REPUBLIC OF TURKEY

ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

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SUPERVISOR
ASSOC. PROF. DR. TUĞÇE DEMİRDELEN

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Hakan ALICI

ABSTRACT

DESIGNING and IMPLEMENTATION of NOVEL SOLAR TRACKER SYSTEM for ÇUKUROVA REGION

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With the increase in the world population, the age of consumption, the industrial-technology revolutions and their effects, the demand for energy increases tremendously. In order to meet the demand, many energy sources have been used for years with the goal of energy production and energy production has been provided. However, fossil fuels, which are used to increase production in order to meet the rapidly increasing demand, seem to have come to an end. Renewable energy sources are accepted as the biggest alternative to fossil fuels and the rate of use of renewable energy sources in production is increasing intensively. Solar energy has the biggest share in this increase due to its environmental friendliness and low installation cost. As a result of developing technological developments, the rate of use of solar energy for energy production purposes is increasing. Another of the studies carried out to meet the increasing energy demand is to provide products with more efficiency than the existing systems. The biggest disadvantage of solar energy panels is that they produce electricity depending on the angle of the sun. This situation causes the production to decrease during the hours when the sun is absent or the angle is different. As a result of the efforts to improve this situation and increase production, solar tracking systems have emerged. These systems increase production by providing an efficiency between 25% and 40% in energy production. The panels prepared in this article have been provided to monitor the sun all day long by providing the movement of linear motors through the Arduino software with the data received from the LDR sensors. By following the sun all day long, the sun rays meet with the panels at the most suitable angle and maximum production is aimed. Double axis, single axis and fixed systems prepared and operated for the solar tracking system were compared with each other. Studies show that if solar power plants in the Çukurova region are to be implemented, it would be more logical to prefer

both single-axis and dual-axis solar tracking systems. Three different systems, namely fixed system, single axis solar tracking system and dual axis solar tracking system, were operated in the same environment and conditions and production data were compared. The importance of the solar tracking system was emphasized by creating portables for the fixed system, single-axis system and dual-axis systems and comparing the production data of the three under the same conditions.

Keywords: solar photovoltaic, solar tracker, renewable energy, solar energy

ÖZET

ÇUKUROVA BÖLGESI İÇİN YENİ GÜNEŞ TAKİP SİSTEMİ TASARIMI VE UYGULAMASI

Hakan ALICI

Elektrik Elektronik Mühendisliği Anabilim Dalı

Danışman: Doç. Dr. Tuğçe DEMİRDELEN

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Dünya nüfusunun artması, tüketim çağı, endüstri-teknoloji devrimleri ve etkileri ile birlikte enerjiye olan talep muazzam bir şekilde artmaktadır. Talebi karşılamak için yıllardır birçok enerji kaynağı enerji üretimi amacı ile kullanılmış ve enerji üretimi sağlanmıştır. Ancak hızla artan talebi karşılamak için üretimi artırmak amacıyla kullanılan fosil yakıtların sonunun geldiği görülüyor. Yenilenebilir enerji kaynakları fosil yakıtlara en büyük alternatif olarak kabul edilmekte ve üretimde yenilenebilir enerji kaynaklarının kullanım oranı yoğun bir şekilde artmaktadır. Bu artışta en büyük payı çevre dostu olması ve kurulum maliyetinin düşük olması nedeniyle güneş enerjisi almaktadır. Gelişen teknolojik gelişmeler sonucunda güneş enerjisinin enerji üretimi amaçlı kullanım oranı artmaktadır. Artan enerji talebini karşılamak için yapılan çalışmalardan bir diğeri de mevcut sistemlerden daha verimli ürünler sunmaktır. Güneş enerjisi panellerinin en büyük dezavantajı, güneşin açısına bağlı olarak elektrik üretmeleridir. Bu durum güneşin olmadığı veya açının farklı olduğu saatlerde üretimin düşmesine neden olur. Bu durumu iyileştirme ve üretimi artırma çabaları sonucunda güneş takip sistemleri ortaya çıkmıştır. Bu sistemler enerji üretiminde %25 ile %40 arasında verim sağlayarak üretimi arttırır. Bu yazıda hazırlanan panellerin, LDR sensörlerinden alınan veriler ile Arduino yazılımı üzerinden lineer motorların hareketi sağlanarak güneşi gün boyu izlemesi sağlanmıştır. Gün boyu güneş takip edilerek, güneş ışınları panellerle en uygun açıda buluşarak maksimum üretim hedeflenir. Güneş takip sistemi için hazırlanan ve çalıştırılan çift eksen, tek eksen ve sabit sistemler birbirleriyle karşılaştırılmıştır. Araştırmalar, Çukurova bölgesinde güneş enerjisi santralleri kurulacaksa hem tek eksenli hem de çift eksenli güneş takip sistemlerinin tercih edilmesinin daha mantıklı olacağını gösteriyor. Sabit sistem, tek eksen güneş takip sistemi ve çift eksen güneş takip sistemi olmak üzere üç farklı sistem aynı ortam ve koşullarda çalıştırılmış

ve üretim verileri karşılaştırılmıştır. Sabit sistem, tek eksenli sistem ve çift eksenli sistemler için portatifler oluşturularak ve üçünün üretim verilerinin aynı koşullar altında karşılaştırılmasıyla güneş takip sisteminin önemi vurgulandı.

Anahtar Kelimeler: fotovoltaik, güneş takip sistemi, yenilenebilir enerji, güneş enerjisi

Dedication

I would like to dedicate my thesis to my beloved son and wife.

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NOMENCLATURE

DC	: Direct Current
AC	: Alternating Current
SPP	: Solar Power Plant
MPPT	: Maximum Power Point Tracking
LDR	: Light Dependent Resistor
PV	: Photovoltaic
HSAT	: Horizontal-axis Single-Axis Solar Tracking
PID	: Proportional-Integral-Derivative
ANFIS	: Adaptive Neural Fuzzy Inference System
PSO	: Particle Swarm Optimization
PWM	: Pulse Amplitude Modulation
I/O	: Input-Output
GEPA	: Turkish Solar Energy Potential Atlas
Arduino IDE	: Integrated Development Environment
Kwh	: Kilowatthour
W	: Watt
MW	: Megawatt
Wh	: Watthour
MLD	: Maximum Light Detection
KWp	: Kilowatt Peak
FFA	: Firefly Algorithm
CSA	: Cuckoo Search Algorithm
MLD	: Maximum Light Detection
Pmax	: Maximum Power at STC
Voc	: Open-Circuit Voltage
Isc	: Short-Circuit Current
Vmp	: Optimum Operating Voltage
Imp	: Optimum Operating Current
GaAs	: Gallium Arsenide
cdTe	: Cadmium Tellurium

A	: Amper
V	: Voltage
S	: Apparent Power
P	: Active Power
β_1	: Sensor 1 Angle
β_2	: Sensor 2 Angle
α	: Sun Angle
θ	: Panel Angle

1. INTRODUCTION

The age of technology and developing industrialization have created a huge need for energy. Increasing population, consumption frenzy, the importance of energy in industry, the energy demand is increasing at an accelerating rate. In order to meet this need, energy production must increase at the same rate. Fossil fuels are one of the most used primary sources to meet energy needs. Fossil resources, which are non-renewable energy sources, do not have enough resources to withstand this energy consumption rate and have come to the point of exhaustion. With the awareness of the destruction caused by fossil fuels, which are being consumed too much, the tendency towards renewable energy sources has begun. Because human beings both want to meet their energy needs and not to harm nature, which is the most important element, while meeting this need. For this reason, it has started to turn to renewable resources for a cleaner and more sustainable life. Solar energy is at the forefront of these energy sources, which are called renewable energy sources. These renewable energy sources are very important because they are environmentally friendly, clean and sustainable. The interest and usage rate of renewable energy sources in the world is increasing very fast compared to other periods. Among the renewable energy sources, solar energy has serious importance. Advantages such as lower installation and operating costs of solar energy systems compared to other renewable energy sources, environmental friendliness, ease of installation and operation make solar energy systems the most important energy source of the future and allow them to be preferred in energy production.

The biggest disadvantage in the operation of solar energy systems is that the sun rays change according to the angle of incidence of the panels during the production phase of electricity from the sun's rays. This change prevents production from remaining constant throughout the day as a result of the movement of the sun during the day and even causes it to decrease. The cloudy weather conditions of the established area, the movement of the sun during the day and the fixed positioning of the panels prevent the same efficiency from the panels at any time of the day. In addition, Cloudy weather conditions and the absence of sun cause production to stop. Cloudy and dark weather conditions directly affect production negatively. Therefore, the sun's radiation values are not the same between seasons. In this article, the daily average solar energy radiation value for Turkey, where the portable system will be installed, is considered as 3.6

kWh/m2. Considering these disadvantages, it was suggested that the traceability of the sun throughout the day would increase the energy production efficiency. In this work, a solar tracking system has been designed to capture the most suitable angle for the panel from sunrise to sunset during the day. In this context, solar tracking systems are developing day by day with technology and it is aimed to achieve the maximum possible production. Especially in recent years, many researchers have been working on tracker systems that allow the panels to be exposed to more sun by imitating the movement of the sun throughout the day. These researchers carry out numerous studies such as new system analysis, design by simulation, comparison of production and performance analysis in their work on the tracker.

These solar tracking systems, on which studies are carried out, are to maximize the production by ensuring that the sun's rays come vertically on the solar PV panels. In this article, three portable units, namely fixed system, single axis tracker and dual axis tracker, are compared in the Çukurova region of Adana province of Turkey, comparing the production data and as a result, the most efficient system is proposed. Çukurova Region has been preferred because it is a suitable region for the establishment of solar energy systems in terms of insolation angle and number of days. Some advantages of the proposed solar tracking systems are presented below;

- When the production data of the portables that are created and produced are presented, it is seen that the tracker technology produces more than the old system.

- It has been presented in the measurements and analysis that the single-axis solar tracking system developed %24,367 and the dual-axis solar tracking system %32,247 more electricity compared to the old-style fixed systems.

- When the developed solar tracking systems are compared among themselves, it is seen that the dual-axis system produces 7.871% more electricity than the single-axis system.

- It has been observed that the installation and operation of the solar tracker system do not bring much additional load compared to normal fixed systems.

- Sun tracking was carried out thanks to the Arduino software and card, and it was verified with the production results that the sun was tracked correctly.

In Chapter 2, the literature review presents the studies on solar tracking systems in recent years. Studies consist of analysis, application and design of uniaxial and biaxial solar tracking systems. The aim of the thesis was emphasized by considering the studies in the literature, the applications we made during the thesis process and the analyzes created with the data of the working systems.

2. LITERATURE REVIEW

Solar tracking systems aim to keep the sun's rays in contact with the solar panels at the most appropriate angle, following all the movement of the sun from sunrise to sunset. Many studies have been conducted to develop these systems, including experiments, simulations, product and system designs, and production analysis. The studies of some researchers who made these studies are shown in Table 2.1.

Tharamuttam JK. and Ng AK. (2017) conducted a study to see how much the radiation in the sun's rays varies under which conditions. During this study, they benefited from sensors and some mathematical models. A hybrid system emerged as a result of their research and studies. The system they propose is a microcontroller-based solar tracking system with a hybrid algorithm. The results of the study concluded that the proposed hybrid algorithm system is more efficient than other old style algorithms in all weather conditions. They suggested this would reduce carbon emissions and electricity costs.

Obara S., Matsumura K., Aizawa S., Kobayashi H., Hamada Y., and Suda T. (2017) developed a special metal hybrid actuator to be used instead of the system with solar energy and electrical components in the proposed system. Tracking System. It is stated that this system consists of two metal hybrid reactors, between which there is an insulating protective plate to block the sun's rays. The developed metal hybrid reactors provide movement to the system based on the temperature difference. This difference, which occurs as a result of the aforementioned temperature change, consists of the change in angle caused by the movement of the sun. Thus, by means of metal hybrid reactors developed, the hydrogen balancing pressure in the system was changed and the sun was monitored all day long. With this developed system, it was aimed to maximize electricity production thanks to the sunlight falling on the panel, and it was informed that they moved the system simultaneously with the normal movement of the sun throughout the day. It has been proven that this solar tracking system, designed and implemented without the use of an electrical component, gives more efficient results than conventional fixed systems. A four-month study was presented about this new type of system developed and suggestions were made on how to use the system more efficiently.

Rani P., Singh O. and Pandey S. (2018) designed a system that will increase production efficiency by tracking the movement of the sun throughout the day with a single axis mechanism connected to the photovoltaic panel. Researchers have preferred Arduino Uno on my site they recommend. It is stated that the system provides maximum production by always monitoring the light intensity by using the maximum light intensity. It has been informed that this solar tracking system, which was developed by the researchers and stated to be open to development, can be carried further technically. They emphasized that they recommend this system for large-capacity solar power generation systems.

Katrandzhiev NT. and Karnobatev NN. (2018), measurements taken using the single axis sun tracking algorithm they developed for photovoltaic systems were compared with a classical fixed system created using a hardware block diagram. The resulting results are presented. They stated that the single-axis solar tracking system they developed and offered as a recommendation absorbs 30% more solar energy on average than the conventional fixed system, and this increases production.

