pin of the.
- Sensor h is connected to the A7 input pin of the.
- Sensor i is connected to the A8 input pin of the.
- Sensor j is connected to the A9 input pin of the

- Sensor k is connected to the A10 input pin of the Arduino.
- Sensor l is connected to the A11 input pin of the Arduino.

Figure 3.6 illustrated the electrical circuit of proposed solar traker and the connection of LDR sensors with Arduino MEGA 2560.

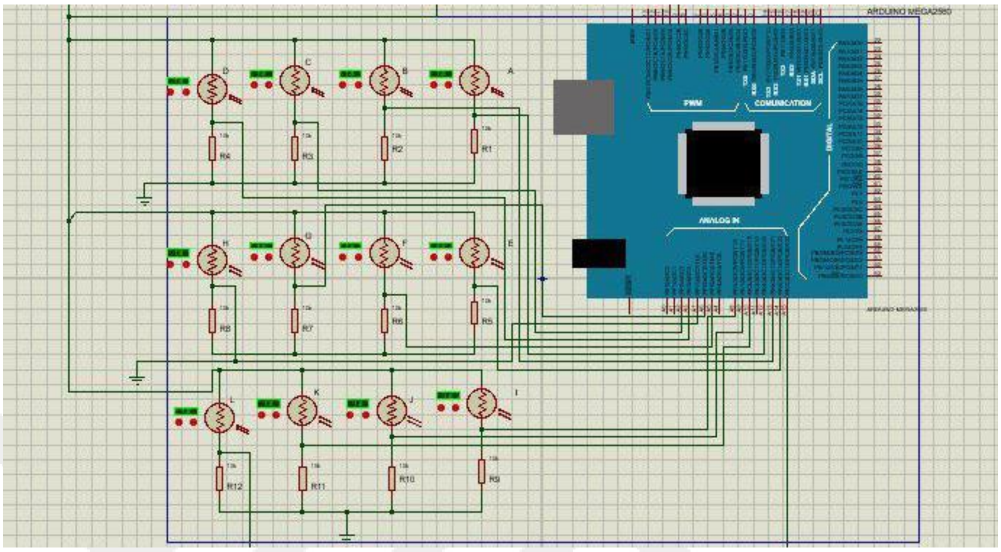

Figure 3.6 Electrical circuit sheme of proposed solar traker that explained the connection of LDR sensors with Arduino MEGA 2560.

3. **Algorithm for solar angles calculation:** A solar tracking system needs to analyze the light intensity (or power production) from the light sensor to verify the best tracking location should panel directed. The photo sensor can sense lights and gives signal to the microcontroller. The microcontroller processes the input and start calculation and then driving tracker motors to appropriate angle. In the proposed power analyzer system design, a 12 LDR has been arranged in 4 x 3 matrix that mounted in upper- half of sphere that would be placed to facing sun moving direction. This matrix will provide real time calculation for 12 position that give more tracking position rather than common 4 light sensors that would give more efficiency and also give a nearest result to high accuracy expensive technique that required GPS and sun location information. The reason of used just 12 sensors, is because we used a microcontroller type Arduino MEGA that have only 12 digital input and can increasing it by use other controllers such as Arduino mega, etc. that has more digital input.

3.1.3 PV Panel Tracker:

This part is responsible on PV panel movement, which is includes the following:

1. **Electrical component and Circuit Design:** The electrical component of the solar tracker includes the microcontroller and motors. Motor drive is one of the very important elements of the automatic solar tracker. It moves the solar panel toward the sunlight direction when the sun moves over the sky. To efficiently utilize a DC motor for specific placing a servo mechanism must be used. A servo mechanism or servo is an automated device which utilizes error sensing feedback to adjust the mechanism performance. They're controlled making use of PWM. In this work two servo motor (rotate from 0 to 180 degree) has been used in order to rotate the mechanical part. The servo motor model is (CYS-S8218) which is digital metal 40KG high gear torque servo, the motor speed rate is 0.20-0.22sec/60 at (6V) or 0.18-0.2sec/60 at (7.2V). The motor torque is 36-38kg.cm at (6V) or 38-40kg.cm.at (7.2V). The operating voltage is either 6.0V or 7.2V. Each servo motor is connected to PWM pins at microcontroller to get direction. Figure 3.7 illustrated the connection of servo motors with Arduino MEGA 2560.

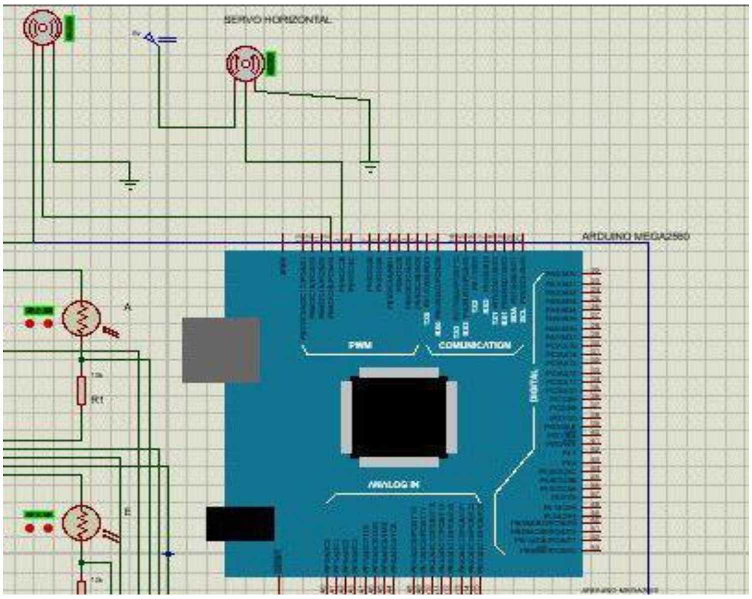

Figure 3.7 Electrical circuit sheme of proposed solar tracker that explained the connection of servo motors with Arduino MEGA 2560

2. **Mechanical Part:** The mechanized model employs rotate and tilt tracking technique in dual axis mode. The structure has been designed by CAD. This design is focused on design combat structure with smooth movement and rigid design. The structure has been designed as multi parts that fabricated by CNC machine and then recombined to one structure. The tracker parts are shown in figure 3.5.

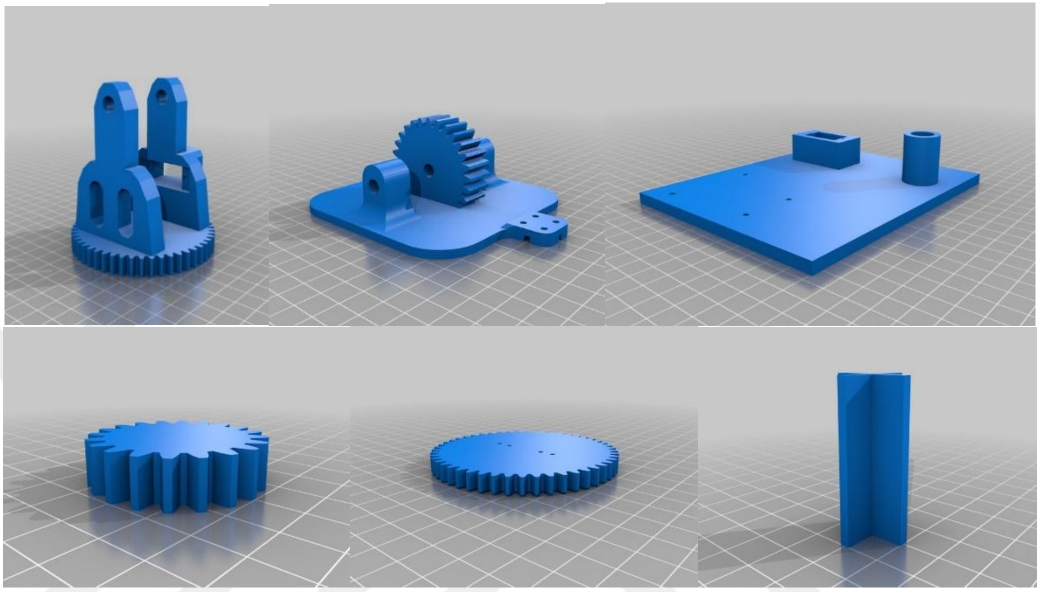

Figure 3.8 Mechanical parts of Tracker (designed by CAD software)

In this work we fabricate a prototype in moderated size for test tracker system before fabrication the real size structure that can hold a heavy PV panel. The mechanical parts have been fabricated from MDF Plates and cutting by CNC machine then arranged and connected with two servo motors in such a way that can allows to be moving in dual axis smoothly. Figure 3.9 shows the proposed solar tracking system and its mechanical and electrical parts.

Figure 3.9 Proposed solar tracking system

3.1.4 Sun Angle Estimation and Tracking Strategy:

As described in section 3.1.2 part 2, the light sensors are arranged depends on their tracker type. Each sensor is connected to input pin of Arduino MCU. The movement of tracker is dependent on the voltage that recorded from each sensor. Each port has been assigned to character that represent the desired LDR. Figure 3.10 illustrate the MUC pin list and voltage gathering.

```
int A;
int B;
int C;
int D;
int E;
int F;
int G;
int a;
int b;
int c;
int d;
int e;
int f;
int g;
int h;
int i;
int j;
int k;
int l;
```

```
void loop() {
  a = analogRead(A0);
  b = analogRead(A1);
  c = analogRead(A2);
  d = analogRead(A3);
  e = analogRead(A4);
  f = analogRead(A5);
  g = analogRead(A6);
  h = analogRead(A7);
  i = analogRead(A8);
  j = analogRead(A9);
  k = analogRead(A10);
  l = analogRead(A11);
```

Figure 3.10 Identification of LDR in MCU

In 12 LDR Matrix the sun angle is determine by following formulas

$A = a + e + i$

$B = b + f + J$

$C = c + g + k$

$D = d + h + i$

$E = a + b + c + d$

$F = e + f + g + h$

$G = I + j + k + l$

Where: A is the ttotal light intensity of the first column sensors, B is the total light intensity of the second column sensors, C is the total light intensity of the third column sensors, D is the total light intensity of the fourth column sensors, E is total light intensity of the first row sensors, F is the sum of the intensity of the second-row sensors and G is the total light intensity of the third row sensors.

The panel redirection is based on changing servo rotational angle depends on previous formula. Table 3.1 show the sun angle estimation.

Table 3.1 Sun tracking angle estimation

	A	B	C	D
E	(0,140)	(40, 140)	(80, 140)	(110, 140)
F	(0,130)	(40,130)	(80,130)	(110,130)
G	(0,125)	(40,125)	(80,125)	(110,125)

From Table 3.1, each cell represents the (x, y) position of LDR. The strategy of determine best angle can be described in follows:

In case the one column, for example (A), get more light than the rest of the columns (the voltage is more than other columns), the MUC will command the servo motor to move at 0 degrees of x-axis. At the same time, a comparison will be used to determine the more incident lighting row. For example, If the E row get more light than the rest of the rows (the voltage is more than others) than the rest of the rows, the MUC will give the command to the vertical servo to move at 140 degrees to redirect the panel with the y-axis. Figure 3.11 illustrate the MCU sun angle estimation calculation

```
   if ((A > B) && (A > C) &&(A > D) )
{myservoh.write(0);  }

else  if ((B > A) && (B > C) &&(B > D) )
{myservoh.write(40);  }
else  if ((C > A) && (C > B) &&(D > D) )
{myservoh.write(80);  }
else  if ((D > A) && (D > C) &&(D > B) )
{myservoh.write(110);  }
else  if ((E > F) && (E > G) )
{myservov.write(140);  }
else  if ((F > E) && (F > G) )
{myservov.write(130);  }
else  if ((G > F) && (G > E) )
{myservov.write(125);  }
else{myservov.write(125);myservoh.write(0);}}
```

Figure 3.11 Arduino MCU sun angle estimation code

CHAPTER 4

SYSTEM TEST AND RESULTS

In this chapter we have test the tracking system in order to investigate the accuracy of system to tracking best angle that will producing maximum power. In the experiment we have monitored the electrical power generated from PV panel that used proposed trackers when run in real operation. The results have been recorded and compered with system that have no tracker. Furthermore, we detail the cost of proposed system in order to comperes with other commercial trackers that available in the markets. Figure 4.1 show the proposed solar tracker at real operation.

Figure 4.1 The proposed tracking system on test.

4.1 Tracker Cost

In this part, we have computed the overall trackers cost in order to compare with other available tracker in the market. For fixed panel the cost is the panel cost. For proposed tracking system, the all trackers have same mechanical part and same MCU but it different in LDR number and it relatively different from 1~2$ at all so it not so different so we compute the cost of matrix one at all. Table 4.1 illustrated the trackers component and its cost.

Table 4.1 Proposed solar tracker parts cost and total cost

Component	Number of item	Total Price
1- Microcontroller Arduino Mega 2560	1	9$
2- Servo high torque	2	40$
3- Mechanical system	1	85$
4- Photo resistor	12	5$
5- Resistance 10k	12	1$
6- Power supply 5 volt	1	6.5$
	Total Cost	146.5$

As shown from table the total cost of tracking system is about 146.5$ which is lower cost compered and even close to commercial low-cost single axis tracker that is price about 124$ (the cost is from eBay in same date making comparison. However, the cost of system can be reduced and can make more rigid and stylish shape when it will be fabricated commercially.

4.2 Tracker Weight Limits and Rigidity

In this part, we have investigated the factors that effected on system weight limits and its rigidity. As explained in chapter 3 in “Mechanical Part” point and appeared in figure 3.5, the mechanical system is that responsible on movement is consisted from two gears that responsible on dual axis movement, where the each one is driven by one servo motor. Thus, the panel weight limits are dependent on the gear’s rigidity and the motor torque. The best gears should be constructed from low weight material which is the aluminum alloy or any rigid light weight material. For servo motor the selection should be dependable on total moving parts (panel and mechanical part) weight. For the panel type, the thin film and the flexible solar cell is a good choice which can reduce the weight of mechanical parts as well as the torque needed from servo motor which reduce the cost of panel. In this work, the gears and mechanical parts has been constructed from MDF plates and some metal screw and junction and used metal gear servo motor of torque 38-40 Kg.cm at 7.2 volt, the test show that the proposed tracker is able to move weight up to 10 Kg.

4.3 Power Analyzer and Tracking Accuracy Test

In this part, we have tested the tracking system in order to investigate the accuracy of system to tracking best angle that will producing maximum power. In the experiment a light source has been spotted on power analyzer from different direction. Figure 4.2 shows the tracking process according to light location.

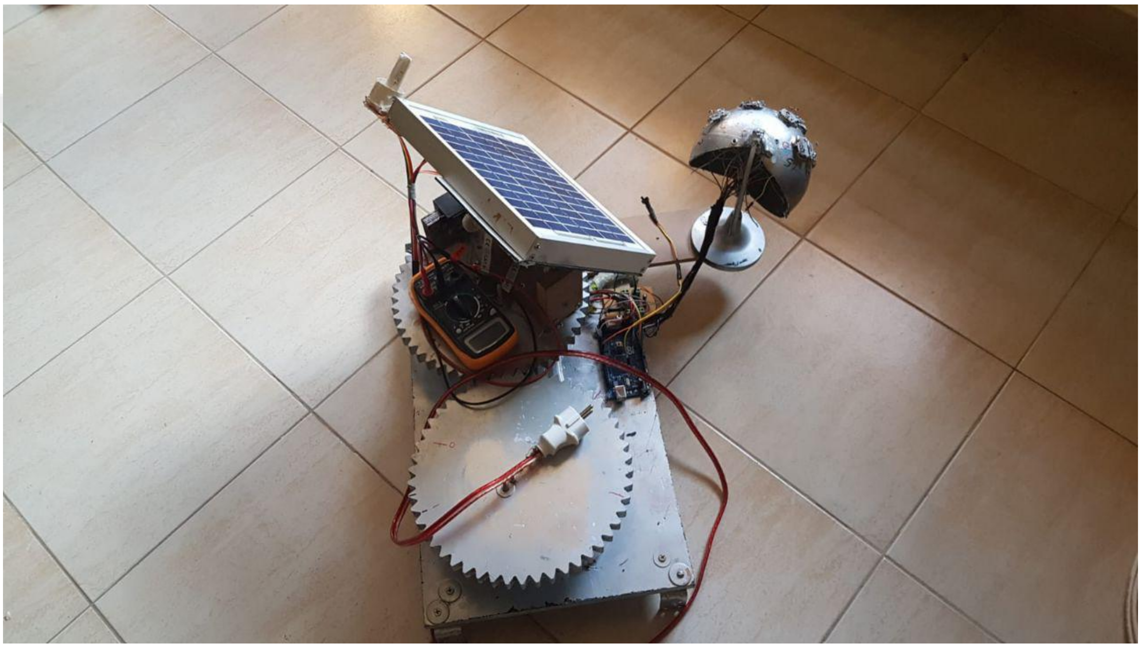

Figure 4.2 Solar trucking system on work which tracked sun positions, as shown the solar panel track the position related to LDR faced the sun light

As shown from figure 4.2, the tracker tracked the light source efficiently, and the panel base directed toward the light direction which is the maximum power generation. The power analyzer work by received the voltage value from all LDR at same time and compered the values, from the principle of LDR when the light level increase, the resistance of the LDR decrease. As this resistance decreases in relation to the other resistor, which has a fixed resistance, it causes the voltage dropped across the LDR to also decrease. The lower LDR voltage mean that the direction of this LDR is the best direction that PV panel can generate the best power generation.

For tracking speed test, the light source has been moved in multi direction to investigate the tracking response time, the test shows that the tracker tracked light rapidly and smoothly and take about ~1 second to change the solar cell location to the higher intensity light direction.

4.4 Power Generation Test

In this part we have test the generation of electrical power from panel with proposed solar trackers and compered with fixed Panel. In our test we used two panels one connected to proposed solar trackers and the second put on the stand at the angle of sun direction. The records have been taken for different cases to determine the efficiency of tracker in real operation.

4.4.1 Power Generation Records from Fixed and 12 Matrix LDR tracker

In this part, we have recorded the electrical voltage generated from both PV panel (with a tracker and without tracker) at the same times at one sunny day from sunrise to sunset. Also, we have checked the maximum power generation from solar panel which is being at θ= 0, where the sun ray is perpendicular to solar panel. In order to get this, the solar panel has been manually directed to sun and we have used voltmeter to check the maximum voltage generated which is represent the generation from solar panel at θ= 0.

Table 4.2 The voltage generated from panel with tracker and without tracker for one day (from 06:35 Am to 17:45 PM) recorded from Bagdad city in 12 April

Time (HH:MM)	Voltage Generated from Solar Panel			Voltage Gain	
	Solar Panel at (θ = 0)	Panel with Tracker	Fixed Panel	Panel θ=0 /Tracker	Fixed Panel/ Tracker
06:35	5.7	4.9	3.1	0.8	1.8
06:45	9.8	9.3	4.3	0.5	5
07:00	13.5	13	7.8	0.5	5.2
07:15	15.2	14.8	8.9	0.4	5.9
07:30	17.3	17	9.8	0.3	7.2
07:45	17.8	17.5	11.6	0.3	5.9
08:00	18.6	18.2	12.4	0.4	5.8
08:15	18.9	18.6	13.7	0.3	4.9
08:30	19.1	18.9	13.9	0.2	5
08:45	19.3	19	14.1	0.3	4.9
09:00	19.5	19.2	14.5	0.3	4.7

09:15	19.7	19.5	14.7	0.2	4.8
09:30	19.7	19.7	15.3	0	4.4
09:45	19.7	19.7	16.5	0	3.2
10:00	19.8	19.7	16.8	0.1	2.9
10:15	19.9	19.9	17.4	0	2.5
10:30	19.9	19.9	17.8	0	2.1
10:45	19.9	19.9	18.1	0	1.8
11:00	20	19.9	18.5	0.1	1.4
11.15	20.1	20	18.9	0.1	1.1
11:30	20.2	20	19.2	0.2	0.8
11:45	20.6	20.5	19.8	0.1	0.7
12:00	20.6	20.5	20.2	0.1	0.3
12:15	21	20.8	20.4	0.2	0.4
12:30	21.2	20.9	20.5	0.3	0.4
12:45	21.4	21.1	20.7	0.3	0.4
13:00	21.5	21.3	20.9	0.2	0.4
13:15	21.5	21.5	21.1	0	0.4
13:30	21.5	21.5	21	0	0.5
13:45	21.5	21.5	20.9	0	0.6
14:00	21.5	21.5	20.5	0	1
14:15	21.5	21.5	19.8	0	1.7
14:30	21.4	21.4	19.4	0	2
14:45	21.4	21.1	19.3	0.3	1.8
15:00	21.3	20.9	17.7	0.4	3.2
15:15	21	20.8	17.1	0.2	3.7
15:30	20.8	20.8	16.9	0	3.9
15:45	19.6	19.5	16.3	0.1	3.2
16:00	19.2	19	15.9	0.2	3.1
16:15	18.7	18.5	15.9	0.2	2.6
16:30	18.6	18.5	15.1	0.1	3.4
16:45	17.5	17.4	14.5	0.1	2.9
17:00	17.2	17	13.6	0.2	3.4
17:15	16.3	16	12.2	0.3	3.8
17:30	15.4	15.1	9.9	0.3	5.2
17:45	7.3	7	5.7	0.3	1.3

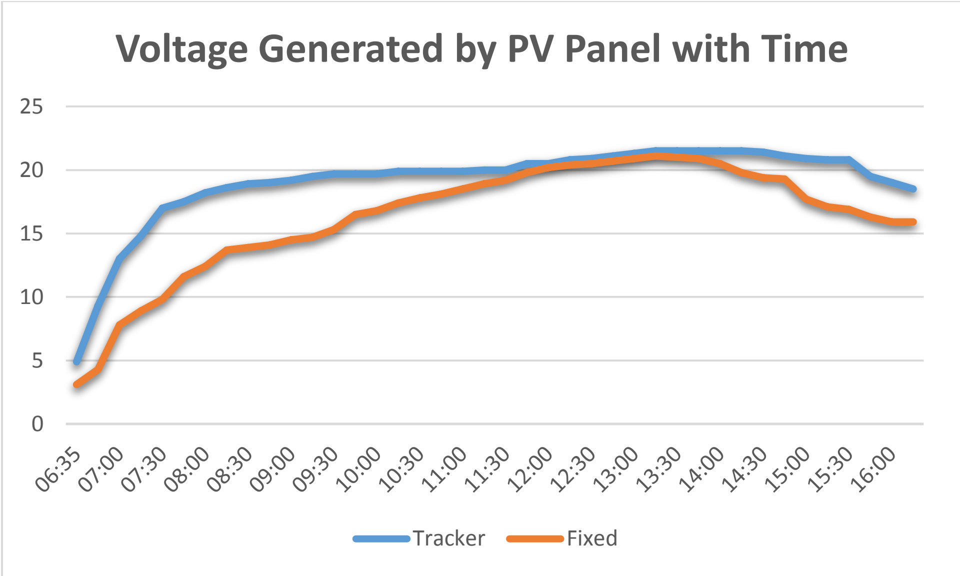

Figure 4.3 Voltage generated from PV panel with time. Orange PV panel with tracker. Blue, PV panel without tracker

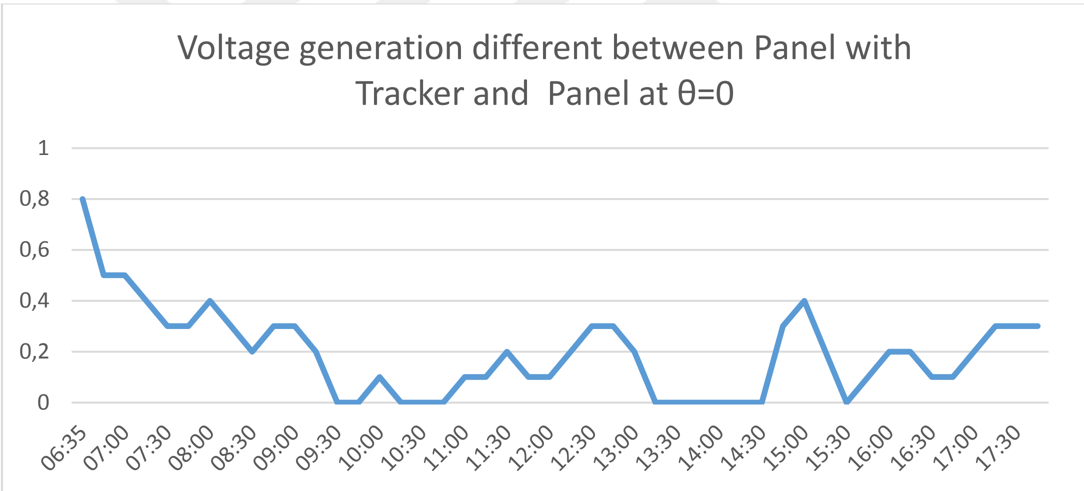

Figure 4.4 PV panel voltage generation difference with time between solar panel at $\theta=0$ and the solar panel with tracker.

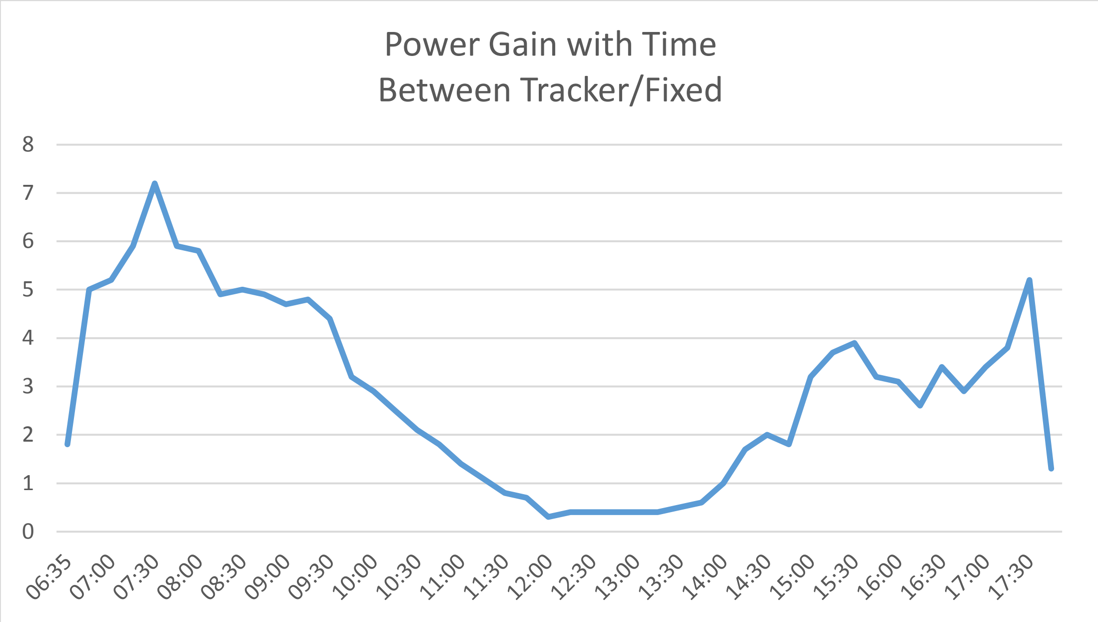

Figure 4.5 PV panel voltage generation difference with time between solar panel with tracker and fixed solar panel.

As shown from table 4.2 and figure 4.2, the PV panel voltage increased with time as the sun intensity increased until reach to maximum voltage at 12:45 when the sun intensity reaches to maximum, the results shows that the panel with tracker generated the power rapidly as the sun intensity increased and reach near from maximum voltage (19 volt) at 10:00 AM and continue to rise until reach the maximum at 12:45 PM then then reduced and continues decreases to 16:30 PM while the voltage generated by fixed tracker has been increased gradually until reach to near maximum power at 13:00 PM then reduced gradually.