Kamal M. and Mohamad MA.(2018) developed a solar azimuth tracking control system specially designed and implemented for solar energy systems. The control unit of this system, which they presented as a suggestion as a result of the study, was created with an AT89S52 microcontroller with a simple control circuit. This system proposed by the researchers is an efficient and inexpensive method in terms of cost and operability used to align the solar panel on a single axis according to the movement of the sun during the day. Researchers emphasized the necessity of developing a microcontroller-based smart controller system in order to solve the problems that may arise in case of failure of the proposed system in future studies.

Jadli U., Uniyal S. and Uniyal I. (2018) developed a single axis controlled solar tracking system in which a relay-based control system was designed with a LDR sensor, servo motor and Op-Amp. Maximum power point tracking (MPPT) has been especially applied in the implementation of this system. They stated that their aim in applying this is to catch the maximum sun intensity. A simulation of the system that provides more efficiency with these systems was created with the help of MATLAB software. As a result of the results, they stated that they proposed a single-axis solar tracking control system, which makes more use of solar energy by tracking the sun and to do this, using MPPT. By presenting the simulation results,

the researchers stated that the fixed tracking systems they proposed benefited more from solar radiation and this had a direct positive effect on production. As a result of this situation, they informed that the proposed system will be more efficient than other classical systems.

Mehdi G., Ali N., Hussain S., Zaidi AA., Shah AH. and Azeem MM. (2019) proposed a solar tracking system that aims to use solar energy at the maximum level by tracking the sun throughout the day and is used to produce more energy in this direction. Photosensitive sensors are used in sun tracking, and the DC motor is controlled with the data of these sensors, and with the help of this motor, the panel is provided to follow the sun. The researchers operated the fixed panels with this system, which was designed under the same conditions and period, and compared the productions of the two. In the light of the findings obtained from the study, they shared that the system they proposed produces 1742.88 Wh of electricity, while the classical fixed system produces 829.6 W of electricity. By sharing the data obtained, the researchers emphasized that the single-axis solar tracking system they proposed produces more electricity than other conventional fixed systems.

Fahad HM., Islam A., Islam M., Hasan MF., Brishty WF. and Rahman MM. (2019) presented the results by comparing the production data and overall costs of the dual-axis control, single-axis control and conventional fixed-axis control systems they developed in Bangladesh. It was reported that the performance of these three systems used was monitored for 12 months by considering panels of the same type and characteristics, conditions and cloudiness rates. When the production results are examined, if an analysis is made by considering the turbidity rates, it is stated that the production of uniaxial and biaxial controlled systems is close to each other. In addition, the researchers emphasized that the maintenance and operating costs of the dual-axis tracking system are higher than the single-axis tracking system, and as a result, considering the weather conditions in Bangladesh, the most logical one is the single-axis tracking system in terms of efficiency.

Ort M.İ. (2016) designed a solar tracker for maximum power generation control with MPPT for use in photovoltaic systems. The simulation models of the proposed system were designed in MATLAB/Simulink and the simulations were run under the control of the calculated data. In this study, it is stated that the systems with the most efficient structure are determined by comparing the data obtained from the maximum power point tracking system simulation.

Tseng K-H., Wang C-Y. and Lin G-H. (2019) conducted a study on the effects of seasons on the fixed system and solar tracking system. As a result of the study, the effects of solar azimuth and altitude during electricity generation in the noontime period of the two systems were presented comparatively. As a result, they compared the production data and efficiency of the fixed system and the solar tracking system and made suggestions about which system is more efficient.

Berrian D., Libal J., Klenk M., Nussbaumer H., and Kopecek R. (2019) simulated how a fixed-angle and horizontal-axis single-axis solar tracking (HSAT) system affects the production efficiency of PV systems with the help of a specially developed tool. The production efficiency of double-surface PV systems was simulated.

Dhawan, A., Malik, O.P. and Kumar R. (2018) performed the mathematical modeling and full simulation of the photovoltaic module using solar energy tracking simulation on MATLAB Simulink. MATLAB/SIMULINK was used for Solar Tracker Application and they made suggestions about energy production efficiency according to the results.

Ray S. and Tripathi AK. (2016) worked on the application design and development of inclined uniaxial and azimuth high biaxial solar tracking systems. LDR sensors are used for sun detection, which is necessary to follow the sun, and the L293D motor driver provides the movement of the solar panel in the desired direction. In addition, a controller consisting of a pre-programmed Atmega8 Microcontroller is used for system control.

Vieira RG., Guerra F., Vale M. and Araújo MM. (2016) conducted a study comparing tracking systems and fixed systems in order to provide more efficiency from solar energy in the equator region. These studies were carried out by considering all the weather data in the region where the system operates. As a result of the results of the study, the performance analyzes of the solar tracking system compared to the classical fixed panel system were compared and suggestions were made.

Sharma A., Vaidya V. and Jamuna K. (2017) used a P&O-based sensorless method in a new unique single axis-controlled solar tracking system they developed. In this design, it is stated

that a sensorless P&O-based and two-level P&O method developed for the single-axis solar tracking system was applied. The results were presented and suggestions were made.

Zhu Y., Liu J., and Yang X. (2020) carried out a design and performance analysis for a single-axis solar tracking system using a new tracking structure in their study. They developed a tracking system as a result of mathematical expressions that took into account the solar radiation model they proposed in their study and the geometric relationship of the sun with the earth. It is reported that the annual solar radiation rate in the tracked panel they designed is 96.40% compared to the biaxial tracked panel. In this study, it was aimed to use solar energy more efficiently and they emphasized that they proposed a uniaxial structure to get maximum production. While the rate of solar radiation falling on the panel where the proposed system is applied is 96.40% compared to the dual-axis tracked panel, the ratios of the existing single-axis tracked panels are between 78.56% and 95.79%. In the light of this information, it is stated that the proposed structure is more advantageous than the existing single axis at every latitude in terms of efficient use of the sun.

Batayneh W, Bataineh A., Soliman I., and Hafees S.A (2019). a discrete single-axis solar tracking system, which is actuated three times a day in the azimuth plane, is proposed to achieve greater efficiency by tracking the sun. A theoretical simulation is made in the system to calculate the optimum viewing angles for the city of Irbid. Additionally, the results of viewing angles were used to validate the simulations and compare this proposed system with a conventional single-axis tracker. Considering the simulation results, it was observed that there were no serious differences in solar energy production and similar results were obtained. In addition, the results of the summer study showed that this system provides about 91-94% of the solar energy harvest of continuous uniaxial solar energy. Experimental results agree with simulation data between 11-17%. It has been stated that this is because the Maximum Power Point Tracking (MPPT) is not used which results in partial loss of all potential of this discrete system.

Pelaez S.A., Deline V., Greenberg P., Stein J.S. and Kostuk R.K. (2019) updated annual energy simulations to evaluate the kWh/m2 increase achieved in single-axis tracking systems using bifacial modules. It was stated that the generated simulation and idea could be more efficient to use for large scale bi-surface PV installation efficiencies. It was stated that bi-surface energy

gains measured between 7–9% and backlight gains of 11% were reported in the simulation. This result is consistent with the expectation modeled within 1-2% of the absolute, and it has been observed to agree with the expectation of the global average. It has been observed that 0.5%-1.5% additional system energy gain will occur by optimizing the viewer behavior and taking into account cloudy conditions.

Fazlizan A., Abdulmula A., Amran A.N., Lim C.H. and Sopian K., (2019) performance analysis of the photovoltaic (PV) monitoring system was performed to evaluate the system performance using field data measurements. This analysis was made by analyzing a dual-axis tracking device with intelligent algorithms called maximum light detection (MLD). As a result of the analysis of comparative results such as sunny and cloudy in a tropical region with constantly dense cloudy weather conditions, it has been observed that the system with MLD monitors significantly increases energy production in all these conditions.

Kiyak E. and Gol G. (2016) the solar tracking system has been controlled with the help of fuzzy logic and PID-based controllers and a solar tracking system was developed to increase the efficiency of solar energy, the importance of which is increasing day by day. In their studies, it was observed that the system for which the solar tracking system was developed increased by 21.2% compared to other systems. It has been observed that the efficiency of the solar tracking system has increased at a high rate and has been indicated as a recommendation. In addition, according to the results of the research and application with the proposed fuzzy logic-based controller and the system with the PID-based controller, it’s stated that the proposed system is 2.39% more efficient than the fixed systems.

Sharma M.K and Jishnu Bhattacharya J. (2020) designed a static cylindrical concentrator using the ray tracing model of COMSOL 5.4, using discrete plasmas and tracking outputs, keeping the concentrator static while the absorber alone follows the daily motion of the sun. First, they validated the optical instrument with the help of analytical ray tracing. The geometric parameters of the capacitor-absorber combination were optimized by systematically scanning across a multivariate gap consisting of the variability of the lens apex angle, the diameter of the condenser, the size of the absorber, and the relative position of the absorber. They pointed out that the uniformity of the overall irradiation and intensity distribution is optimized for a particular lens material (Silicon glass). Optimal parameters determined for a cylindrical Fresnel

lens with a diameter of 20 cm; prism angle ¼ 37; distance between absorber and concentrator axis ¼ 11 cm; Suction width ¼ 5 cm. These findings indicate that the geometry performance is compared to a similar finned absorber arrangement without the use of a static concentrator. Information was presented that using a static concentrator for one day on 21 March and at a selected location in Kanpur, India increased energy harvest by approximately 52%. In the application of this system, it has been shown that, on average, using a static concentrator gives an increase of about 49% when the overall annual variations and the radiated portion of solar radiation are included in the forecast model.

Yanev KM, Mahindroo PN, and Tsamaase K. (2018) proposed a monitoring system for the sun to reach the panels at the steepest angle by using a special controller design and analysis method in their study. They stated that the design strategy of the controller of the system that emerged as a result of the study was based on the application of the ITAE criterion. They stated that the light tracking system was intact and the analysis before and after the controller application was made using the Dpartitioning method. They present evidence that the method is very effective in graphically determining the regions of stability in terms of the uncertain parameter of the system. After the robust controller application, they examined the system robustness and stated that their results showed insensitivity in terms of gain changes. It is explained that after the robust controller is applied, the step response of the robust light tracking system does not oscillate and the system becomes insensitive to parameter changes. They emphasized that this is of great importance for the operation of the system, as the direction of the brightest light can change rapidly due to clouds or other atmospheric effects. With the robust controller, the system is recommended to avoid stress and vibrations and smoothly guide the PV panel to its new location.

Sinha S. and Chandel SS (2016) determined the optimum configurations for a fixed and monitored 6 kWp roof-mounted micro wind-based hybrid system using fixed slope and solar line photovoltaic-based micro wind hybrid power systems to increase the electricity generation potential. With this study, it is aimed to perform an analysis study on Photovoltaic systems. They used the system they developed by focusing on the photovoltaic component of the hybrid system to produce more electricity. The results are presented by comparing different configurations of hybrid systems with fixed slope, monthly optimum slope, annual optimum slope and 6 different solar tracking photovoltaic systems. In the study, they shared the

information that the monthly and seasonal optimum slope angles determined for the critically important location vary between 0 and 60 and the annual optimum slope angle is 29.25. It is stated that the optimum configuration for all solar tracking systems except the two-axis tracking system is 7 kWp photovoltaic system, one 5 kWp wind turbine, 10 batteries and one 2 kWp inverter. It is stated that the optimum configuration for the two-axis tracking system and two types of fixed slope systems is considered to be 8 kWp photovoltaic system, 5 kWp wind turbine, 10 batteries and 2 kWp inverter. The results are presented with data that monthly adjusted horizontal axis, daily adjusted horizontal axis, continuously adjusted horizontal axis and dual axis tracking system produce 4.88% to 26.29% more energy per year than the current fixed slope photovoltaic system. In addition, they stated that the energy cost for biaxial tracking is higher than for all tracking systems and fixed pitch photovoltaic systems. However, they also explained that despite the higher costs to maximize power output, hybrid systems have more advantages over other systems for dual-axis tracking.

Zhu Y., Liu J. and Yang X. (2020) developed the single-axis solar tracking system, which was designed as a unique structure that they specially designed in their study, in order to provide more efficient production. It was stated that the normal vector of the panel was developed in order to analyze the properties of the developed structure. It has been reported that this analysis study is a numerical validation of the system based on an estimated solar radiation model in addition to the sun-earth geometric relationships data. In their particular study, they observed that designs that are not suitable for existing single-axis tracking systems with their axes of rotation horizontal, vertical or inclined to the ground surface limit their tracking performance. While the rate of solar radiation falling on the tracked panel of the original system that emerged with the study was 96.40% compared to the dual-axis tracked panel, it was revealed that it was between the rates for the existing single-axis tracked panels. 78.56% and 95.79%. It has been informed that the structure of this unique system, which emerged with his studies, has advantages in terms of radiation gain compared to uniaxial systems found at almost all latitudes.

AL-Rousan N.A., Isa N.A.M. and Desa M.K.M (2020) proposed two new efficient solar tracking systems that they developed with the principle of Adaptive Neural Fuzzy Inference System (ANFIS) in their study. They stated that it is aimed to design and implement more efficient single and double axis solar tracking control systems that increase production, increase tracking system performance, accurately predict the movements of the sun and minimize the

error. They used experimental data to test the proposed sun tracking controllers, using the month, day and time as input variables to predict the optimum positions (tilt/orientation angles) of the sun tracker systems. It was stated that the ANFIS models that emerged as a result of the study were evaluated to find the feature and robustness of following the optimum angles that obtain the maximum solar radiation. It is stated that the proposed controllers are optimal for controlling solar tracking systems with high prediction rates and low error rates, and the selected architecture, optimum tilt and orientation angles can be successfully predicted together with the selected variables. It is stated that these emerging models provide superior results with five membership functions and can achieve high performance for both single-axis and dual-axis solar tracking systems.

Alami M.E, Hadlach H., Hajri A., Habibi M., and Bri S., (2017) studied a technical solution application that allows the conversion of a photovoltaic panel fixed to a movable panel to improve power generation performance. For these studies, they gave the information that it has been proven that they can monitor the position of the sun with an efficient and inexpensive 100% functional smart system. Implementation of this command to monitor the sun allowed its consistency with the mechanical device to be tested and its effectiveness verified, and it was noted that the tests performed yielded a very significant energy gain through the optimization of the replaced components. The advantage of the work done is to minimize the production costs, which do not exceed 20 euros, as they replace the comparison circuit of the old systems with a program inside the microcontroller. It is stated that the perspective of the study is to improve the processing and transmission of all the information detected in the solar tracker to a station using smart antennas associated with the developed embedded system.

Antonanzasa J., Urracaa R., Martinez-de-Pisona FJ, and Antonanzasb F., (2018) aimed to bring the photovoltaic panels to the most suitable location in real-time with the algorithm they developed. They add to the knowledge that the data obtained show significant potential for increased radiation collected in high latitude regions. It was reported that the system prediction model, which works with the algorithm developed in a short time, can increase the daily effective irradiation by more than 16% at all stations or up to 264Wh/day/m2 on certain days. It has been added that the developed system especially benefits from closed and broken cloud situations ($kt'<0.40$). It was stated that due to the positive results obtained in the estimation analysis, no significant gain was obtained for the cases with $kt'<0.05$ or $kt'>0.6$ and two

estimation algorithms were tested. The first model, based on five-minute radiative persistence measurements, also showed promising annual irradiance increases of up to 2.51% at the northernmost station and more than 1.1% at the other three stations, and a reduction in the number of false positives. In addition, the second prediction model working with the NWP of hourly global horizontal radiation from the WRF model was found to underperform from baseline, in part due to the large impact of false positives. Looking at the results of the analysis, it was stated that the potential for irradiation increase with a SATS is available in Europe, showing larger potential locations with low solar irradiance. They proposed an operational forecasting algorithm to make the most of irradiation in cloudy conditions.

Sabir M.M. and Ali T. (2016) worked on an optimal controller design using particle swarm optimization (PSO), firefly algorithm (FFA) and Cuckoo Search Algorithm (CSA) in their proposed biaxial solar tracking system. It is stated that three swarm intelligence-based meta-heuristic techniques were applied to tune the proportional-integral-derivative (PID) controller for both axes, and 100 independent studies were performed for each algorithm to obtain sufficient data for statistical analysis. It was informed that statistical analysis was performed for the obtained data and minimum, maximum, mean, variance and standard deviation were calculated for the necessary parameters. In their studies, they stated that the PSO convergence regarding the optimum point for the studied problem is slower. In addition, they deduced from observation and statistical analysis that the search begins far from the optimum point. For the FFA algorithm, while the random behavior around the optimum point is constant, the random behavior around the optimum point is not very smooth, but its convergence to the optimum point is smooth and fast compared to PSO. Afterward, it was emphasized that the average fitness value obtained with FFA was closer to the optimum than PSO. Compared to both PSO and FFA, observation data are described that the behavior of CSA about the optimum point is very smooth and converges to the optimum very quickly. It was specially stated that the fitness value obtained with CSA was much better than PSO and FFA. For the optimum solution of the investigated problem, it was informed that the variance and standard deviation of the data obtained with CSA were small compared to PSO and FFA. Based on the results and observations of the exercise, it is concluded that CSA performs PSO and FFA for the studied problem, and it can also be concluded that the performance of CSA will be better than FFA and PSO for other engineering optimization problems. It is also stated that the output of the FFA performs the PSO and both CSA and FFA are more economical in terms of a number of

parameters and computational cost, that is, fewer parameters need to be specified in the case of CSA and FFA for optimization problems.

Zengwei Z., Zhen Z., Yongfeng J., Haolin L., and Shengcheng Z. (2019) designed and measured bi-surface photovoltaic (PV) panels (BP) with inclined and horizontal east-west solar trackers (IEW/HEW) to track the sun in energy production. They stated that they determined the average radiation distribution on a typical radiation day to estimate annual performance relative to annual radiation. In this study, it was stated that the data were taken from three regions in China for example purposes and compared with optimum fixed mono facial PV systems, annual radiation increases of IEW and HEW and BP were analyzed and reported under different arrays spacing and albedo conditions. In addition, they additionally proposed a method for estimating the angular loss of diffuse radiation. Finally, a validation experiment was conducted in Taizhou to confirm the calculation results.

Lee K.Y., Chung C.Y., Huang B.J., Kuo T.J., Yang H.W., and Cheng H.Y., (2017) proposed a new algorithm for a single axis maximum power generation solar tracker to determine the optimum stopping angle in order to increase the maximum electrical energy daily production efficiency. It is stated that the instantaneous power produced at different angles during rotation is recorded and compared, that is, the most suitable angle can be determined to produce the maximum power. After the rotation (detection) is completed, the photovoltaic modules are rotated to the obtained angle to produce the maximum power. It is explained that the proposed system is at an advanced stage in the 1A-3P solar tracker research and it is aimed to further increase the efficiency of the 1A-3P solar tracker as the aim of the study. In conclusion, a new algorithm for single axis maximum power generation (1A-MPG) solar tracker based on a 1A-3P solar tracker was developed to automatically determine the optimum standing angle for PV modules, avoid any shading and then increase it.

Table 2.1. Categorizing the studies on solar tracking systems

Analysis Type of Solar Tracking System	Study Description	References
Experimental and Simulation	Automatic microcontroller-based solar tracker design	Tharamuttam JK, Ng AK (2017)
	New solar tracking system study using metal hydride (MH) actuator	Obara S, Matsumura K, Aizawa S, Kobayashi H, Hamada Y, Suda T (2017)
	An analysis of Arduino based single-axis solar tracker	Rani P, Singh O, Pandey S. (2018)
	Solar tracker design using AT89S52 microcontroller	Kamal M, Mohamad MA. (2018)
	Solar tracker system created using LDR sensors	Jadli U, Uniyal S, Uniyal I.(2018)
	With the help of MATLAB/Simulink, a simulation model of the solar tracker system was created and the application was made under the specified operating conditions.	Ort M.İ (2016)
	Simulation study of production efficiency of bifacial PV systems	Berrian D, Libal J, Klenk M, Nussbaumer H, Kopecek R (2019)

Experimental and Simulation	Single-axis algorithm developed with the aim of maximum efficiency in electricity generation	Lee K-Y, Chung C-Y, Huang B-J, Kuo T-J, Yang H-W, Cheng H-Y (2017)
	Solar Tracker Implementation Using MATLAB/SIMULINK	Dhawan, A., Malik, O.P., Kumar R.., (2018)
	Single-axis-tracking systems using bifacial modules	Pelaez SA, Deline C, Greenberg P, Stein JS, Kostuk RK.(2019)
	A design consisting of LDR sensors to detect sunlight, L293D motor driver for solar panel movement and programmed Atmega8 Microcontroller for system control	Ray S, Tripathi AK.(2016)
	Experiment and analysis of solar radiation model based on solar-earth geometric relations of the newly designed solar tracking system	Zhu Y, Liu J, Yang X. (2020)
Optimization	New type algorithm of the single-axis solar tracker	Katrandzhiev NT, Karnobatev NN. (2018)
	Comparison of production data of single-axis, dual-axis and fixed angle control solar tracking systems	Fahad HM, Islam A, Islam M, Hasan MF, Brishty WF, Rahman MM (2019)
	Optimization of controlled-based solar tracking system designed with LDR-Arduino materials	Mehdi G, Ali N, Hussain S, Zaidi AA, Shah AH, Azeem MM (2019)

	Comparing fixed system and solar tracking system	Tseng K-H, Wang C-Y, Lin G-H. (2019)
	Maximum light detection (MLD) analysis	Fazlizan A, Abdulmula A, Amran AN, Lim CH, Sopian K(2019)
	The solar tracking system optimization using a microcontroller	El Alami M, Hadlach H, Hajri A, Habibi M, Bri S. (2017)
Optimization	Implementing two levels of P&O method in a sensorless P&O based single-axis solar tracking system	Ghabusnejad S, Majdi A, Davari SA (2019)
	Control of the operation of the solar panel, which improves solar energy efficiency with the algorithm applied for the prototype of the developed solar tracking system	Sharma A, Vaidya V, Jamuna K (2017)
	Three swarm intelligence-based meta-heuristic algorithms were used to optimize the PID controller	Sabir MM, Ali T (2016)
	Optimization of material selections to make maximum level use of the radiation intensity of the sun	Sharma MK, Bhattacharya J. (2020)

Analysis	Performance analysis of bifacial PV panels	Zengwei Z, Zhen Z, Yongfeng J, Haolin L, Shengcheng Z (2019)
	New controller design and implementation of D-partition analysis method	Yanev KM, Mahindroo P, Tsamaase K (2018)
	Analysis of the operating data of the solar tracking system controlled using fuzzy logic and PID based controllers	Kiyak E, Gol G.(2016)
	Comparison of six different solar tracking systems with a fixed angle system and optimization of the system with the help of HOMER software	Sinha S, Chandel SS (2016)
	The proposed two new efficient intelligent solar tracking control systems based on the Neural Fuzzy Inference System (ANFIS) principle	AL-Rousan NA, Isa NAM, Desa MKM (2020)
	Analysis of production data at different locations, taking into account the cloudiness of solar radiation data in Europe	Antonanzas J, Urraca R, Martinez-de-Pison FJ, Antonanzas F (2018)
	Isotropic and HDKR anisotropic models	Batayneh W, Bataineh A, Soliman I, Hafees SA (2019)
	Operational analysis and performance comparison between static and mobile systems in the region where the solar tracking system is applied compared to the conventional fixed panel.	Vieira RG, Guerra F, Vale M, Araújo MM (2016)

3. MATERIALS AND METHODS

3.1. Energy

Energy is a term used to perform any work in the universe or to transform mechanical and thermal energies. Energy is an indispensable resource for human beings. The energy that has developed throughout history has served to facilitate the life of human beings. The most important example of this is electrical energy. Electrical energy has become the most used type of energy in the universe, thanks to its ability to transform into many types of energy. Lamps are used to convert electrical energy into light energy, resistors are used to convert it to heat energy, and motors are used to convert it into mechanical energy. As time passed, the need for energy and the methods used to meet this need has increased in the face of the increasing demands of human beings. Energy, which makes life easier, has started to harm people with the preference of various methods and energy sources in production in order to keep up with the consumption speed in the process of the rapid increase in production. In particular, the awareness of the damage caused by fossil fuels to nature and the destruction it will leave to future generations, and in addition, the fact that fossil fuels are faced with running out of them has enabled researchers to use other energy sources. The use of renewable energy sources in electrical energy production is very important for environmentally friendly energy. Especially with the use of solar energy, inexhaustible fuel and energy production has been provided.