The power difference between maximum generation power from solar cell at θ =0 and the solar panel with tracker is illustrated in table 4.1 and figure 4.4, as shown from the result the difference in power generation is little and it reach up to 0.8 volt in maximum and in overall average about ~0.2 volt per unit time. This approve that the proposed tracker can got close result from maximum solar power generation.

The power gain got from tracker through day is illustrated in table 4.1 and figure 4.5, as shown from the result the power gain is reach up to 7 volt and in overall average about ~2.8 volt per unit time. This approve that the proposed tracker can got higher efficiency than fixed one.

4.4.2 Power Generation Records from Fixed, 4 LDR and 12 Matrix LDR Solar Tracker at Different Locations

In this part, we have recorded the electrical voltage generated from both PV panel (with a tracker and without tracker) at the same times at one sunny day from sunrise to sunset from Baghdad city for one week to check the stability of system in real condition of operation. Tables 4.3 and figures 4.6 show the result of voltage generated by PV panel with tracker in Baghdad city. The readings have been taken under sunny-clear sky weather condition.

Table 4.3 The voltage generated from panel with tracker in Baghdad city for one week (from 06:35 Am to 18 PM) recorded in date from 17 to 23 April

Time (HH:MM)	Voltage Generated by PV panel with time for week days						
	Sat	Sun	Mon	Tus	Wed	Thu	Fri
06:35	5.7	5.3	5.6	5.5	5.4	5.8	5.4
07:00	13.5	13.4	13.7	13.5	13.6	13.6	13.4
07:30	17.3	16.8	17.1	16.9	17	17.2	16.9
08:00	18.6	18.6	18.8	18.5	18	18.1	18.4
08:30	19.3	19.2	19.4	19	19.1	19.3	19.2
09:00	19.5	19.5	19.6	19.3	19.2	19.4	19.5
09:30	19.7	19.7	19.9	19.6	19.4	19.7	19.6
10:00	19.9	19.8	20	19.8	19.7	19.8	19.8
10:30	19.9	19.7	20	19.8	20	20	19.9
11:00	20	19.9	20.3	20.1	20.1	20	19.9
11:30	20.2	20.5	20.6	20.3	20.1	20	19.9
12:00	20.3	20.6	20.1	20.3	20.6	20.4	20
12:30	20.9	20.8	20.7	20.7	20.8	20.7	20.8
13:00	21.5	21.3	21.5	21.4	21.5	21.5	21.3
13:30	21.4	21.5	21.2	21.2	21.4	21.4	21.4
14:00	21.3	21.4	21.4	21.1	21.3	21.4	21.5
14:30	21.3	21.4	21.4	21.5	21.4	21.4	21.4
15:00	20.8	20.8	20.6	20.5	20.9	20.9	20.9
15:30	20.7	20.8	20.6	20.6	20.7	20.5	20
16:00	20.1	20.2	20.6	20.7	20.2	20.4	20.6
16:30	19.9	20.3	20.6	20.5	20.1	20.5	20.6
17:00	19.1	19.2	20.2	20.1	20.5	20.5	20.4
17:30	18.8	18.5	18.4	18.3	18.3	18.4	18.4
18:00	7.3	6.3	7.5	5	6.7	7	5.5

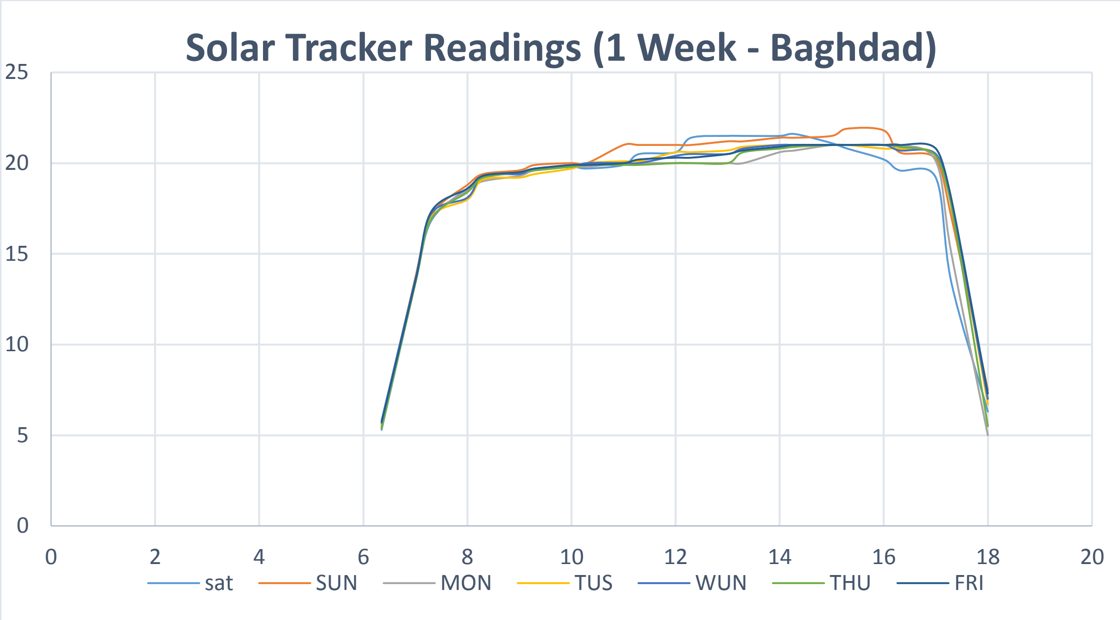

Figure 4.6 Voltage generated with time recorded from PV panel with proposed tracker from Baghdad City

AS shown from result in table 4.3 and figure 4.6, the proposed tracker works perfectly and tracked the sun efficiently without no problem were the readings are very close with each day, where the records taken under sunny-clear sky condition.

4.4.3 Power Generation Records from Fixed, 4 LDR and 12 Matrix LDR tracker

In this part, we have recorded the electrical voltage generated from both PV panel (without tracker, with a 4 LDR tracker and 12 matrix LDR tracker) at the same times at one sunny day from sunrise to sunset. Also, we have checked the maximum power generation from solar panel which is being at θ= 0, where the sun ray is perpendicular to solar panel and compered with ideal solar power measured by used ideal solar power meter. The following tables and figures show the power generation results for 10 days from 22 September to 1 October at Gaziantep city.

Table 4.4 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 22 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.6	18.9	19.2	802
10:00	19.11	19.8	19.93	880
11:00	19.3	20.4	20.7	962.6
12:00	19.42	20.9	20.9	1003
13:00	19.18	20.7	20.9	969.6
14:00	18.86	20.2	20.5	937.2
15:00	18.11	19.9	20.1	890
16:00	17.97	19.5	19.7	820
17:00	17.72	18.6	18.91	703

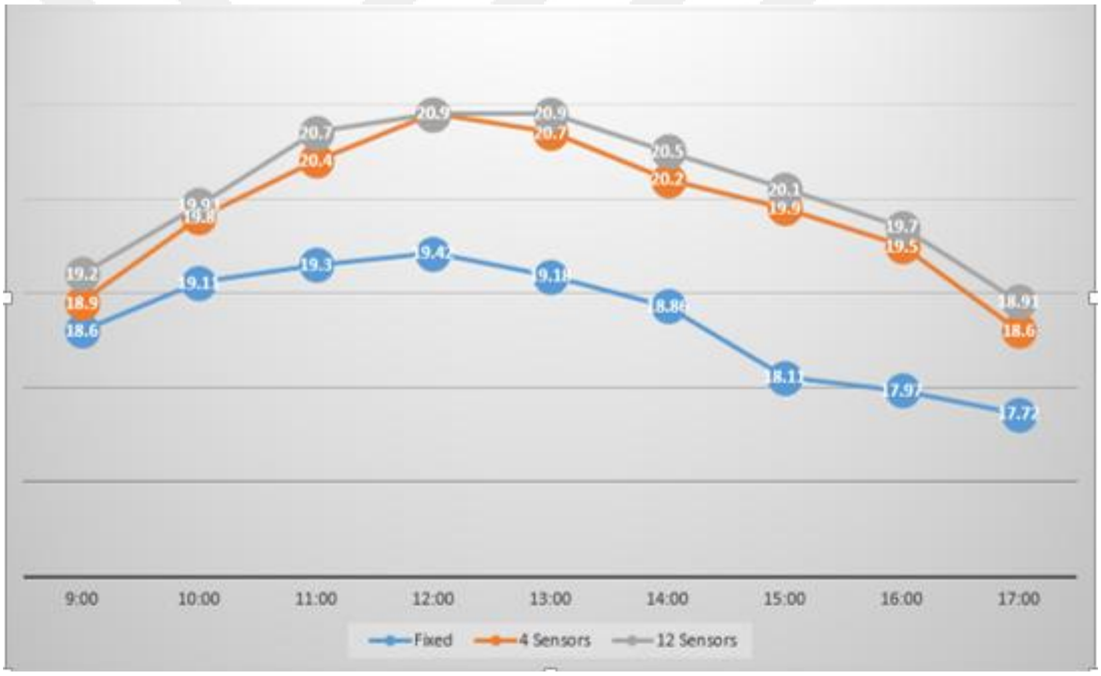

Figure 4.7 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 22 September

Table 4.5 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 23 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.8	19.1	19.2	810

10:00	19.15	19.9	19.87	865
11:00	19.29	20.3	20.5	964
12:00	19.48	20.9	20.9	997
13:00	19.22	20.8	20.9	953
14:00	18.72	20.5	20.6	912
15:00	18.43	20.1	20.3	869
16:00	18.2	19.7	19.9	812
17:00	17.87	19.1	19.3	689

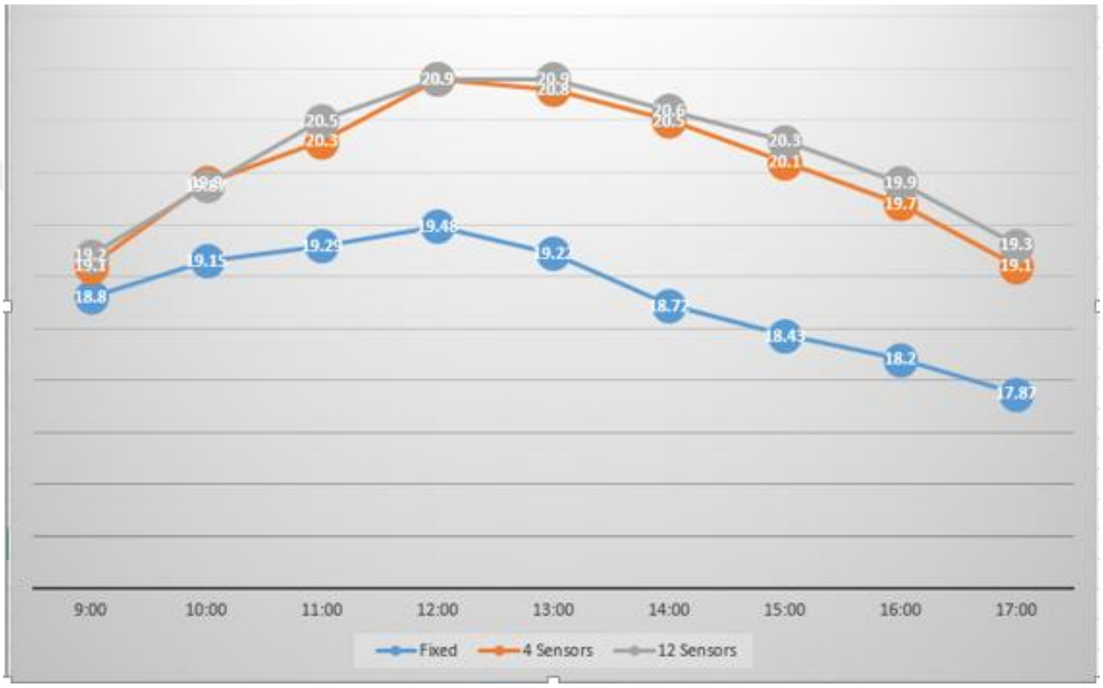

Figure 4.8 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 23 September

Table 4.6 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 24 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.8	19	19.1	802
10:00	19.1	19.8	20	892
11:00	19.23	20.34	20.5	962.6
12:00	19.45	20.7	20.9	1002
13:00	19.23	20.6	20.8	976

14:00	18.72	20.2	20.4	952
15:00	17.97	19.8	19.9	903
16:00	17.87	19.4	19.8	794
17:00	17.54	18.4	18.6	678

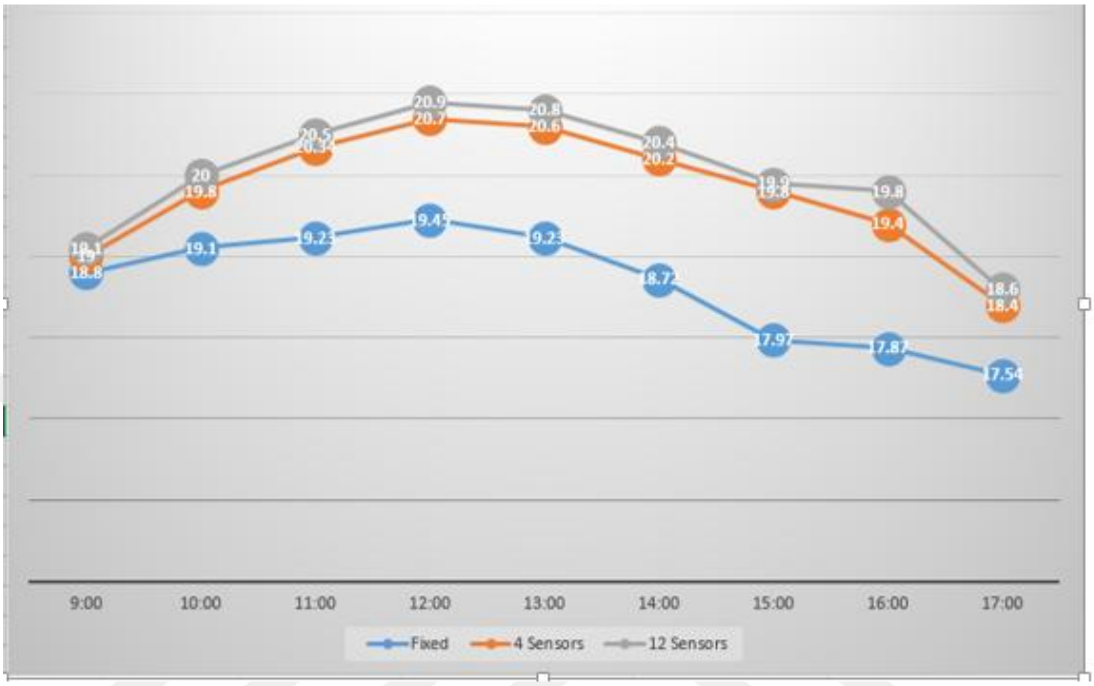

Figure 4.9 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 24 September

Table 4.7 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 25 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.34	19.3	19.3	823
10:00	19.34	20	20.2	908
11:00	19.23	20.6	20.7	972
12:00	19.54	20.8	20.9	1009
13:00	19.32	20.6	20.8	986
14:00	18.82	20.2	20.4	964
15:00	18.12	19.8	19.9	924
16:00	17.92	19.4	19.8	912
17:00	17.23	18.5	18.8	682

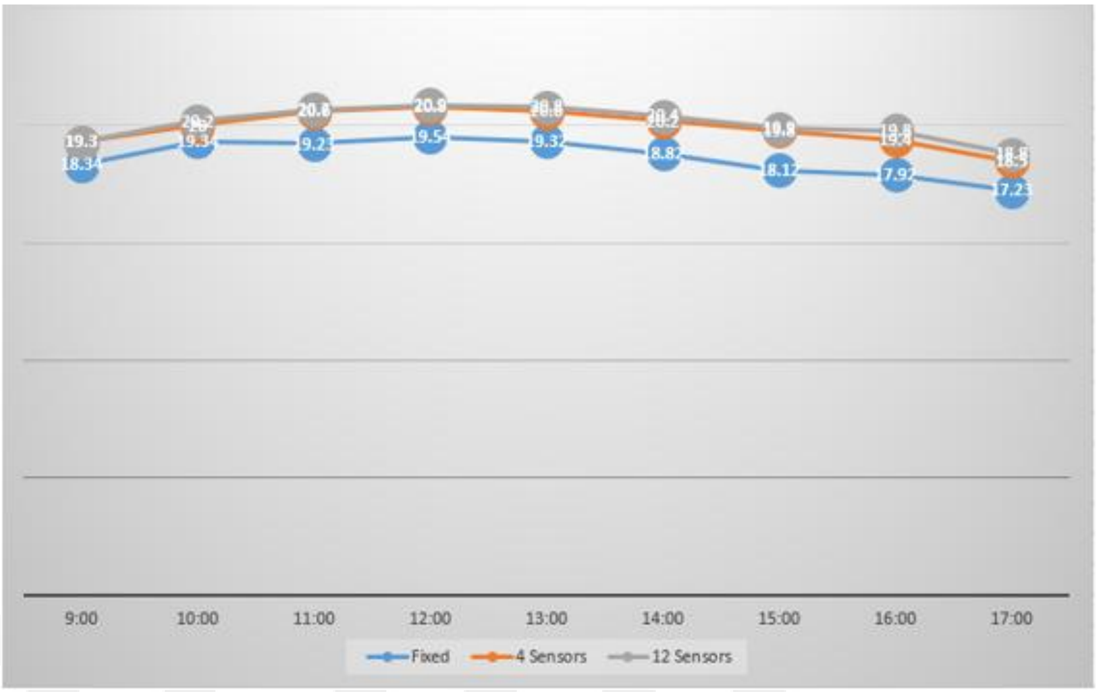

Figure 4.10 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 25 September

Table 4.8 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 26 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.53	19.6	19.6	838
10:00	19.56	20.1	20.3	923
11:00	19.43	20.5	20.8	987
12:00	19.6	20.7	20.9	1012
13:00	19.32	20.7	20.8	1001
14:00	18.97	20.3	20.6	973
15:00	18.38	19.7	20	931
16:00	17.43	19.5	19.7	919
17:00	17.36	18.8	18.6	693

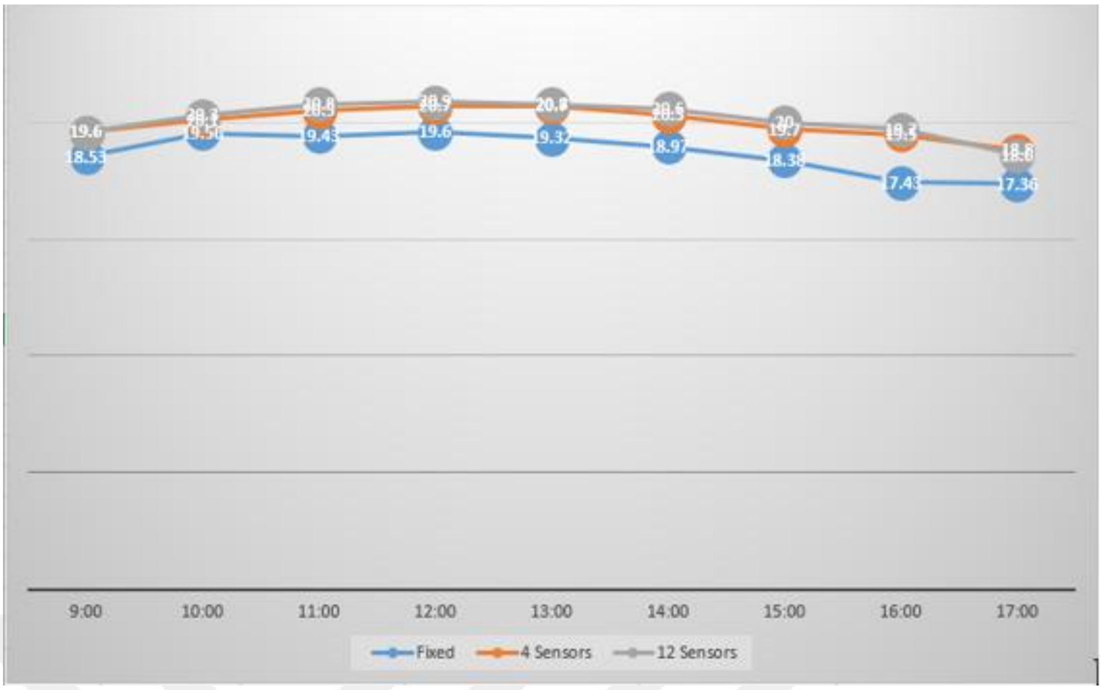

Figure 4.11 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 26 September

Table 4.9 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 27 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18	18.7	18.8	825
10:00	18.9	19.6	19.6	911
11:00	19.23	20.1	20.1	967
12:00	19.56	20.8	20.9	981
13:00	19.1	20.9	20.9	974
14:00	18.63	20.2	20.5	949
15:00	18.23	19.7	19.9	920
16:00	17.43	19.4	19.4	904
17:00	17.21	18.3	18.3	717

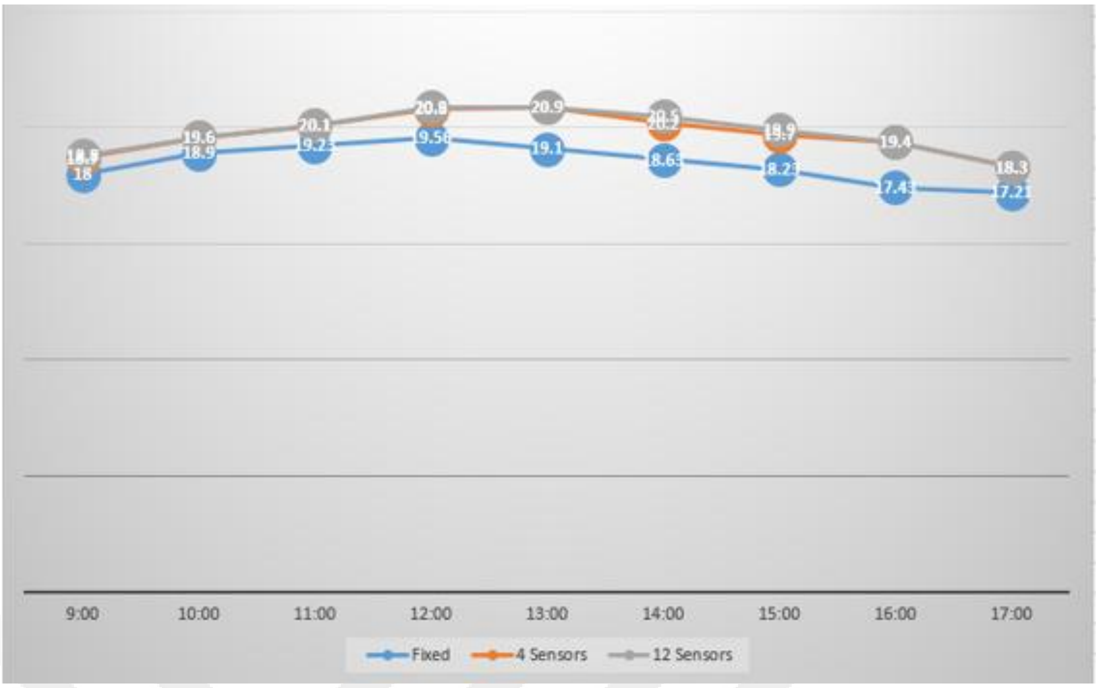

Figure 4.12 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 27 September

Table 4.10 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 28 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.3	18.8	18.8	817
10:00	19.12	19.8	19.9	925
11:00	19.37	20.1	20.2	987
12:00	19.6	20.9	20.9	1009
13:00	19.32	20.9	20.9	990
14:00	19.1	20.4	20.4	967
15:00	18.65	19.8	19.7	243
16:00	17.33	19.5	19.7	929
17:00	17.4	18.6	18.9	745

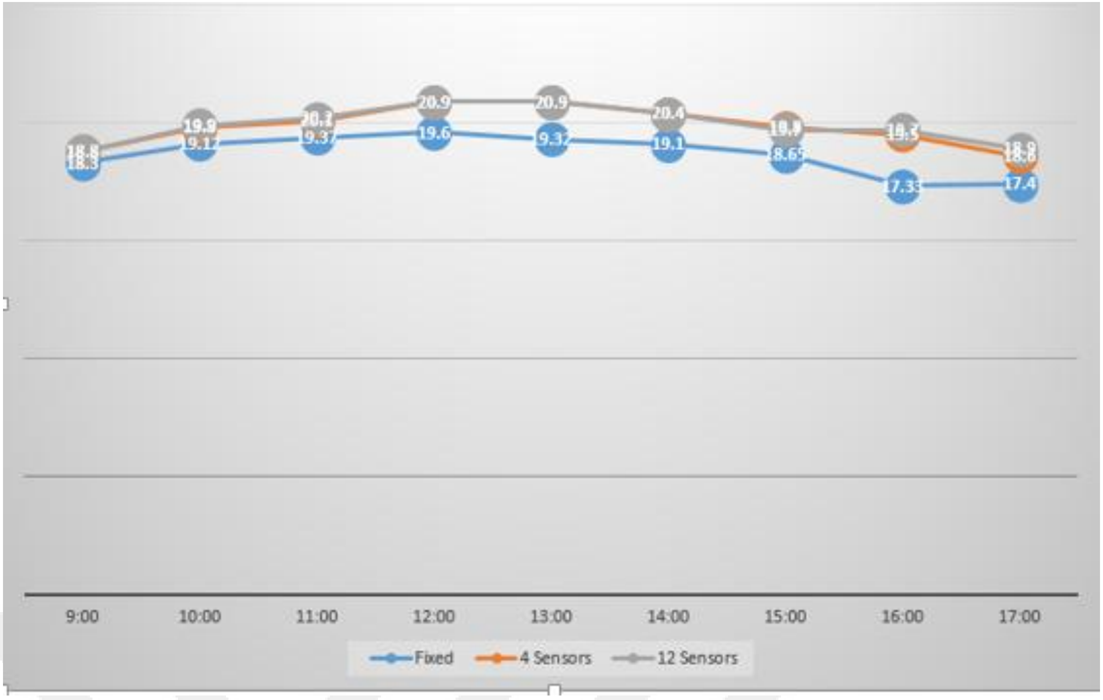

Figure 4.13 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 28 September

Table 4.11 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 29 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.5	18.8	18.9	824
10:00	19.22	20	20.1	941
11:00	19.35	20.2	20.2	980
12:00	19.73	20.8	20.8	1005
13:00	19.32	20.6	20.7	1003
14:00	19.1	20.1	20.2	952
15:00	18.98	19.7	19.8	236
16:00	17.76	19.3	19.5	915
17:00	17.2	18.8	19	728