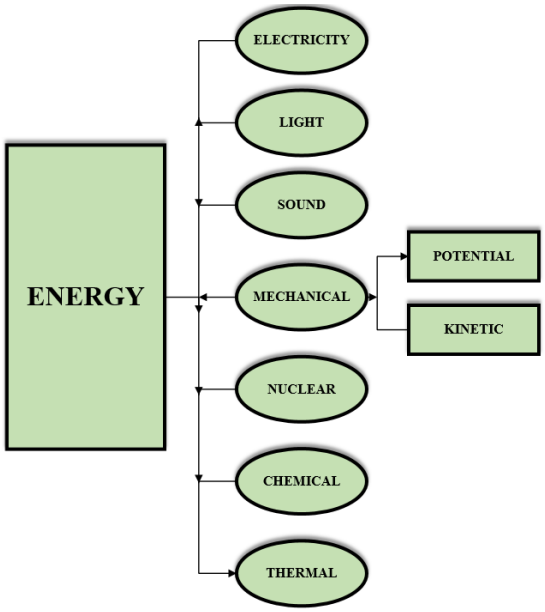

Figure 3.1. Types of energy

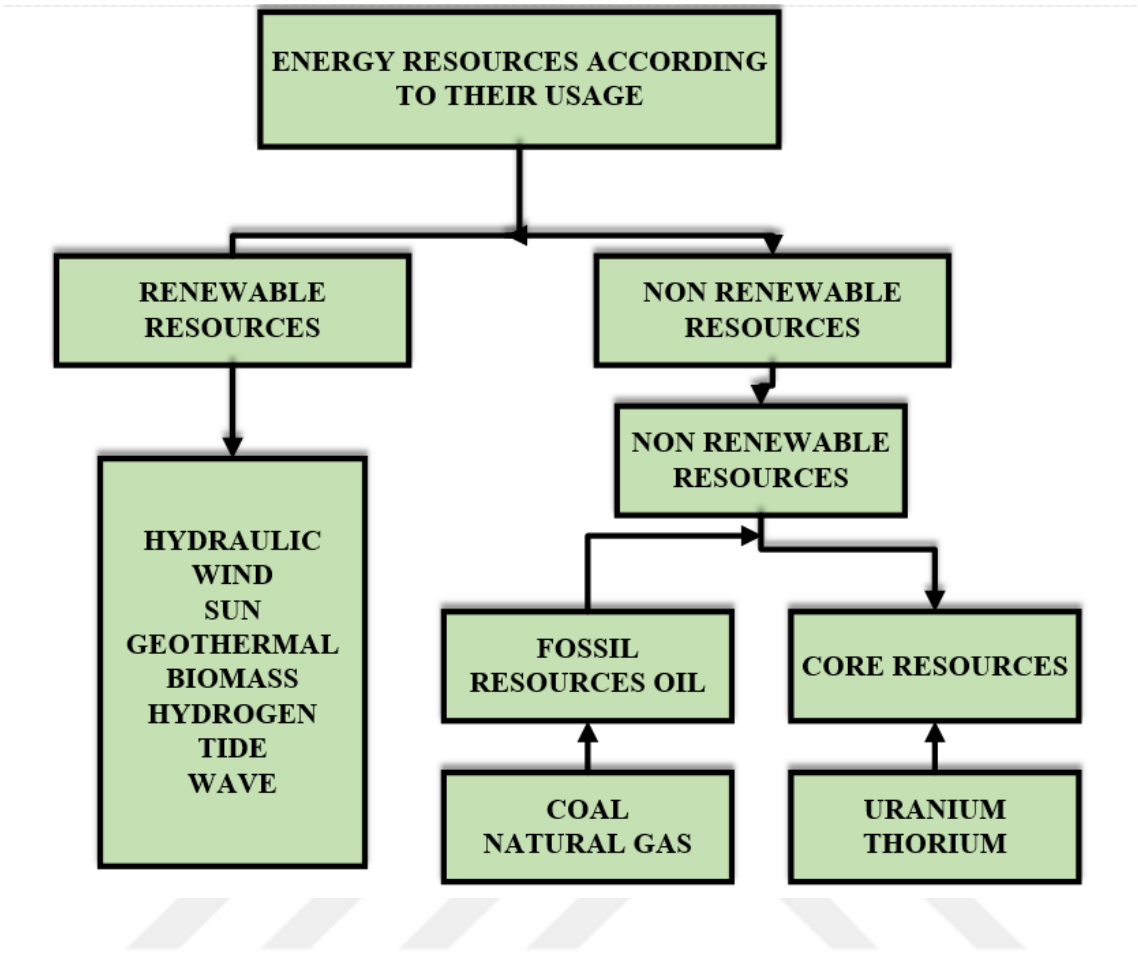

Figure 3.2. Classification of energy sources

3.1.1. Solar Energy

The world's cleanest and most environmentally friendly energy sources are renewable energy sources. Solar energy, which is one of these sources, is a radiant energy. The solar energy structure consists largely of hydrogen and therefore it is shown as a clean energy source. Solar energy is defined as the radiant energy released as a result of the conversion of hydrogen into helium. These radiations are converted into electrical energy by means of solar panels.

Advantages of Solar Energy;

- Solar energy is an environmentally friendly energy source with its use.
- Solar energy, which is called renewable, is actually an inexhaustible source of energy.
- It can be used in almost every field and time where energy is needed.

- Installation and operating costs are very low compared to their peers.
- It is a natural, environmental and human-friendly energy source. There are no environmentally harmful wastes.
- It is not dependent on foreign sources because its raw material is the sun. It is not affected by economic depressions.

Solar energy is defined as the radiant energy released by the fusion process (conversion of hydrogen gas into helium) in the core of the sun. The sun is known as a clean and inexhaustible renewable energy source that can meet all the energy needs of the world (13,730 MTEP for 2017) with its approximately 3.9x1026 W power. It is accepted that every second the sun emits a huge amount of energy into the solar system. Only a very small amount of this energy reaches the world. An average of 1367 W falls on each square meter of the outer surface of the atmosphere. The atmosphere absorbs some of this incoming radiation, usually consisting of X-rays and ultraviolet rays, and reflects some of it.

The amount of energy reaching the earth's surface from sunlight in one minute is thought to be more than the energy used in a year worldwide. Recent studies on the evaluation of such a large and renewable energy source have accelerated significantly. Countries have accelerated the transition to renewable energy in order to avoid the damage caused by fossil resources to the environment. In this way, many pieces of research are carried out on the production of heat and electricity from solar energy, and their use is constantly increasing over the years. Although there are multiple methods for generating electricity from solar energy, the overall trend is focused on photovoltaic systems, where the light from the sun is directly converted into electricity. As solar energy has been the first energy source used by people for centuries, it has started to be used in different technological areas as of 1970. With the development of technology, there has been progress in the way of use and a decrease in costs. In addition to these, it has always been recorded as environmentally friendly energy. Especially the fact that it is a clean energy source and that it works at a low cost after the installation has increased the importance and effectiveness of solar energy.

Turkey has a high solar energy potential thanks to its region and geographical location. According to the Turkish Solar Energy Potential Atlas (GEPA) prepared by the Ministry of Energy and Natural Resources of the Republic of Turkey, the average annual total sunshine

duration is 2741.07 hours and the average annual total radiation value is calculated as 1527.46 kWh/m2. The general potential outlook and monthly average global radiation distribution in GEPA are given below.

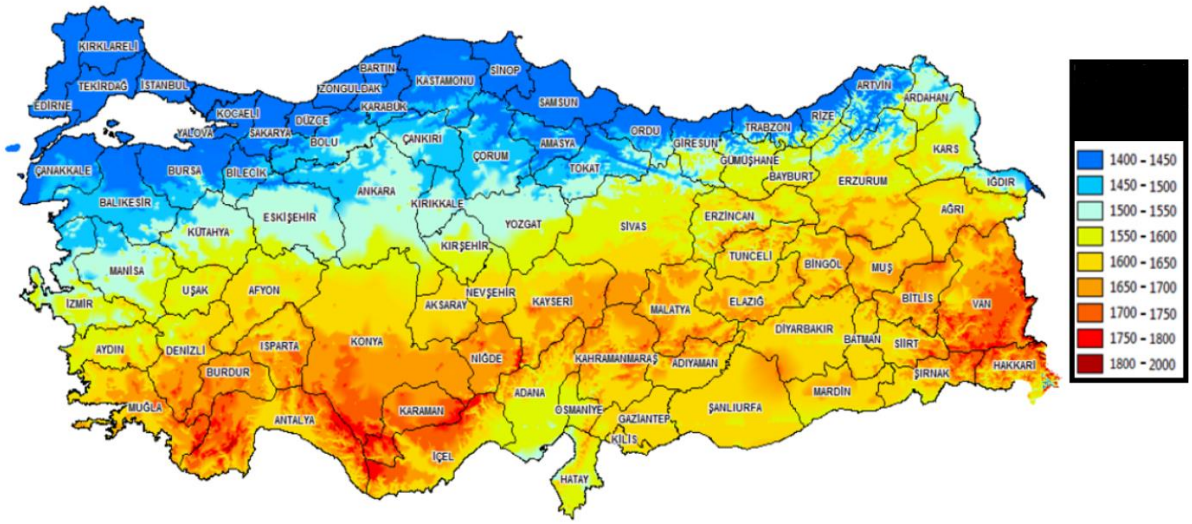

Figure 3.3. Total Radiation Distribution of Turkey (kWh/m2 - year)(T.C. Enerji ve Tabii Kaynaklar Bakanlığı (2021))

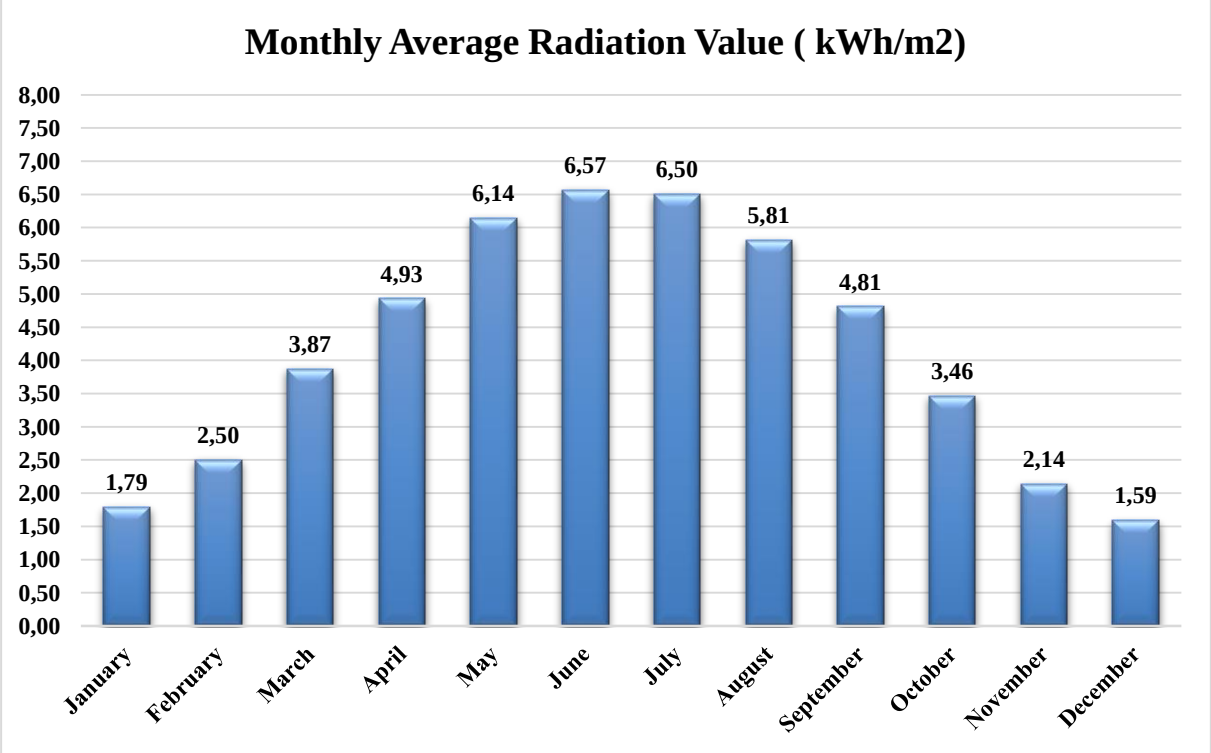

Figure 3.4. Monthly Average Radiation Value in the Turkey (kWh/m2)

3.1.2. Photovoltaic System Technology

Solar modules, which are the basic components of the structures used in photovoltaic solar systems; converts solar energy directly into electrical energy.

The photovoltaic phenomenon, first introduced by the French scientist Edmond Becquerel in 1839, was discovered by emitting light from an electrode in a conductive liquid. In 1877, W. G. Adams and R.E. Photovoltaic effect were observed in the solidified selenium by Day. This development was followed by the selenium solar cell developed by C. Fritts in 1883 and located on a thin gold layer with a gold efficiency of 1%. In the continuation of these developments, W. Hallwachs designed a semiconductor junction solar cell using copper and copper oxide. In 1904, this effect started to be understood better with the photoelectric effect article, which was discussed in terms of quantum by Einstein. The production of electricity from the sun, which started with the first Si p-n junction solar cell produced by Bell Laboratories in 1954, has reached the present day and great developments have occurred in this process.

The basic principle in photovoltaic solar technologies is photovoltaic conversion. The mentioned transformation occurs in two different stages. The first stage is the creation of pairs of charges, which are positive-negative current carriers, and the second stage is the separation of the pairs from each other by an electric field. While forming the PN junction, the n-type semiconductor material with excess electrons and the p-type semiconductor material with an excess positive charge are brought side by side. There is a structurally created electrical field at this joint. All energy conversion events take place in this region. Solar photons coming to this joint give their energy to the electrons in this joint, and the negative-positive charges formed with this energy are separated from each other by the existing electrical field. Thus, direct current is produced in the circuit. This produced direct current can be stored in a battery group or loaded into the grid via DC/AC inverters.

Silicon is the most widely used material in photovoltaic solar technologies. Among the various semiconductor materials in the universe, the most suitable ones for the production of solar cells are used as semiconductors such as silicon, cadmium sulfide, gallium arsenide and cadmium telluride. Solar cell technology is extremely rich in terms of materials used and construction types.

Solar cells are divided into crystals and amorphous. The most common are silicon solar cells; They are produced in structures with different technologies, such as single (mono) crystalline, multi (poly) crystalline, thin film and strip. The surface of the solar cell, whose surfaces are shaped in the form of squares, rectangles, and circles, usually has an area of around 100 cm^2 and a thickness of 0.2–0.4 mm.