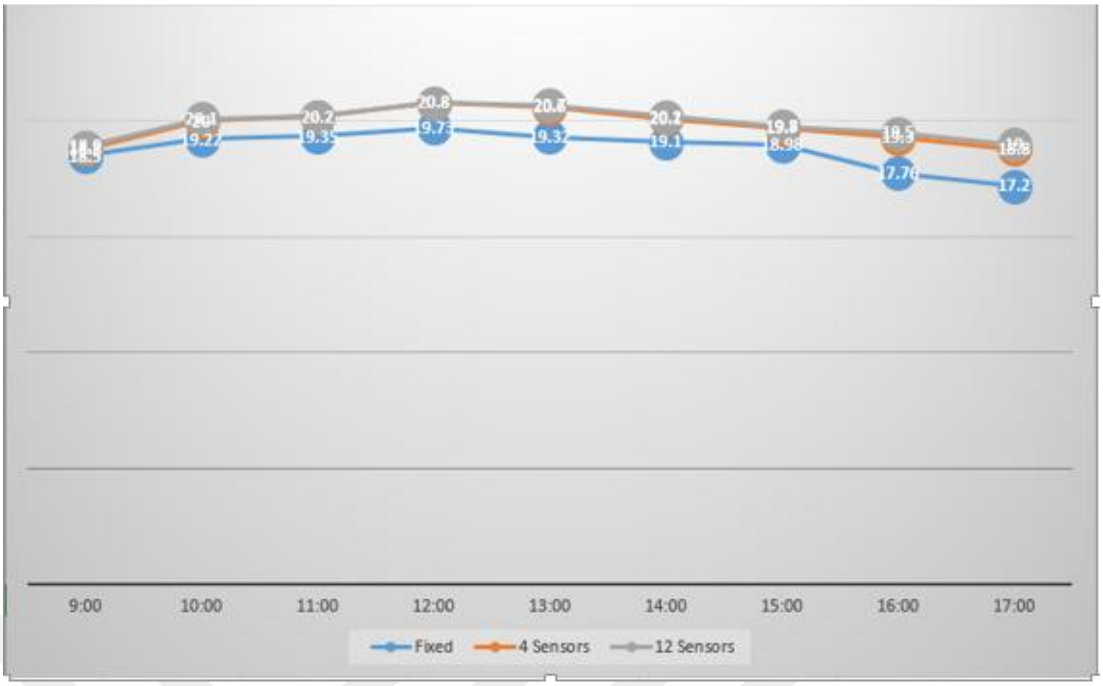

Figure 4.14 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 29 September

Table 4.12 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 30 September

Time	Fixed	4 Sensors	Matrix (12 sensors)	Sun Power (watt/m2)
9:00	18.5	18.8	18.9	829
10:00	19.22	20	20.1	949
11:00	17.24	18.7	18.9	974
12:00	18.13	19.5	19.7	988
13:00	18.9	20.1	20.2	1001
14:00	18.81	20.1	20.2	993
15:00	17.83	18.7	18.7	961
16:00	17.21	18.2	18.2	915
17:00	16.36	17.6	17.7	728

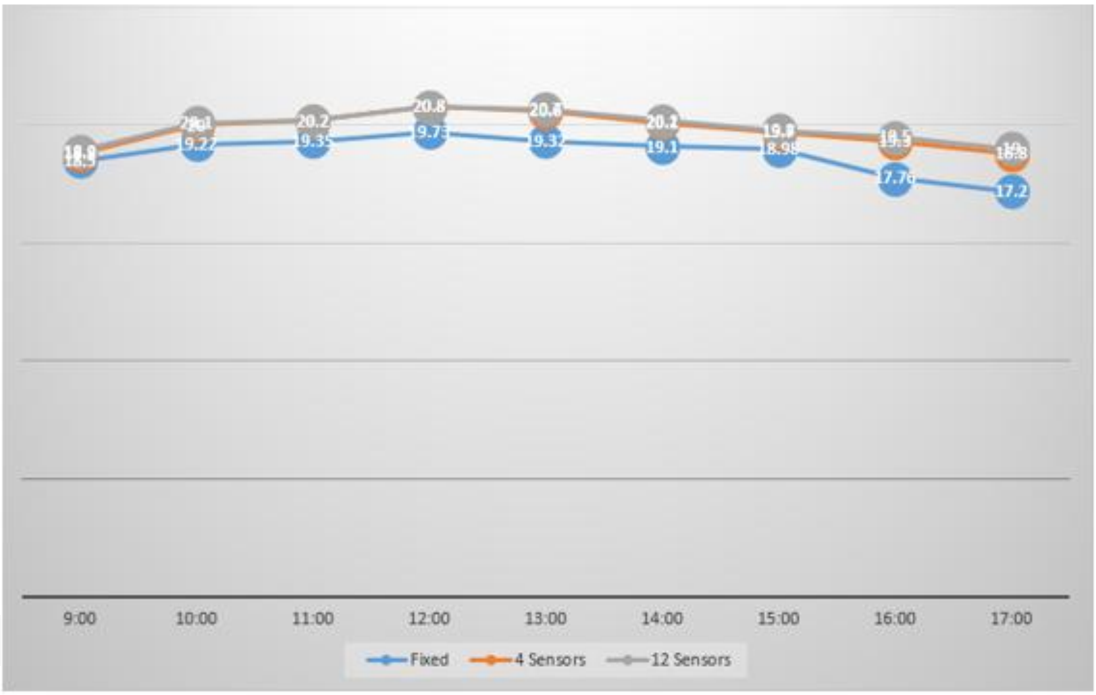

Figure 4.15 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 30 September

Table 4.13 The voltage generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 1 October

Time	Fixed	4 Sensors	Matrix (12 sensors)	Solar Sun power watt/m2
9:00	16.45	17.6	17.6	412
10:00	17.34	18.3	18.5	756
11:00	18.5	19.6	19.7	812
12:00	19.3	20.2	20.2	934
13:00	18.83	20	20.1	907
14:00	18.66	20	20	883
15:00	18.23	19.5	19.7	863
16:00	17.86	18.6	18.9	811
17:00	16.9	18	18.1	703

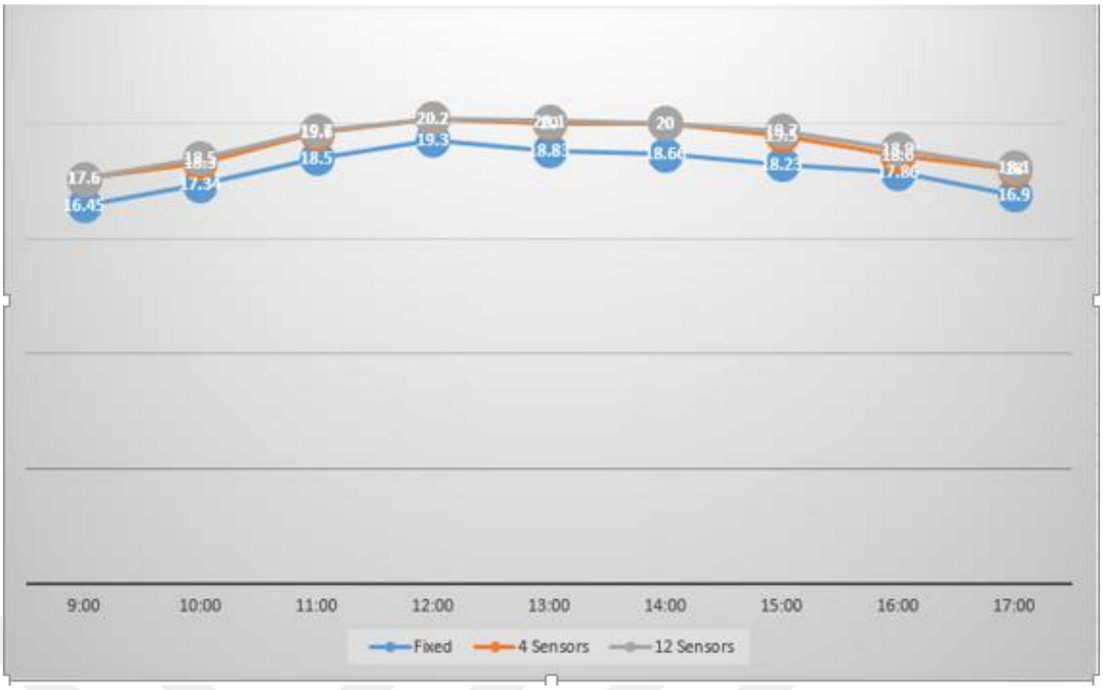

Figure 4.16 PV panel voltage generation difference with time between solar panel without tracker and 4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 1 October

As shown from tables from 4.4 to 4.13 and figures from 4.7 to 4.16, the PV panel voltage increased with time as the sun intensity increased until reach to maximum voltage at 12:00 pm when the sun intensity reaches to maximum. The results show that the panel with tracker (in both 4ldr and 12 matrix LDR) generated the power rapidly as the sun intensity increased and then reduced and continue to decreases until reach the minimum at 17:00 PM. Then, it reduced gradually until 16:30 PM, while the voltage generated by fixed tracker has been increased gradually until reach to maximum power at 12:00 PM then reduced gradually. From results the readings of solar panel with tracker is more than solar without tracker for about 1 volt per second. For readings of 4 LDR tracker and 12 matrix tracker the results shows the voltage generated is relatively close and the 12 matrix LDR got the more voltage generated when compared with 4 LDR in range about 0.1 to 0.3 volt. There is low voltage generation in days 30/9 and 1/10 this because the weather was cloudy.

4.4.4 Power Generation Records from 8 on panel LDR and 8 Matrix LDR tracker

In this part, we have recorded the electrical voltage generated from both PV panel (without tracker, with an 8 on panel LDR tracker and 8 matrix LDR tracker) at the same times at one sunny day from sunrise to sunset. Also, we have checked the maximum power generation from solar panel which is being at θ= 0, where the sun ray is perpendicular to solar panel and compered with ideal solar power meter. The following tables and figures show the power generation results for 10 days from 25 October to 3 November at Gaziantep city.

Table 4.14 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 25 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.8	18.2	18.3
10:00	18.5	19.1	19.2
11:00	18.89	19.7	19.8
12:00	19.11	20.1	20.1
13:00	19.18	20	20
14:00	18.86	19.5	19.5
15:00	18.11	19	19
16:00	17.67	18.5	18.6
17:00	17.32	17.8	17.9

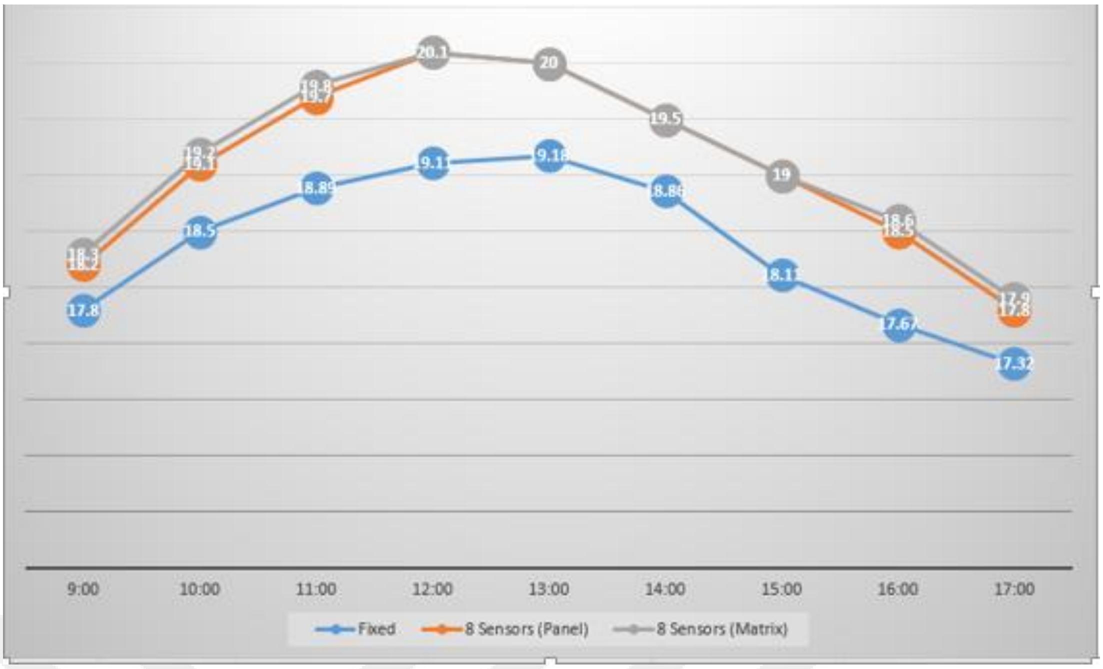

Figure 4.17 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 25 October

Table 4.15 The voltage generated from panel without tracker and 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 26 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.9	18.5	18.5
10:00	18.6	19.4	19.5
11:00	18.76	19.9	20
12:00	19.22	20.3	20.3
13:00	19.18	19.9	20
14:00	18.77	19.5	19.5
15:00	18.23	19.1	19.1
16:00	17.6	18.8	18.9
17:00	17.43	18	18

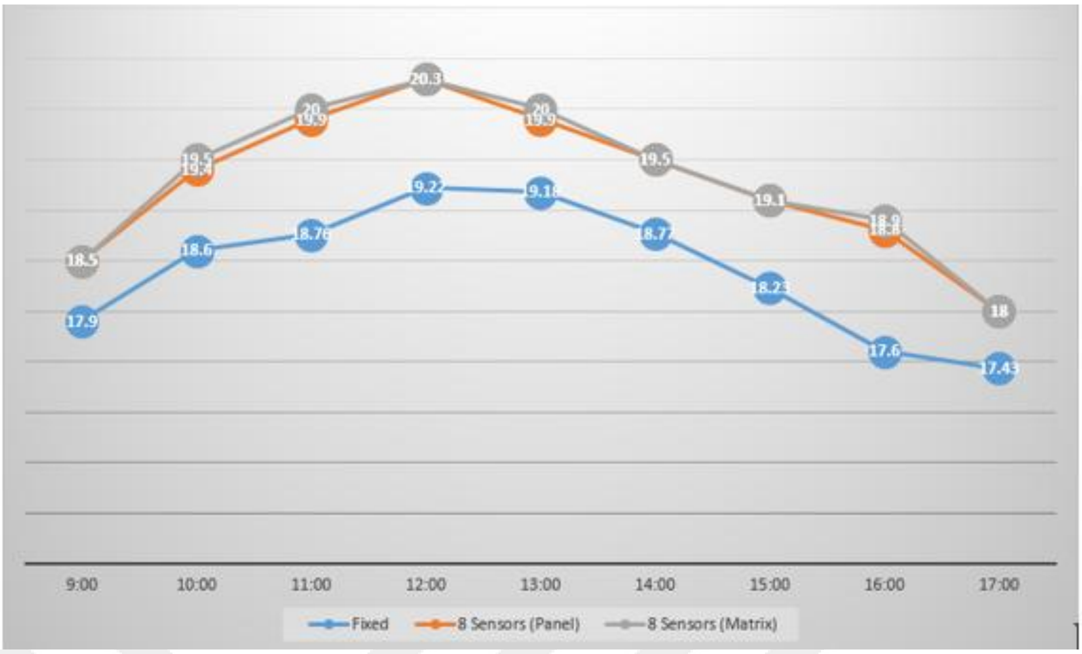

Figure 4.18 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 26 October

Table 4.16 The voltage generated from panel without tracker and for system of 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 27 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.7	18.4	18.5
10:00	18.67	19.2	19.2
11:00	19.31	19.8	19.9
12:00	19.82	20.1	20.1
13:00	19.8	20	20
14:00	19.1	19.6	19.7
15:00	18.5	19.2	19.3
16:00	17.5	18.7	18.7
17:00	17.21	18.1	18.1

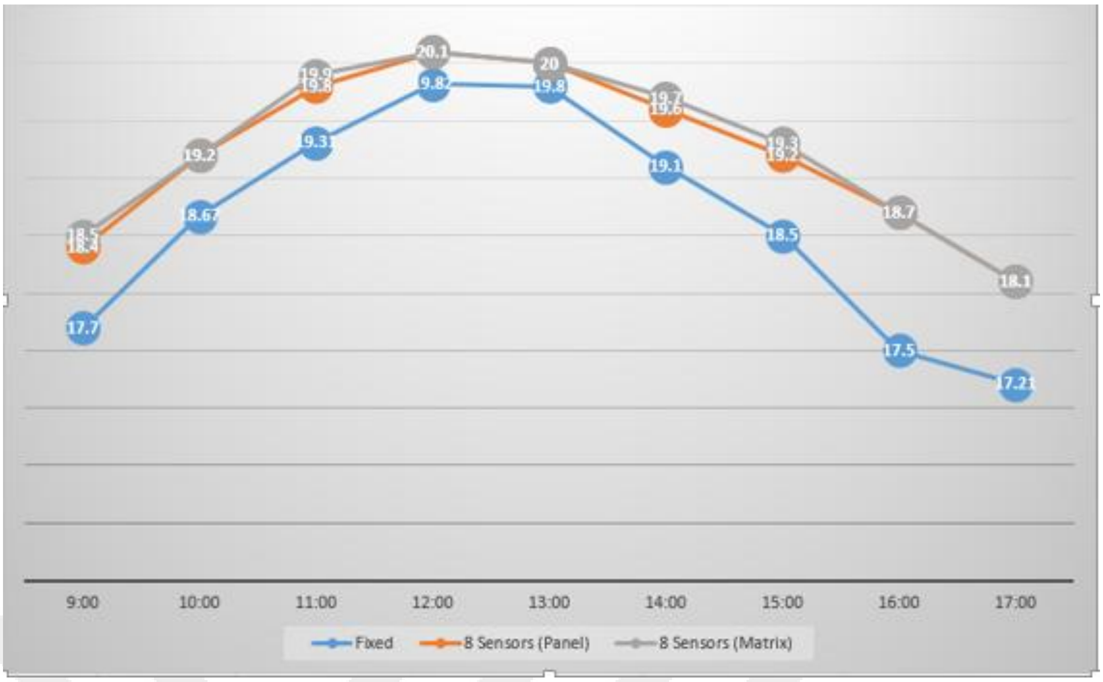

Figure 4.19 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 27 October

Table 4.17 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 28 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.6	18.5	18.5
10:00	18.15	19.4	19.5
11:00	18.74	19.9	20
12:00	19.32	20.3	20.3
13:00	19.7	19.9	20
14:00	18.96	19.5	19.5
15:00	18.31	19.1	19.1
16:00	17.67	18.7	18.8
17:00	17.32	18	18

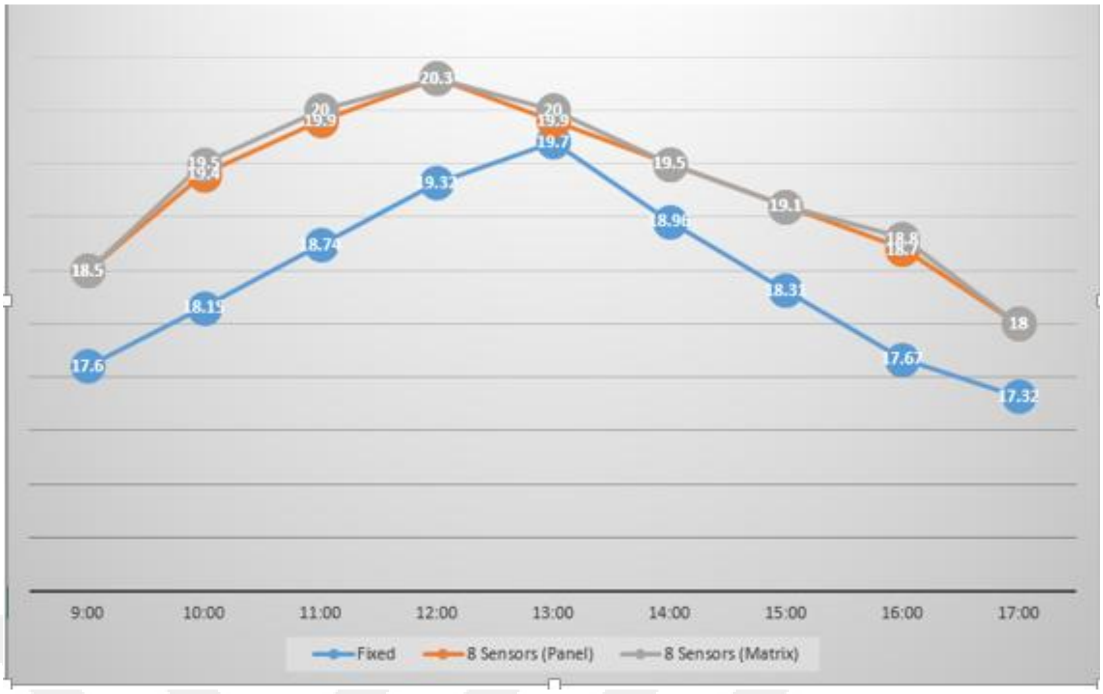

Figure 4.20 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 28 October

Table 4.18 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 29 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.34	18.5	18.5
10:00	18.23	19.5	19.6
11:00	18.93	19.9	20
12:00	19.9	20.4	20.4
13:00	19.9	20.2	20.3
14:00	19.53	20.1	20.2
15:00	18.68	19.8	19.8
16:00	17.76	19.3	19.4
17:00	17.1	18.5	18.6

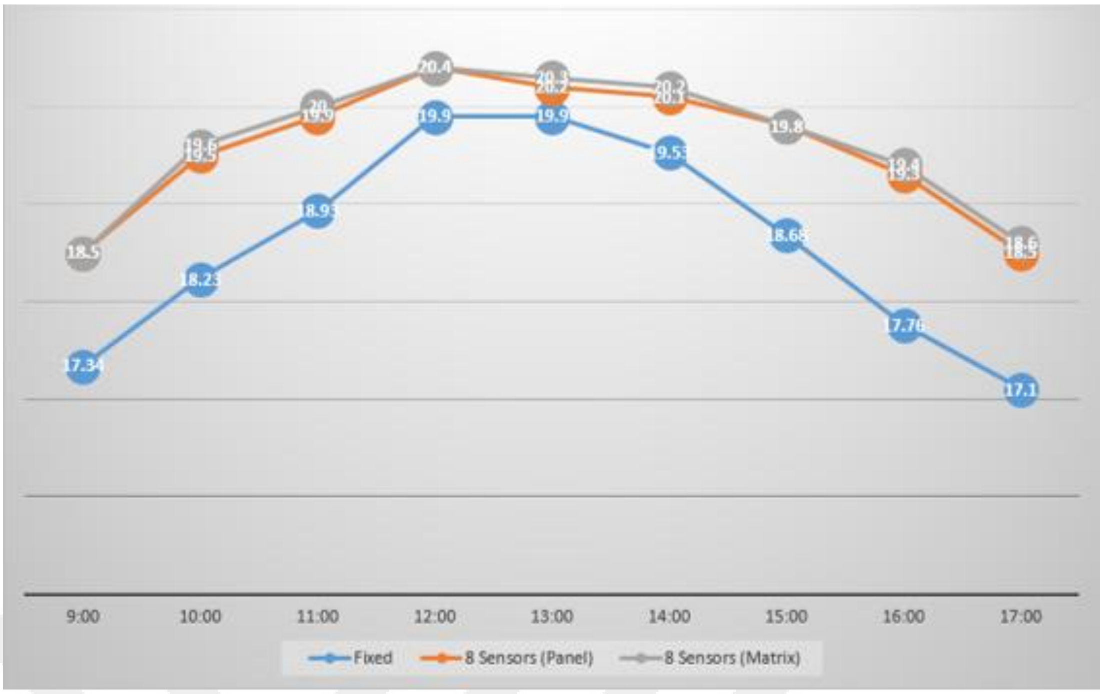

Figure 4.21 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 29 October

Table 4.19 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 30 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.47	18.5	18.5
10:00	18.14	19.4	19.5
11:00	18.76	19.9	20
12:00	19.5	20.1	20.2
13:00	20	20.2	20.2
14:00	19.26	19.7	19.8
15:00	18.11	19.3	19.3
16:00	17.37	18.8	18.9
17:00	16.93	18.3	18.3

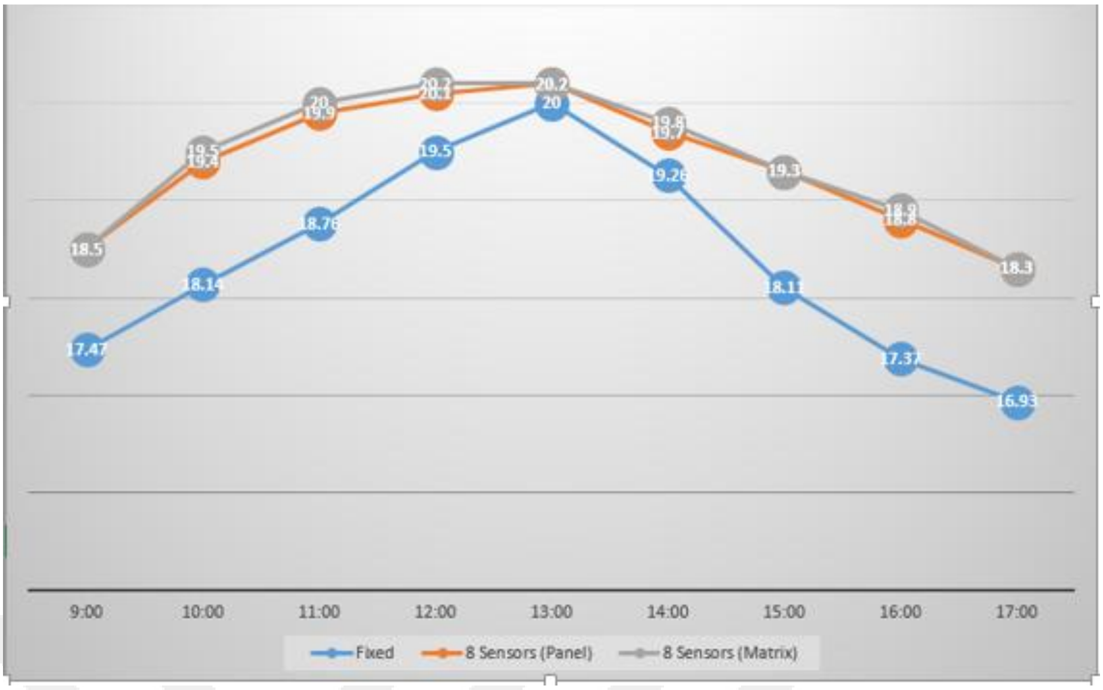

Figure 4.22 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 30 October

Table 4.20 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 31 October

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	16.8	18.4	18.5
10:00	18.23	19.4	19.5
11:00	18.76	19.8	19.8
12:00	19.5	20	20
13:00	20	20.3	20.4
14:00	18.9	19.8	19.9
15:00	18	19.1	19.3
16:00	17.17	18.6	18.7
17:00	16.75	18.2	18.3

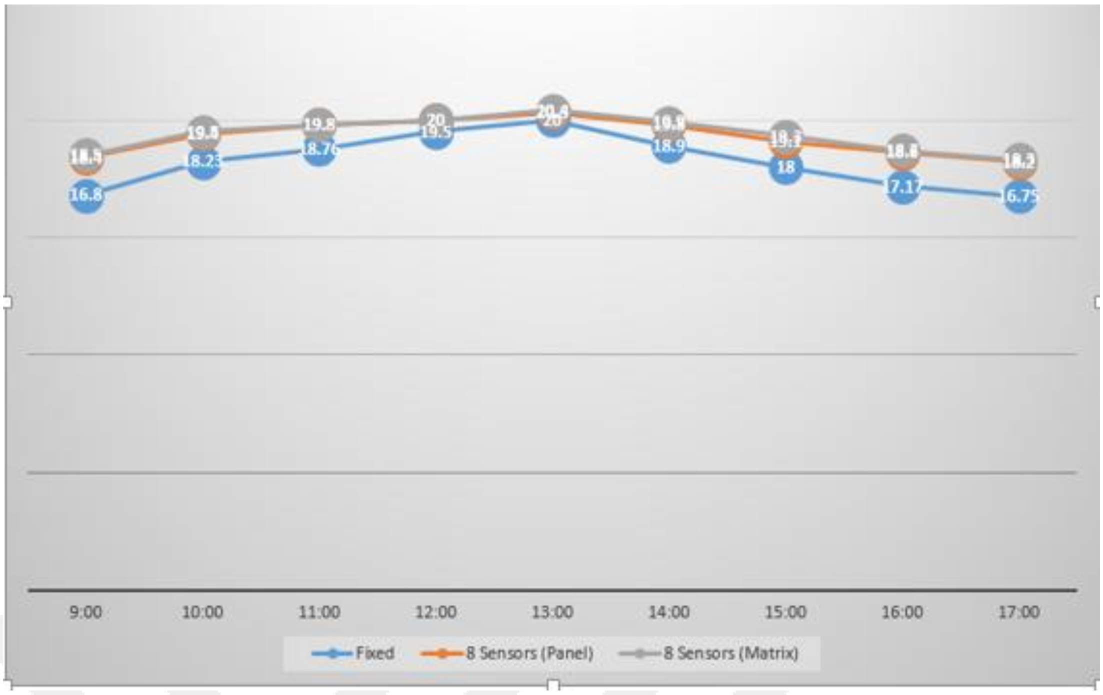

Figure 4.23 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 31 October

Table 4.21 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 1 November

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.42	18.5	18.5
10:00	18.43	19.4	19.5
11:00	19.1	19.7	19.8
12:00	20	20.2	20.2
13:00	19.8	20	20.1
14:00	19.22	19.8	19.8
15:00	18.68	19.5	19.6
16:00	17.76	19.1	19.1
17:00	17.1	18.5	18.6