Solar modules are formed by combining solar cells. Today, the surface area of solar modules used for electrical energy production has reached 2 m2 and their power has reached 400 Wp. With the combination of solar modules, high power solar panels and solar power plants (SPP) can be installed. Using today's technologies, a 1 MWe SPP can be installed on an area of 15-20 decares. In particular, the required electrical energy can be produced at the consumption points with the SPPs installed on the roofs and facades of the buildings.

As of the end of December 2020 in Turkey, our installed power based on solar energy is 6,667 MW, its share in total electricity production is 3.6%, and the change in installed power over the years and its share in total electricity production are given in the charts below.

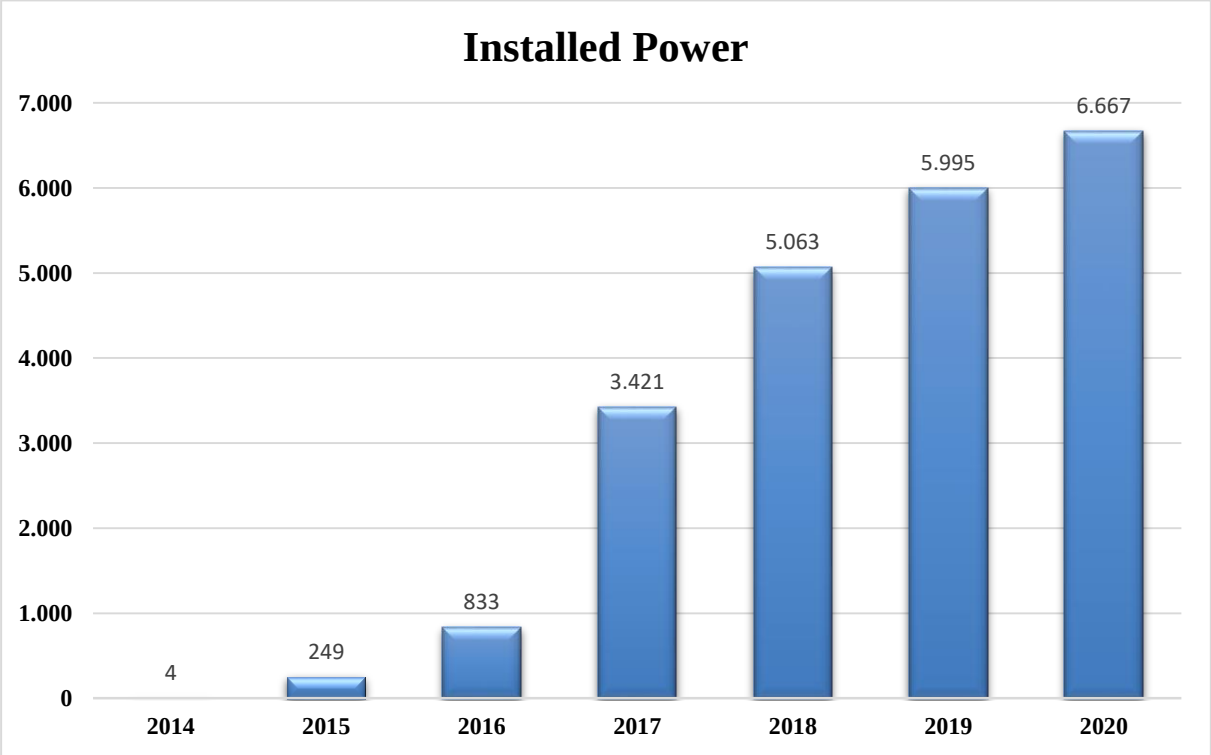

Figure 3.5. Installed power in Turkey

3.1.3. Solar Cells and Solar Modules

Semiconductor materials that can directly convert the sun's rays that come into contact with their surfaces into electrical energy are called solar cells. The solar cell is called a photovoltaic cell. In terms of shape, their surfaces are in the form of circles, squares and rectangles, with an average area of 90-150 cm2 and a thickness of 0.20-0.40 mm.

The main components of solar cells are diode, thyristor and transistor. Solar cells are produced using inorganic semiconductor materials such as silicon/silicon (1.1 eV), gallium arsenide (GaAs-1.43eV), cadmium tellurium (cdTe). It is understood that the structure of solar cells is simply similar to a diode and consists of P or N junctions in its structure.

Figure 3.6. Solar Cell

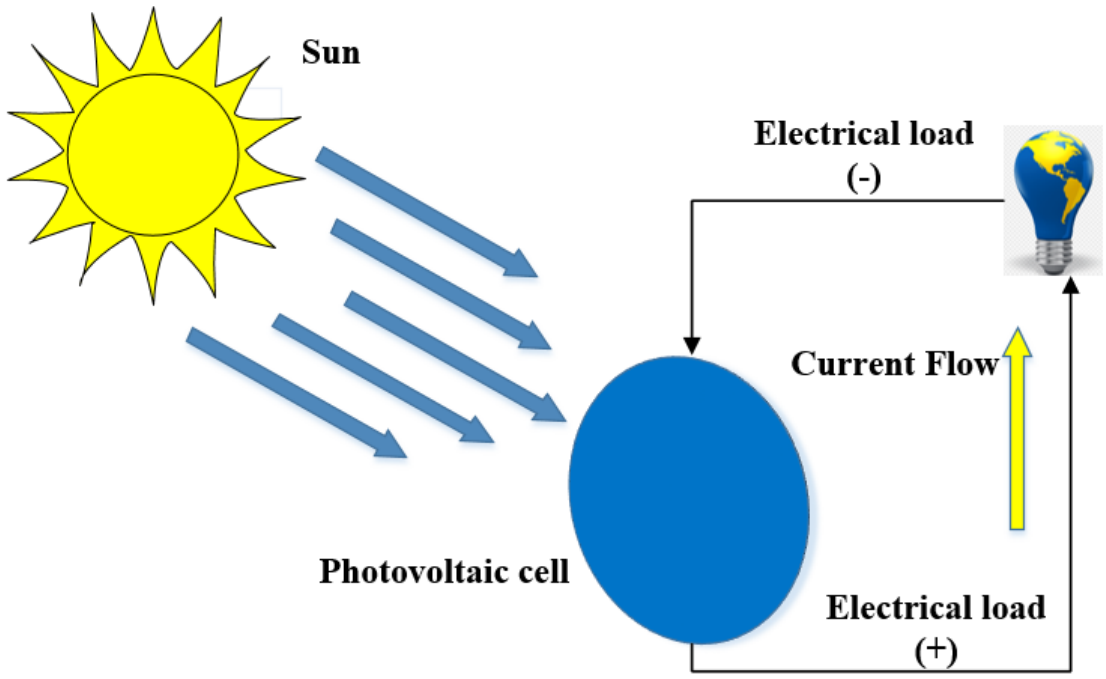

Figure 3.7. Photovoltaic cell diagram

With the help of metal contacts placed on both sides of the connection, photon currents are collected. The top layer of the solar cell cells is covered with a protective glass that will reflect minimally and absorb a large amount of light. N and P type semiconductor materials are under the special layer that is used for protection and has the feature to prevent the reflection of the light.

It is included in the silicon solution as an element (phosphorus etc.) in the 5th group of the periodic table. N-type silicon is obtained from silicon, which is the most widely used semiconductor in the production of solar cells. Since silicon has 4 electrons in the outer orbital of phosphorus and 5 electrons in its outer orbit, a single electron in phosphorus donates an electron to the crystal structure. For this reason, Group 5 elements are called donor and N-type solids.

It is desired to obtain P-type silicon by adding one of the elements in group 3 of the periodic table (aluminum, indium, gallium, boron, etc.) to the silicon melt. The last orbital of these elements is missing 3 electrons. Therefore, electron deficiency occurs in the crystal. The absence of the missing electron is called a "hole" or a "hole". It is assumed to carry a positive charge. Such substances are called P-type or acceptor solids. The P-type semiconductor material is more electron-rich than the N-type material.

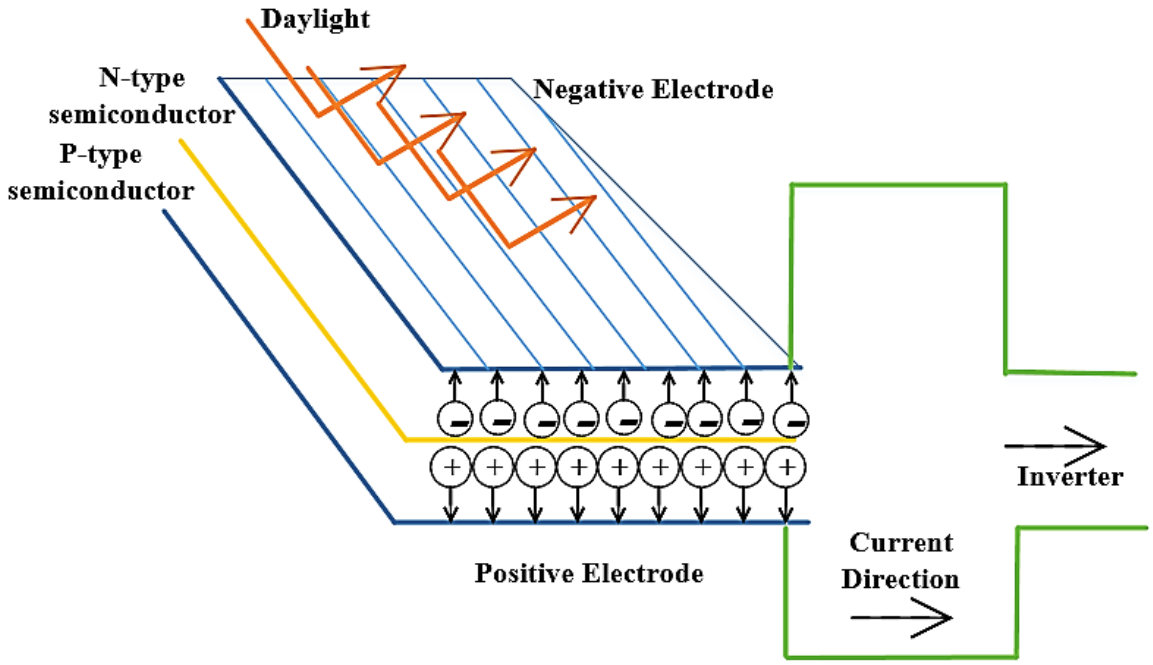

Figure 3.8. Solar Cell Battery Structure

Semiconductor connections are created by adding the necessary additives into the P or N type base material. The PN junction is formed by the voltage supply between N and P type materials. Positive charge accumulates in N region and Negative charge also accumulates in P region. When PN joint occurs; N-type electrons, which are the majority carriers, form a current towards P-type electrons, and this current progression continues until the charge balance of both sides is established. P-type silicon is obtained by adding an element from group 3 (aluminum, indium, boron, etc.) to the melt. Since there are 3 electrons in the last orbit of these elements, electron deficiency occurs in the crystal. The absence of missing electrons is called "hole" or "beautiful" and is assumed to carry a positive charge. Such materials are called "P-type" or "receiving" additives.

By providing 2-stage photovoltaic conversion in the joint area, the semiconductor joint begins to function as a solar cell. First, electron-hole pairs are formed by shining light on the junction region. Secondly, the electron-hole pairs formed are separated from each other by the electric field in the region. The electron-hole pairs separated from each other create a useful power output at the ends of the solar cell. According to the photoelectric effect principle; When solar energy comes to the PN junction, the electron charge in the photons creates 0.15 - 0.5 Volts, that is, a voltage potential difference between the PN materials. When photons in the structure of sunlight are absorbed by the surface of the solar cell; Electrons move towards the positive side of the joint and holes move towards the negative side of the joint, causing an electric current. As the radiation falling on the solar cell increases, the electric current produced by the solar cell also increases. Since the body of the solar cell is made of semiconductor material, it is modeled with a diode. The losses that occur during the transmission of the energy produced in the connection to the poles are shown with the series resistance. This series resistance directly affects cell efficiency. Junction: It is the buffer zone formed as a result of bringing P and N type additives side by side, and it is the surface that separates the N and P type regions. Typically, a PV cell has an area of 25 - 30 cm square and produces about 1 W of power. The structure formed by mounting a large number of photovoltaic cells on a surface by connecting them in series or parallel to increase the power output is called "solar cell module", "solar module solar panel" or "photovoltaic module". In photovoltaic systems, solar cells are connected in series to increase the voltage, while modules are connected in parallel to increase the amount of current that the module will feed. Depending on the demand power, solar modules can be connected in series and parallel to create systems that produce energy at the desired power level. The

efficiency and installation of solar cells determine the performance of the solar panel. It is connected in anti-parallel to bypass the current in the solar cell with the by-pass diode used for protection against faults.