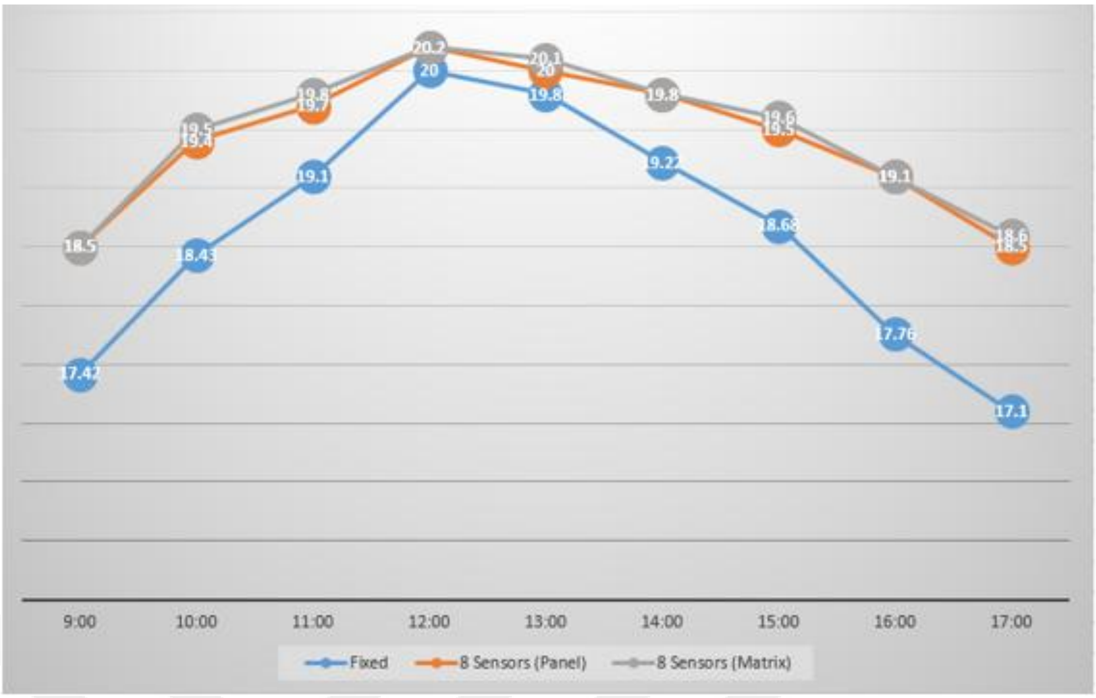

Figure 4.24 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 1 November

Table 4.22 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 2 November

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.16	18.4	18.4
10:00	18.73	19.7	19.8
11:00	19.8	20.1	20.2
12:00	20.3	20.3	20.5
13:00	19.9	20	20
14:00	19.1	19.8	19.9
15:00	18.43	19.3	19.3
16:00	17.78	19	19.1
17:00	16.95	18.2	18.3

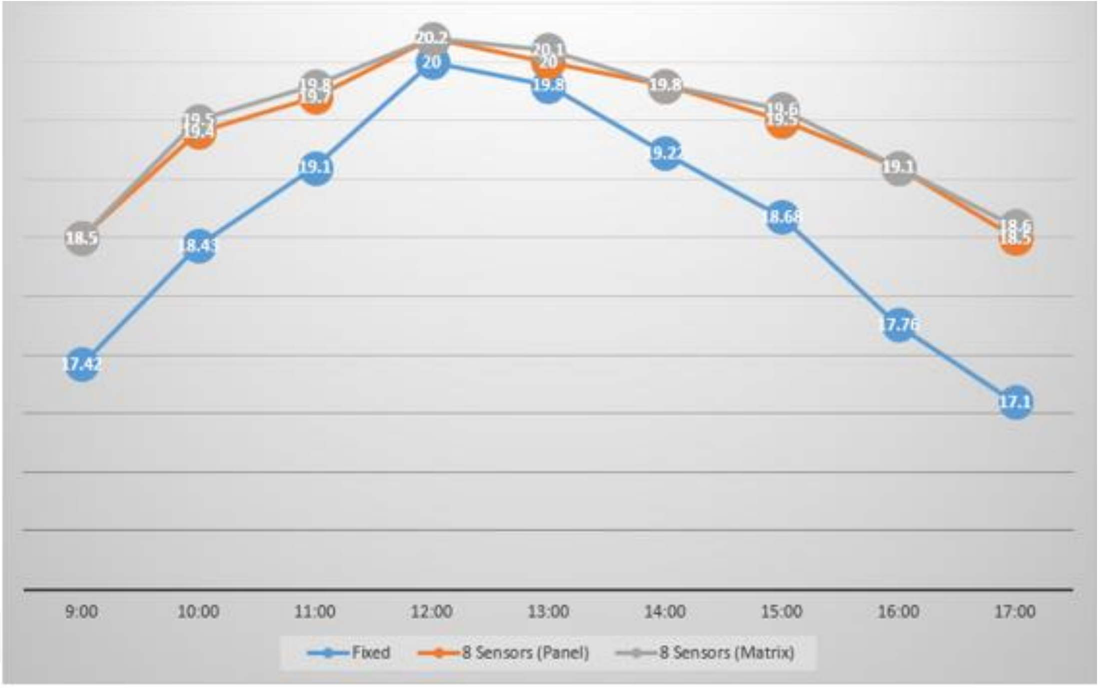

Figure 4.25 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 2 November

Table 4.23 The voltage generated from panel with 8 LDR on panel tracker and 8 matrix LDR tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city in 3 November

Time	Fixed	Panel (8 LDR sensors)	Matrix (8 LDR sensors)
9:00	17.33	18.4	18.5
10:00	18.6	19.6	19.8
11:00	19.72	20.2	20.2
12:00	20.41	20.4	20.5
13:00	19.83	20	20.1
14:00	19.22	19.8	19.9
15:00	18.16	19.4	19.4
16:00	17.53	19.1	19.2
17:00	16.73	18.3	18.3

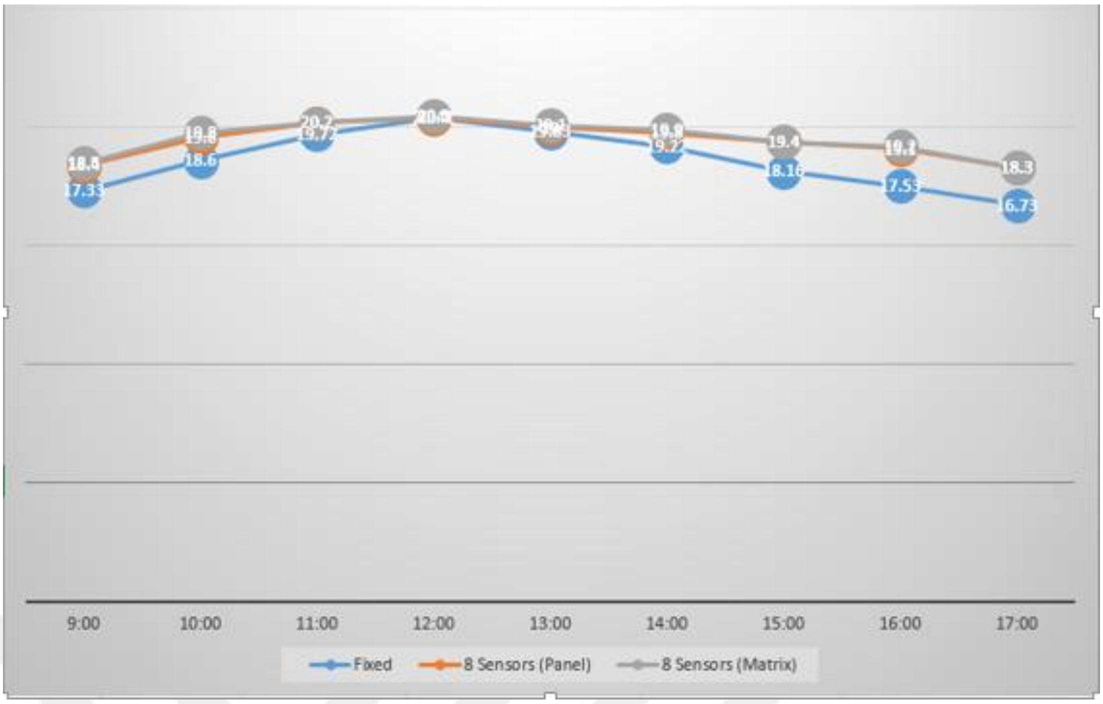

Figure 4.26 PV panel voltage generation difference with time between solar panel with 8 LDR on panel tracker and 8 matrix LDR tracker from Gaziantep city in 3 November

As shown from tables from 4.14 to 4.23 and figures from 4.17 to 4.26, same as previous results the PV panel voltage increased with time as the sun intensity increased until reach to maximum voltage at 12:00 pm when the sun intensity reaches to maximum. The results show that the panel with tracker (in both 8 LDR and 8 matrix LDR) generated the power rapidly as the sun intensity increased and then reduced and continue to decreases until reach the minimum at 17:00 PM. As well, the voltage generated by fixed panel has been increased gradually until reach to maximum power at 12:00 PM then reduced gradually. From results the readings of solar panel with tracker is more than solar without tracker for about 1 volt per second. For readings of 8 LDR tracker and 8 matrix tracker the results shows the voltage generated is relatively close and many times has same values as with the 8 matrixes however, the 8 matrix LDR got more voltage when compared with 8 LDR in about 0.1 volt.

4.4.5 Power Generation Results

We have also calculated the power generated from solar panel in cases of no tracker, 4 LDR tracker and 8 Matrix LDR tracker and compered it with ideal solar intensity detector for 1 day. The power of panel per time is calculated from following formula:

Panel Power (watt per time) = Generated voltage (volt per time) x panel current

Where, the panel current is 0.25 A, and active area of panel dimension is 0.22x0.20 ~ 0.044m^2, thus the power per m^2 should be 22.7 * Panel Power

Panel Power = 22.7 * 0.25 **Generated voltage (volt per time)**

= 5.68 **Generated voltage (volt per time)**

The ideal solar power generated is computed by solar intensity detector which can measured the power in (watt/m^2). We used the panel area to evaluate the power generation in (watt/m^2). The result is shown in table 4.24 and figure 4.27.

Table 4.24 The voltage and power generated from panel with tracker and without tracker in one day (from 9:00 Am to 17:00 PM) recorded from Gaziantep city

Time	Fixed	4 LDR Sensors	Matrix 12 LDR sensors	Solar Sun power watt/m2	power fixed	power of 4 LDR Sensors	Power of 12 LDR sensors
9:00	16.45	17.6	17.6	112	93.436	99.968	99.968
10:00	17.34	18.3	18.5	756	98.4912	103.944	105.08
11:00	18.5	19.6	19.7	812	105.08	111.328	111.896
12:00	19.3	20.2	20.2	934	109.624	114.736	114.736
13:00	18.83	20	20.1	907	106.954	113.6	114.168
14:00	18.66	20	20	883	105.989	113.6	113.6
15:00	18.23	19.5	19.7	863	103.546	110.76	111.896
16:00	17.86	18.6	18.9	811	101.445	105.648	107.352
17:00	16.9	18	18.1	703	95.992	102.24	102.808

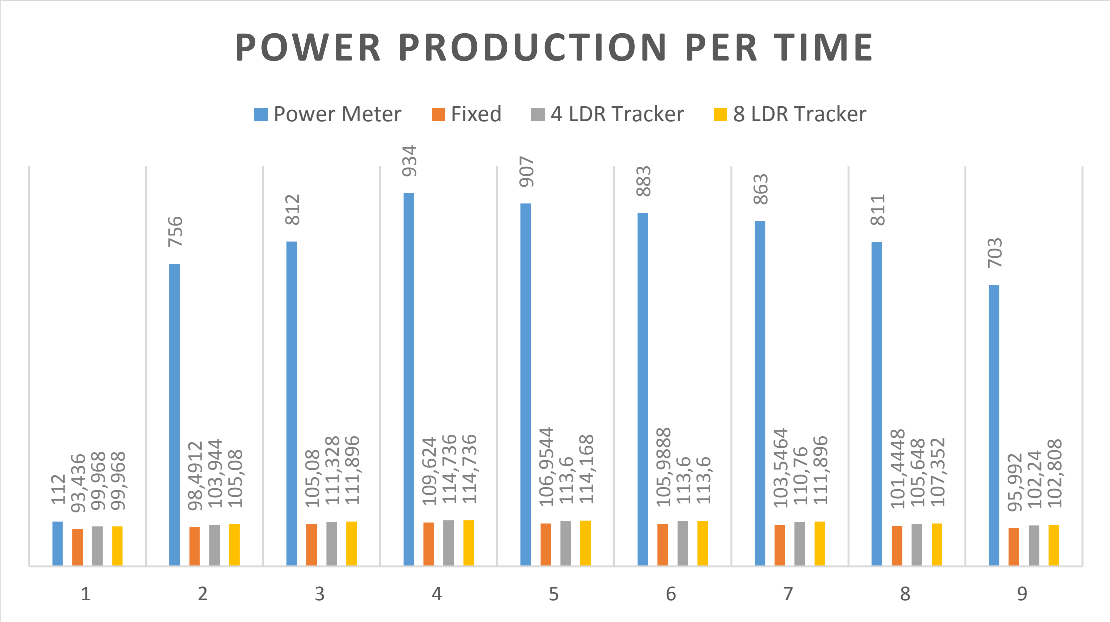

Figure 4.27 PV panel voltage generation difference with time between solar panel without tracker,4 LDR tracker and 8 matrix LDR tracker from Gaziantep city in 1 October

As shown from table 4.24 and figure 4.27, the power difference between maximum generation power from solar power meter and the solar panel in three cases (without tracker, 4 LDR tracker and 12 matrix tracker) is about 2 times and the power generated of trackers is little and more than fixed tracker.