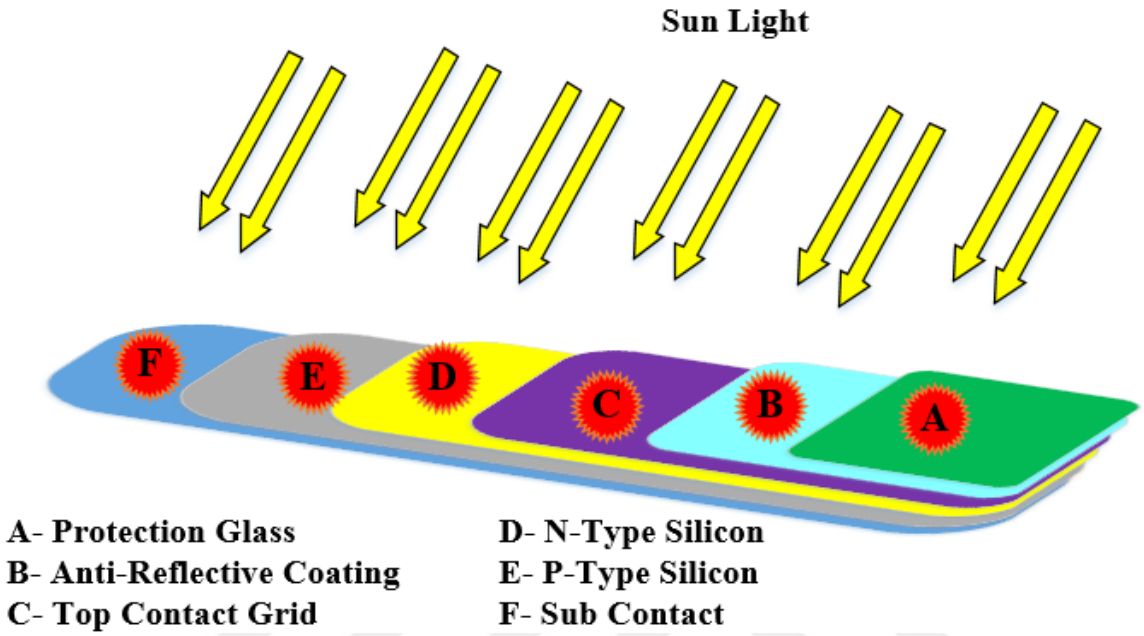

Figure 3.9. Photovoltaic panel structure

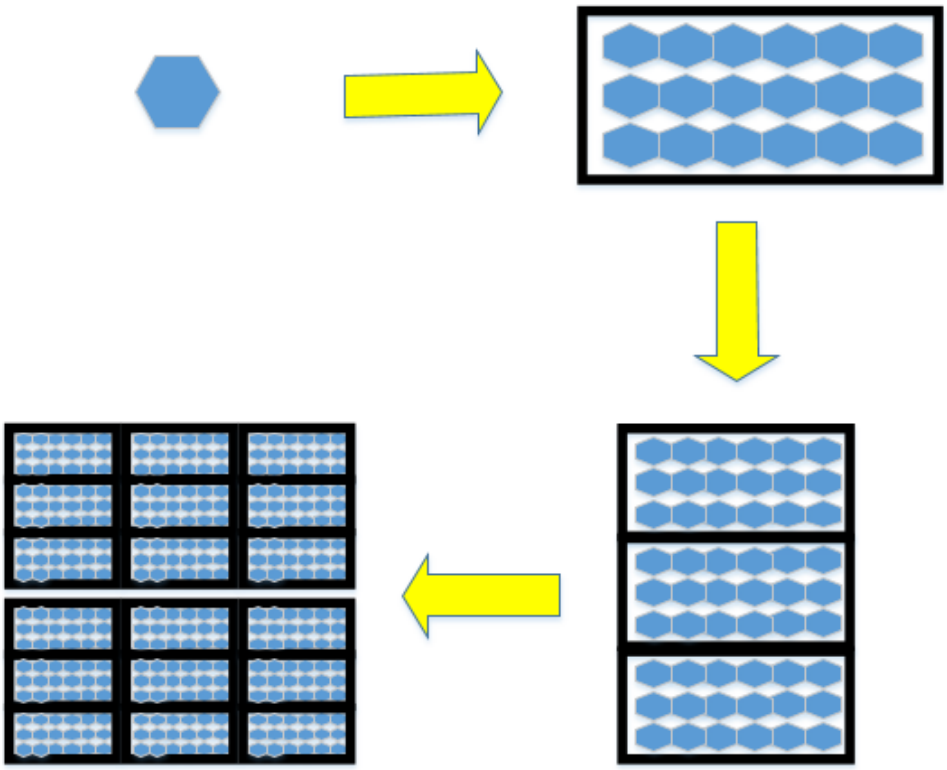

Figure 3.10. Phases of transition from solar cell to Photovoltaic system

Figure 3.11. General view of Portable Photovoltaic System

By connecting solar cells in parallel or series in certain numbers, solar panels of desired powers and sizes are created. When combined, the solar panels created with solar cells are covered with a glass layer to cover the cells. This layer has the feature to protect the cells and has a high light transmittance feature. Solar cells are usually connected in series to increase the voltage. Connecting the cells in parallel provides a higher current.

3.1.4. Inverter

An inverter is an electronic device capable of electrical power conversion. Inverters convert voltages from DC (direct current) sources to AC (alternating current) voltage with variable or constant frequency and amplitude, thanks to electronic circuit elements. Inverters can handle interruptions, fluctuations, imbalances, harmonics, etc. in the system. It is used to prevent problems and ensure that the system works more effectively and efficiently. Within the framework of this purpose, it reduces the motor and mechanical part faults caused by these problems by cleaning the voltage fluctuations and peaks coming from the network by passing them through the filter circuit. In this way, the repair and maintenance costs of these parts are minimized and their lifespan is extended. In addition, energy efficiency is achieved by reducing the inverter's reactive energy. Inverters called an electronic device that makes an electrical power conversion, are used in many areas ranging from small power supplies used to feed many devices to large systems powering electrical distribution systems.

In the energy field, inverters are used to produce uninterrupted, balanced and higher quality energy in renewable energy plants that produce intermittent and variable production such as

wind and solar. In addition, inverters are used to draw energy with the desired feature from energy storage systems such as batteries. In particular, as a result of the studies on the benefits of renewable energy sources and the increase in the need and demand for these systems, more quality and stable inverter types with more features are produced in order to make the energy obtained from wind and solar energy systems suitable for use. Devices with a microprocessor or low voltage control, alarm and warning outputs, overload protection and static regulation are offered to the market by manufacturers. Since there is no inrush current, the devices that do not damage the network operate at minimum and maximum ranges.

In solar energy systems, it helps to pass the consumption stage by converting the DC voltage from the panels onto the AC voltage in a healthy way. Two kinds of solar inverters will do this function. The first is the inverter that converts with a square wavelength output, called a modified sinus inverter. It is shown in figure 3.12. This type of inverter is used in simpler and cheaper projects. It is preferred for devices that are not affected by poor quality and unbalanced load from the network. The other one is the inverters that give output in the form of a full sinus, called a full sinus inverter. It is shown in figure 3.13. It is used in areas where electronic devices are fed and high-quality energy is needed. Full sine inverters are more efficient than modified sine inverters.

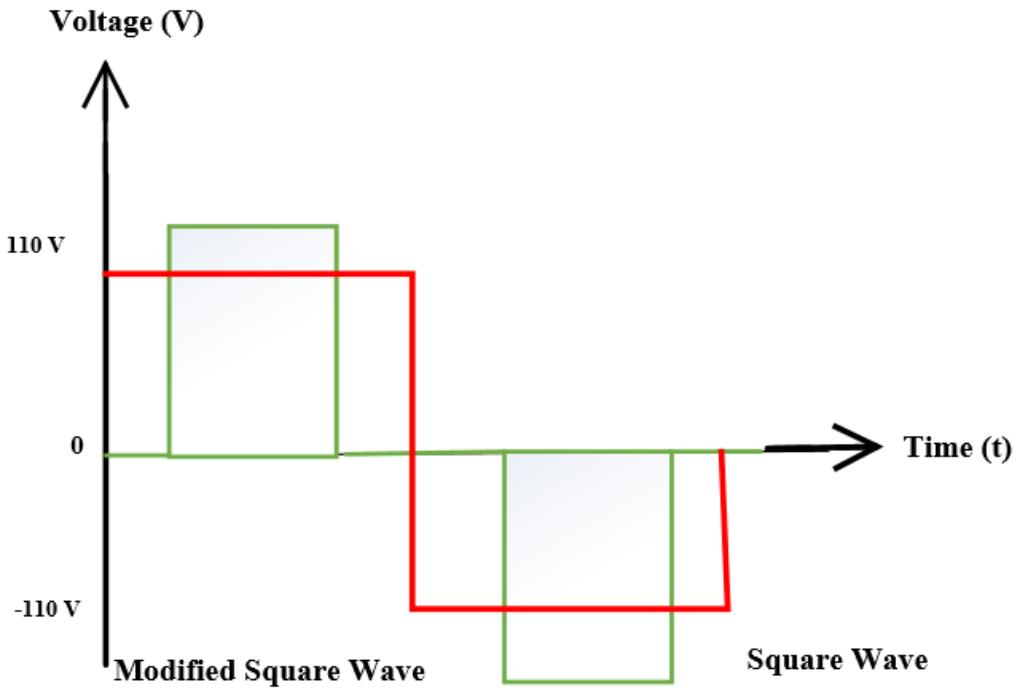

Figure 3.12. Modified Square Wave Chart

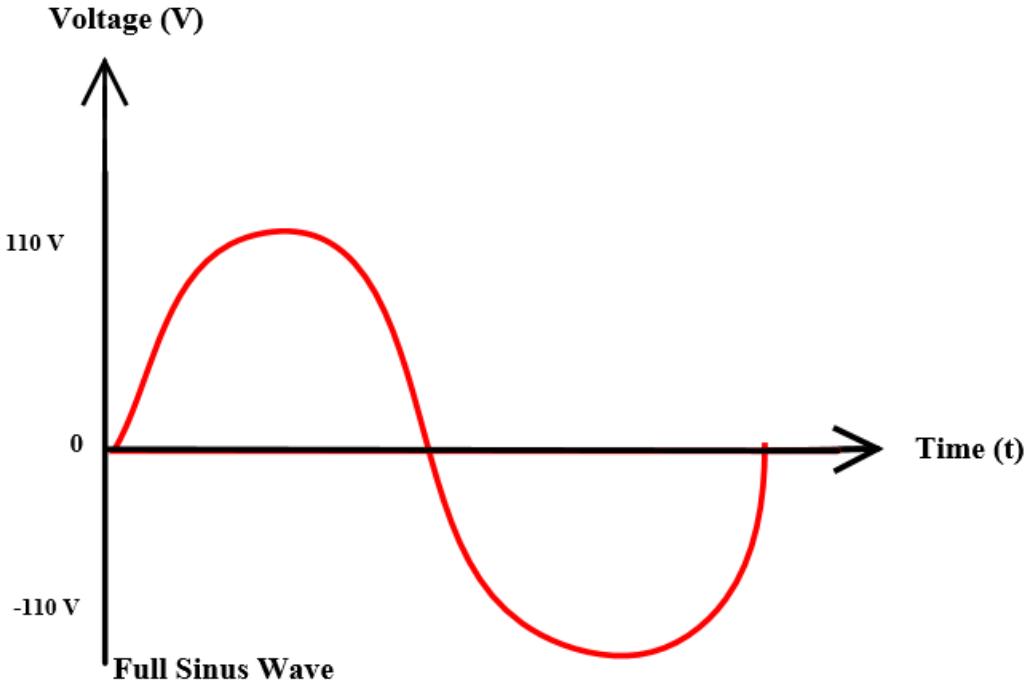

Figure 3.13. Full Sinus Wave Chart

Figure 3.14. Inverter used in Portable Photovoltaic System

3.1.5. Solar Charge Controller

The solar charge controller is a kind of regulator that transfers the energy from solar panels to batteries and loads. The charge control unit is used to fill the batteries with electrical energy obtained from solar energy. The charging voltage is regulated in accordance with the batteries and when the batteries are about to be full, the current is reduced to protect the batteries.

A complete discharge of a battery can shorten its life drastically. Therefore, load control is extremely important in solar energy systems. The charge control circuit protects the batteries from over-discharge by cutting off the energy to the load below a certain voltage.

Overcharging any type of battery can cause irreparable damage. Overcharging lead-acid batteries boils the liquid inside, causing excessive gas formation. This can cause damage to the battery plates, swelling, or explosion of the battery.

There are two different types of charge controllers for solar energy systems.

- The first is PWM (Pulse amplitude modulation) controllers, which are widely used throughout the industry. PWM controllers basically act as a switch between the solar panel and the battery. The charging current is controlled by quickly opening and closing the switch. The controller constantly checks the status of the batteries and determines how wide the pulses to be sent will be. When the battery is full, pulses are sent out briefly and every few seconds. When the battery is discharged, the pulses are too long or the controller works to be always on.
- The second is MPTT (Maximum power point tracking) charge control devices, which have a more advanced and more complex structure. MPTT controllers measure the voltage of the panel and reduce it to the voltage suitable for the battery. Current and voltage values are continuously optimized to achieve maximum power. In this way, it can work more efficiently than the PWM controller.

Figure 3.15. Solar Charge Controller used in Portable Photovoltaic System

3.1.6. LDR Sensor

"Light sensitive resistor (LDR)," one of the basic components of light sensors, is a passive circuit element that detects the light falling on it or the environment, and also changes the resistance values according to the intensity of the light. LDR, which is also used as a photoresistor, functions almost the same as the photodiodes and phototransistors found in sensors. However, it differs from them in structure. LDR is passive and causes a change in resistance as a result of light detection; In photodiodes and phototransistors, light perception is achieved with the help of pn junctions.

LDR consists of semiconductor material with high resistance value due to its structure. In its structure, mostly cadmium sulfide (CdS) is used as a semiconductor. Photons, whose energy (light) falls on them, transfer their energy to the electrons in the valence electron band (high resistance), causing them to jump to the conductive region. In this way, the resistance of the semiconductor material begins to decrease with the entanglement of more energetic electrons in the conductive region. (Resistance is the resistance shown against the flow of electrons.) As the falling light intensity increases, the amount of electrons jumping to the conductive band also increases and the resistance of the material decreases.

The change in resistance according to light intensity is as follows:

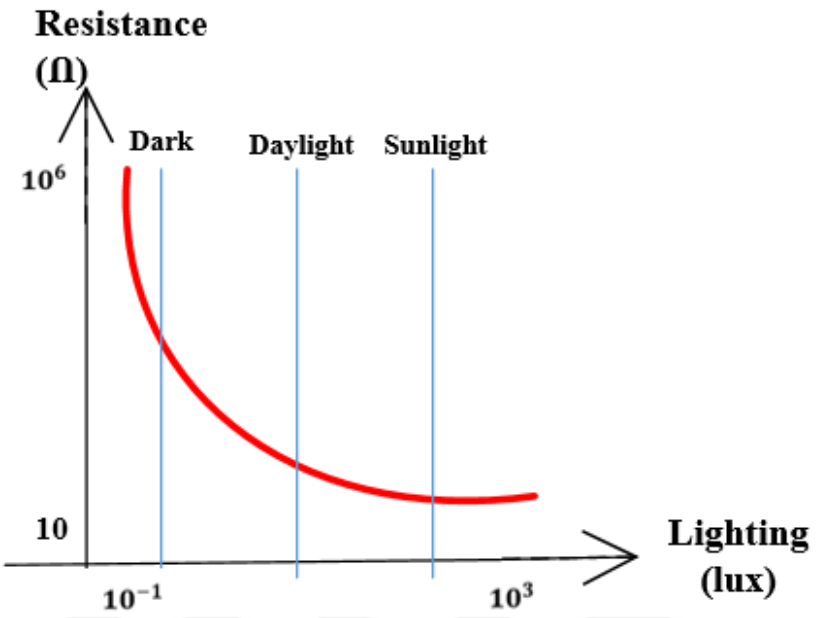

Figure 3.16. The change in resistance according to light intensity

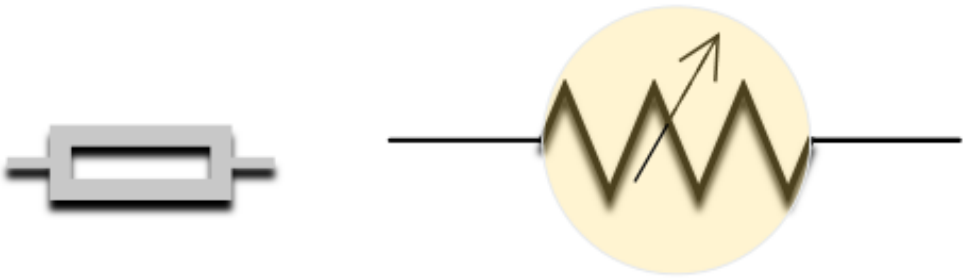

Figure 3.17. Photoresistor icon

Since LDRs are sensitive to light, their resistance values in the dark are very high and are in the MΩ range. According to the applied light intensity, the resistance values decrease non-linearly and regress to kΩ levels.

Each different semiconductor material used in LDR has its own wavelength sensitivity to light. If the applied light is not in the wavelength sensitivity range of the material, there is no change in the resistance value. Therefore, the wavelength range of light and the amount of resistance change of each semiconductor material are different.

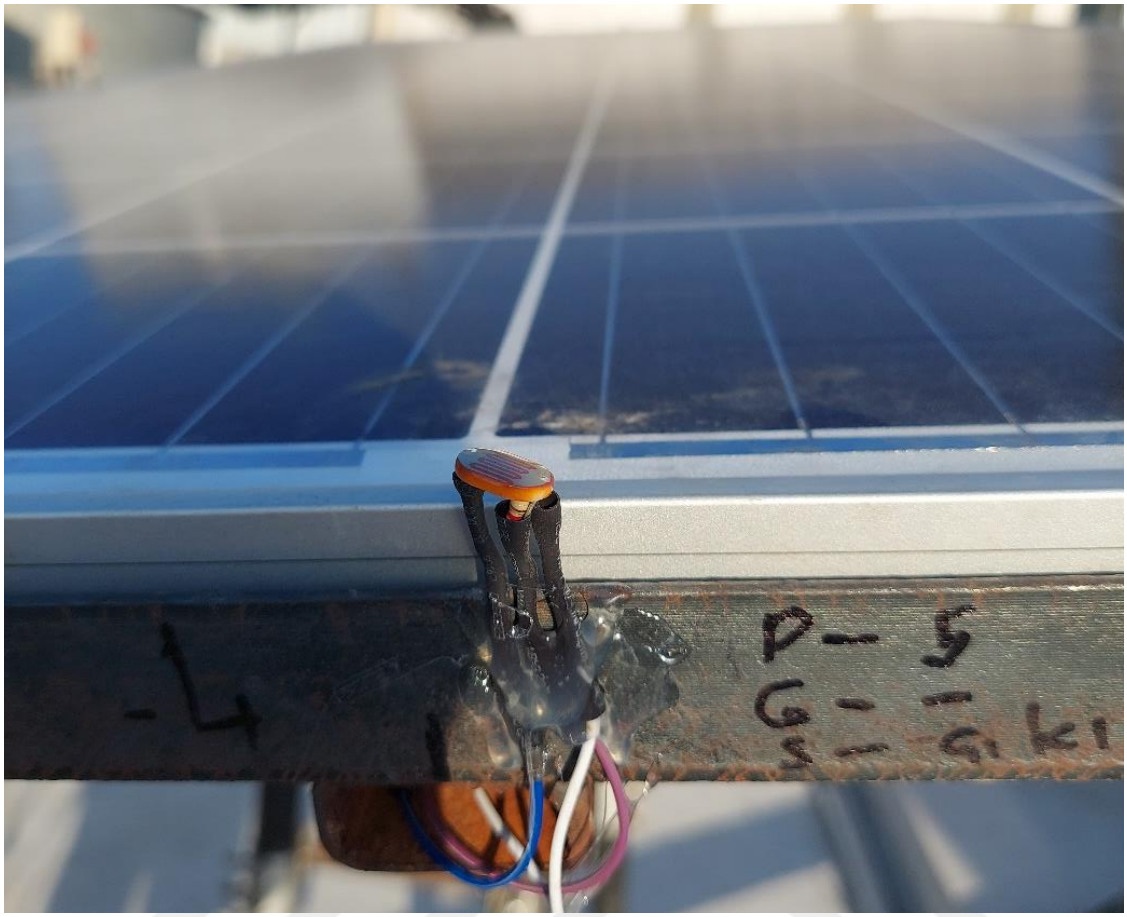

Figure 3.18. LDR used in Portable Photovoltaic System

3.1.7. Solar Tracker Actuator

Linear actuators are electrical devices that convert the rotational motion of electric motors (AC or DC motors) into linear motion. Linear motion is generated by turning the screw of the linear actuator by means of a motor. The screw rotates clockwise or counterclockwise causing the shaft (basically a nut on the screw) to move up and down, creating a push/pull effect for the load. An electric linear actuator can be used wherever a machine pushes or pulls a load, lifts or lowers a load, roughly positions a load, or rotates a load.

Solar tracker actuators used in this study are robust and powerful actuators designed for solar tracker systems operating in linear motor logic. Actuator data used in this application are given below. This type of actuator features high load capacity, long service life and low power consumption. Sensors are placed at the endpoints of the shafts to ensure that they stop at their limits.

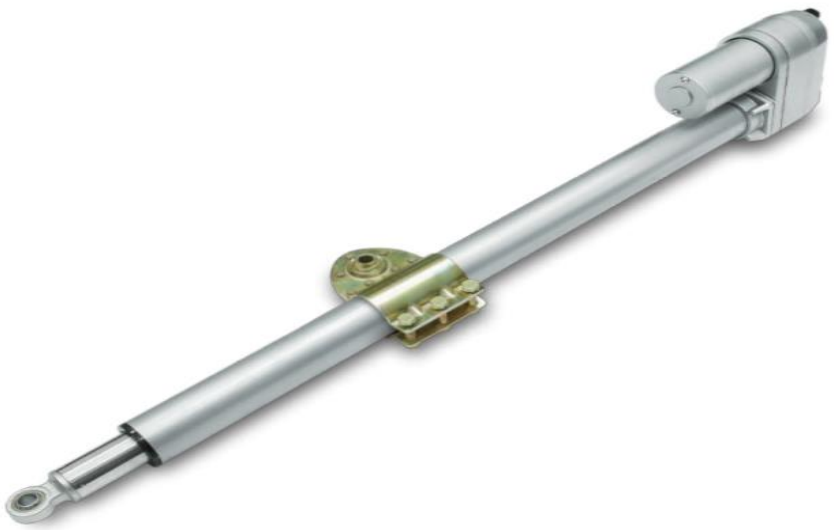

Figure 3.19. Solar tracker actuator

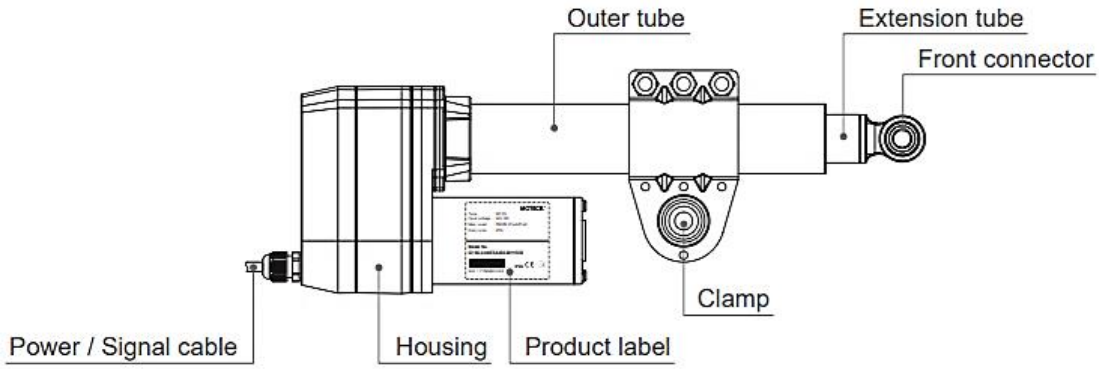

Figure 3.20. Solar tracker actuator structure

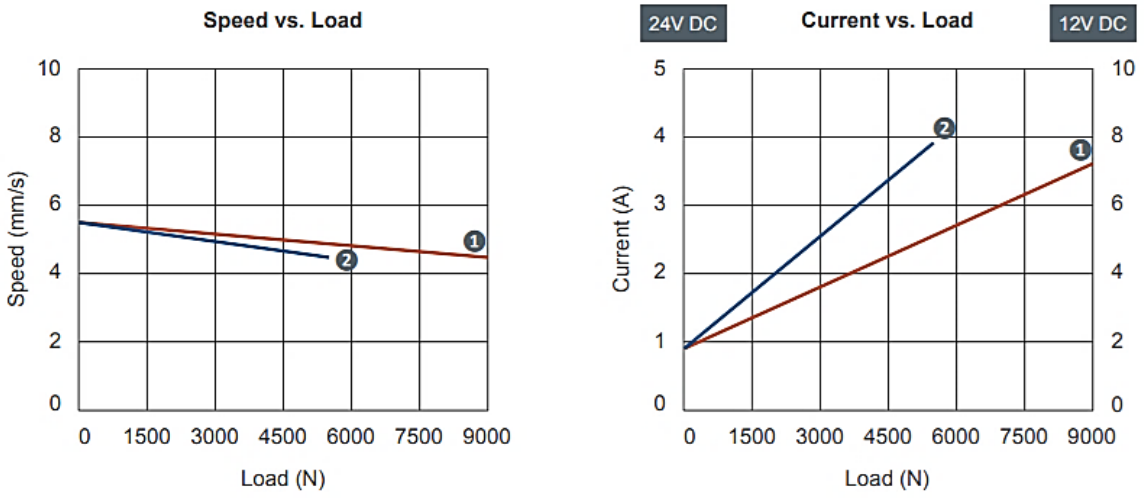

Figure 3.21. Solar tracker actuator characteristic

3.1.8. Ardiuno

Arduino is used as a single board microcontroller and a software package used to program it. The hardware consists of a simple open hardware design for the controller with AtmelAVR processor and onboard I/O support. Arduino can be defined as a small computer that you can program to handle the inputs and outputs between the device and the external components you connect to it. Arduino is known as a Physical or Embedded Computing platform and is defined as an interactive system that can interact with its environment using hardware and software at this information threshold. Arduino can be used to develop stand-alone interactive objects or with the aid of a computer, it can be connected to a computer, network, or even the Internet to send and receive data from the network and even from the Arduino, and then act on this data to external systems. In other words, a set of data can be sent from some sensor to a website, which can then be displayed in graph form. Arduino connects to LEOs, dot matrix displays. It can be connected to buttons, switches, motors, temperature sensors, pressure sensors, distance sensors, GPS receivers, Ethernet modules or just about anything else that has or can have data, creating controllers and outputs.