4.4.6 Error Analysis of System Tracking

In this part we calculate error in redirection of tracker to sun to be perpendicular with sun. First, we recorded reading from solar tracker in three cases, one is the solar panel at (θ = 0), this has been achieved experimentally by adjust the direction of solar panel manually and checked the readings from voltmeter, when found the maximum voltage then the panel redirected to this location. For error calculations we calculated the error of tracking as a difference between voltage generated from tracker when solar panel at (θ = 0) and the voltage from fixed and 12 LDR matrix tracker. The results shown in table 4.25 and figure 4.28.

Table 4.25 Tracking error from panel with tracker and without tracker based on readings takes for 12 April (from 06:35 Am to 17:45 PM) recorded from Bagdad city

Time (HH:MM)	Voltage Generated from Solar Panel			Error in Tracking	
	Solar Panel at (θ = 0)	Panel with Tracker	Fixed Panel	Panel θ=0 /Tracker	Fixed Panel/ Tracker
06:35	5.7	4.9	3.1	0.8	2.6
06:45	9.8	9.3	4.3	0.5	5.5
07:00	13.5	13	7.8	0.5	5.7
07:15	15.2	14.8	8.9	0.4	6.3
07:30	17.3	17	9.8	0.3	7.5
07:45	17.8	17.5	11.6	0.3	6.2
08:00	18.6	18.2	12.4	0.4	6.2
08:15	18.9	18.6	13.7	0.3	5.2
08:30	19.1	18.9	13.9	0.2	5.2
08:45	19.3	19	14.1	0.3	5.2
09:00	19.5	19.2	14.5	0.3	5
09:15	19.7	19.5	14.7	0.2	5
09:30	19.7	19.7	15.3	0	4.4
09:45	19.7	19.7	16.5	0	3.2
10:00	19.8	19.7	16.8	0.1	3
10:15	19.9	19.9	17.4	0	2.5
10:30	19.9	19.9	17.8	0	2.1
10:45	19.9	19.9	18.1	0	1.8
11:00	20	19.9	18.5	0.1	1.5
11.15	20.1	20	18.9	0.1	1.2
11:30	20.2	20	19.2	0.2	1
11:45	20.6	20.5	19.8	0.1	0.8
12:00	20.6	20.5	20.2	0.1	0.4
12:15	21	20.8	20.4	0.2	0.6
12:30	21.2	20.9	20.5	0.3	0.7
12:45	21.4	21.1	20.7	0.3	0.7
13:00	21.5	21.3	20.9	0.2	0.6
13:15	21.5	21.5	21.1	0	0.4
13:30	21.5	21.5	21	0	0.5
13:45	21.5	21.5	20.9	0	0.6
14:00	21.5	21.5	20.5	0	1
14:15	21.5	21.5	19.8	0	1.7
14:30	21.4	21.4	19.4	0	2
14:45	21.4	21.1	19.3	0.3	2.1
15:00	21.3	20.9	17.7	0.4	3.6
15:15	21	20.8	17.1	0.2	3.9
15:30	20.8	20.8	16.9	0	3.9
15:45	19.6	19.5	16.3	0.1	3.3

16:00	19.2	19	15.9	0.2	3.3
16:15	18.7	18.5	15.9	0.2	2.8
16:30	18.6	18.5	15.1	0.1	3.5
16:45	17.5	17.4	14.5	0.1	3
17:00	17.2	17	13.6	0.2	3.6
17:15	16.3	16	12.2	0.3	4.1
17:30	15.4	15.1	9.9	0.3	5.5
17:45	7.3	7	5.7	0.3	1.6

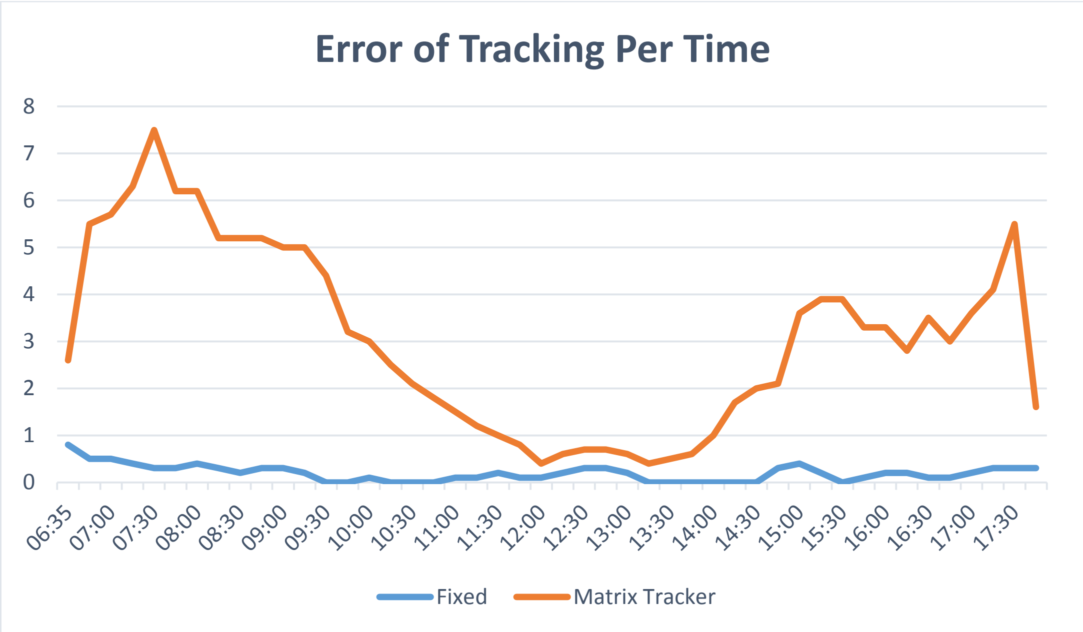

Figure 4.28 Tracking error with time, Orange represent fixed tracker errors, and the blue represent the 12 matrix LDR tracking error

As Shown from results, the 12 matrix LDR tracker has a little tracking error reach in some time to zero while the fixed tracker has a more tracking error.

4.4.7 Estimating Uncertainty in Solar Tracker Reading Measurements

In this part we calculated the uncertainty in repeated measurements, based on [45], the uuncertainty error can be calculated from following Steps:

1- **Measurements of Several Days Records**

   In this part we have taken several measurements from sun tracker in same time in same condition for several days. We take voltage production readings from every tracker which has been recorded at 12:00 pm for 7 days. Table 4.26 shows the voltage records for all tracking system methods.

Table 4.26 Voltage records for all tracking system methods for 7 days in same weather condition and same time

Tracking types	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day
Fixed	19.42	19.48	19.45	19.54	19.6	19.56	19.6
4 on panel LDR	20.7	20.9	20.7	20.8	20.7	20.8	20.9
8 on panel LDR	20.9	20.9	20.1	20.7	20.8	20.8	20.9
8 Matrix LDR	20.9	20.9	20.1	20.9	20.9	20.7	20.9
12 Matrix LDR	20.9	20.9	20.9	20.9	20.8	20.9	20.7

2- Calculating the Average (Mean) Value

The mean values for records can be calculated from following formula [45]:

$$Average \ \ mean \ = \frac{v1 + v2 + \cdots + v_n}{N}$$

Where: x, voltage value, N is the number of days. The Average mean of record from table 4.26 is shown in table 4.27.

Table 4.27 Mean values of the measurement

Tracking types	Mean Value
Fixed	19.52143
4 on panel LDR	20.78571
8 on panel LDR	20.72857
8 Matrix LDR	20.75714
12 Matrix LDR	20.85714

3- Calculating the Variance of the Average of Measurement

To do this, we first, find the difference between each of each 7 days measurement and the average by subtract the measurement in table 4.26 from average value of table 4.27. Then, add up the squares of these differences, then find the average of these added squares by dividing the result by 7. Table 4.28 show the results.

Table 4.28 Variance of the Average of the Measurement

Fixed							
Difference	-0.1014	-0.0414	-0.0714	0.0186	0.0786	0.0386	0.0786
Squares of Differences	0.0103	0.0017	0.0051	0.0003	0.0062	0.0015	0.0062
Sum	0.0313						
Variance of the Average		0.0045					
4 LDR on panel							
Difference	-0.0857	0.1143	-0.0857	0.0143	-0.0857	0.0143	0.1143
Squares of Differences	0.0073	0.0131	0.0073	0.0002	0.0073	0.0002	0.0131
Sum	0.0486						
Variance of the Average		0.0069					
8 on panel LDR							
Difference	0.1714	0.1714	-0.6286	-0.0286	0.1714	0.1714	0.1714
Squares of Differences	0.0294	0.0294	0.3951	0.0008	0.0051	0.0051	0.0294
Sum	0.4943						
Variance of the Average		0.0706					
8 Matrix LDR							
Difference	0.1429	0.1429	-0.6571	0.1429	0.1429	-0.0571	0.1429
Squares of Differences	0.0204	0.0204	0.4318	0.0204	0.0204	0.0033	0.0204
Sum	0.5371						
Variance of the Average		0.0767					
12 Matrix LDR							
Difference	0.0429	0.0429	0.0429	0.0429	-0.0571	0.0429	-0.1571
Squares of Differences	0.0018	0.0018	0.0018	0.0018	0.0033	0.001	0.0247
Sum	0.0371						
Variance of the Average		0.0053					

4- **Computing of the Standard Deviation**

To find the standard deviation (standard uncertainty), is the square root of the variance. Then the Thus, the voltage measurements of each tracker are:

Measurement = (measured value ± standard uncertainty) unit of measurement

Table 4.29 shows the standard deviation values and uncertainty error.

Table 4.29 The standard deviation values and the Uncertainty of Measurements of each tracker

Tracking types	Mean Value	Measurements
Fixed	± 0.0669	V_{avg} ± 0.0669
4 on panel LDR	± 0.0833	V_{avg} ± 0.0833
8 on panel LDR	± 0.2657	V_{avg} ± 0.2657
8 Matrix LDR	± 0.2770	V_{avg} ± 0.2770
12 Matrix LDR	± 0.0728	V_{avg} ± 0.0728

4.4.8 Power Lose by Tracking System

In this part we calculate power loss from system that required to suppling controller and monitor sun and the power needs for moving panel. Table 4.25 illustrated the power lose from tracking system per 1 day.

Table 4.30 Power losses from tracking system

Power Lost from Power Analyzer Unit	0.74 Watt
Power Lost from Tracking Unit	70 Watt per movement
Total Power Lost from system in 1 Day	900 Watt per day

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

A dual-axis automated solar tracking system beside the controlling and monitoring system has been proposed and implemented in this thesis. The tracker has been designed to be efficient, low-cost and reliable. The tracker has a control unit called “Power Production Analyzer” that includes a microcontroller unit type “Arduino MEGA 2560” that included the tracking algorithm, it also includes LDR that arrange depends on system type. Three trackers have been used 4 LDR tracker, 8 LDR on panel tracker, 8 LDR matrix tracker and 12 LDR matrix tracker. For 4 LDR tracker it arranged in container of + shape where the LDRs position upper, lower, left right. The 8 on panel tracker positioned on the panel itself where the LDRs arranged in center of each panel sides and corners. The 8 matrix is 2 x 4 LDRs and 12 matrix is 3 x 4 LDRs that positioned on hemi spherical structure. The Power Production Analyzer has been used to determine the best panel direction that PV panel can be generate the maximum power related to intensity of incident solar light. From the experimental result, the solar tracking system can track the light source movement efficiently, this related to the efficient monitoring and control system that developed to pre-calculate the maximum production angle of the light where directed PV panel toward it. The results shows that the tracking system is more efficient than fixed panel were the difference is about 1 volt per second. The results also shows that the accuracy of tracing system is depends on number of LDRs used and its arrangement, where the accuracy increased as LDRs increases because of the more position can be tracked. Also, the results shows that the tracker based matrix of dedicated spherical unit is relatively more accurate than on tracker with LDRs arranged on the solar panel where the voltage generation is about 0.1 more.

The tracker cost is relatively low cost and near the cost of one axis tracker. Furthermore, the tracker structure is rigid and can be fabricated from light materials such as aluminum alloy and can used flexible low weigh solar cell that reduce the torque needed by servo motors and as a result reduce power needed to move tracker.

The main benefit from “Power Production Analyzer” it can detect the best location that can tracker product power even with some not detected effects such as buildings or tree shadows. In addition, this unit can be used to control a large number of solar cell (such as in solar frame) which can be reduces the cost of overall system.

5.2 Suggestion for Future Works

Even this steady got a high accuracy in solar tracking, but it needs more improving by side of hardware and software.

1. For “Power Production Analyzer” suggestion, it can be using more resolution matrix by increasing the number of LDR matrix, so it can detect the best direction that PV panel can product the maximum power.

2. For mechanical and electrical part suggestion, it need to investigate the best material that can be using for design mechanical parts with take in consecration the best solar panel that can produce high power and determine the weight and the servo motor that can drive the tracker smoothly.

3. For software suggestion, it can be using some intelligence algorithm such as neural network which can be utilized with image processing technique to tracking best direction instead of LDR.

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