Inside the Arduino board is an Atmel AVR Microprocessor, a crystal or oscillator and a linear regulator in volts. Depending on the type of Arduino working, a USB socket is available to connect to a PC for uploading or receiving data. The board exposes the I/O (input-output) pins of the microcontroller so that these pins can be connected to other circuits or sensors. To program the Arduino (do what you want) we use the Arduino IDE (Integrated Development Environment), a free software where you write code in the language that Arduino understands (a language called C). The IDE allows you to write a computer program, which is a set of step-by-step instructions that you then upload to the Arduino.

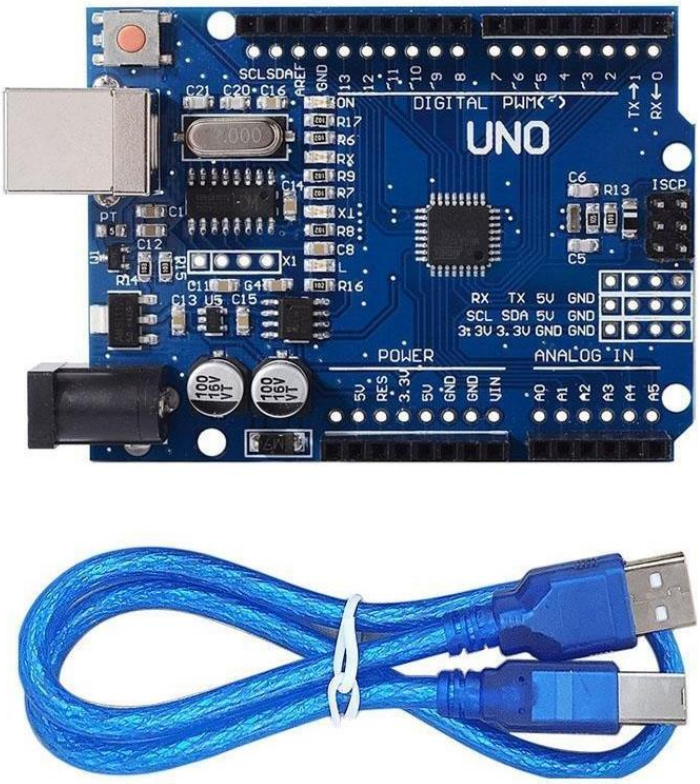

Figure 3.22. Arduino Uno Overview

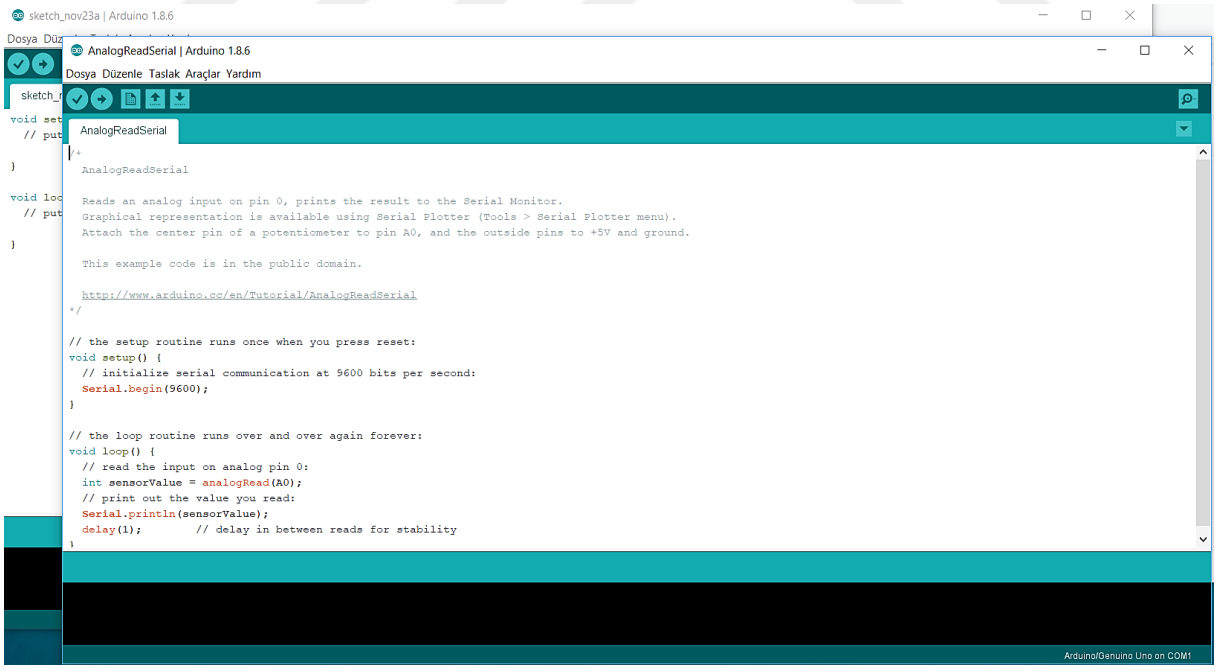

Figure .23. Arduino IDE interface

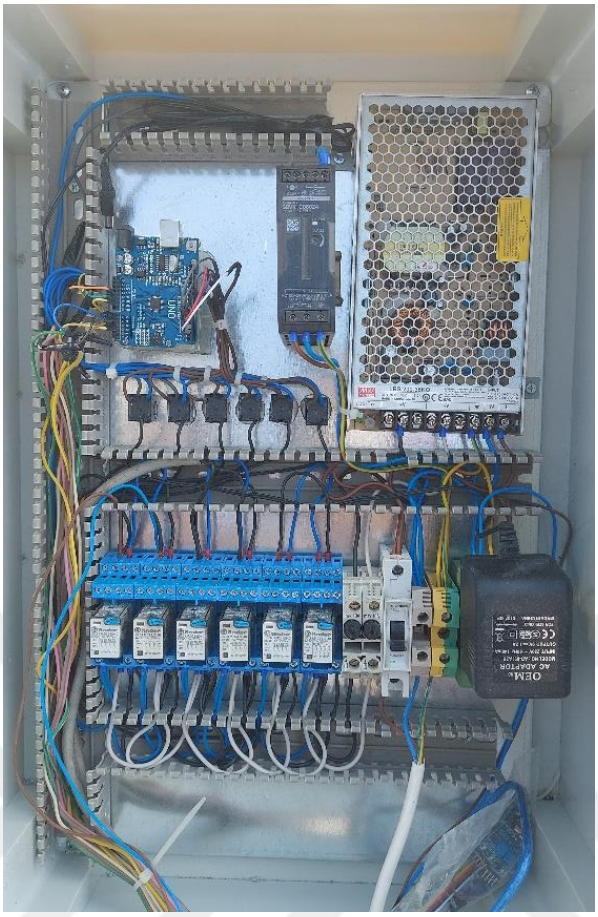

Figure 3.24. Arduino used in Portable Photovoltaic System

3.2. Solar Tracking Systems

The number of uses of solar energy systems, which are in the literature as an environmentally friendly and renewable energy source, is increasing rapidly. However, the biggest disadvantage of solar energy systems is that the amount of production changes during the day according to the angle of the sun. For this reason, solar tracking systems have been developed to obtain more efficiency from solar energy systems. Thanks to this system, which aims to keep the electricity production at the highest level by following the sun's rays during the day, the effectiveness of solar energy systems has increased even more.

In Figure 3.22, there is a block diagram showing the materials used in the solar tracking system. Photosensitive LDR sensors are placed at the panel ends and the sun angle information received from these sensors is transmitted to the system controller. The system controller, on the other hand, transmits the information it receives to the motor, which is the movement part of the panel, to follow the sun. The control unit calculates the incoming data and commands the motor

part to move in order to catch the sun's rotation direction. Events taking place in this order allow the panel to follow the sun. This system monitors the movement of the sun all day long and tries to keep the production at the maximum level by taking the sun rays at the right angles. In Figure 3.23, the general view of the material layout of the uniaxial solar tracking system is given.

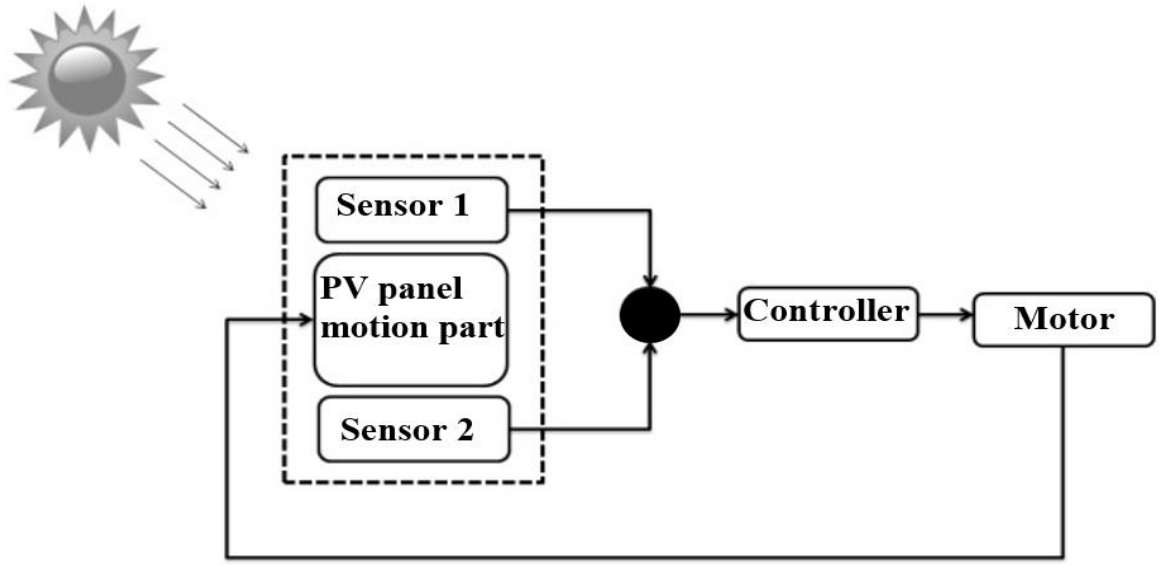

Figure 3.25. Solar Tracking System Block Diagram

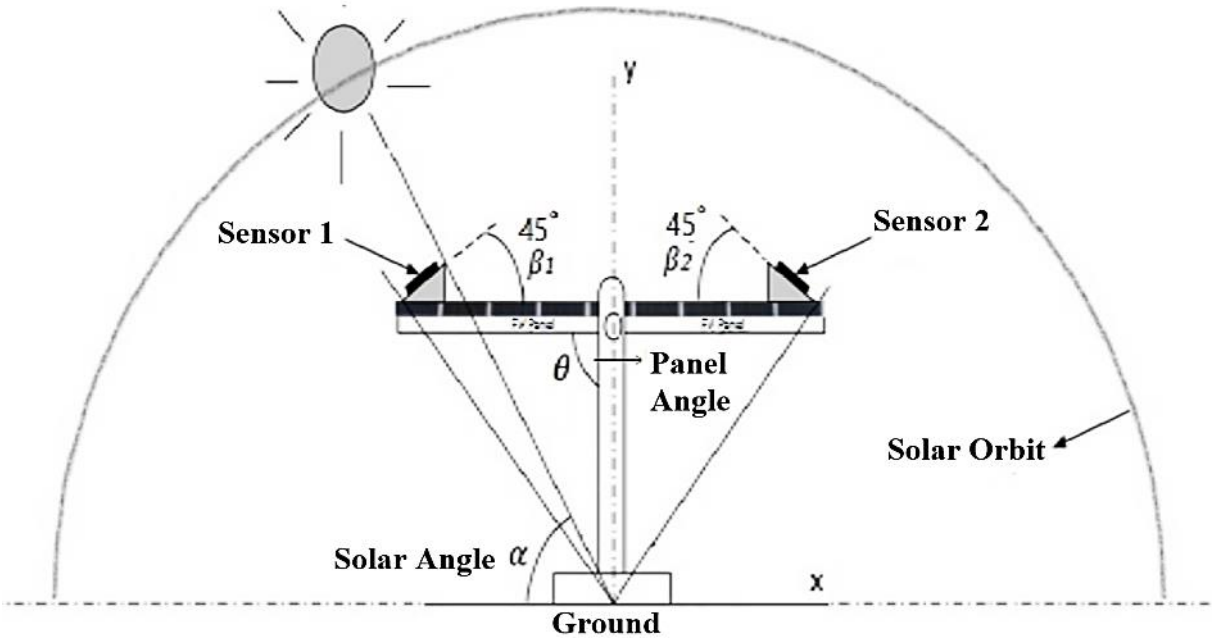

Figure 3.26. Solar Tracking System Overview (Ort. M.İ., 2016).

There are two main types of solar tracking systems based on the directions their sun moves: single-axis solar tracking system and dual-axis solar tracking system.

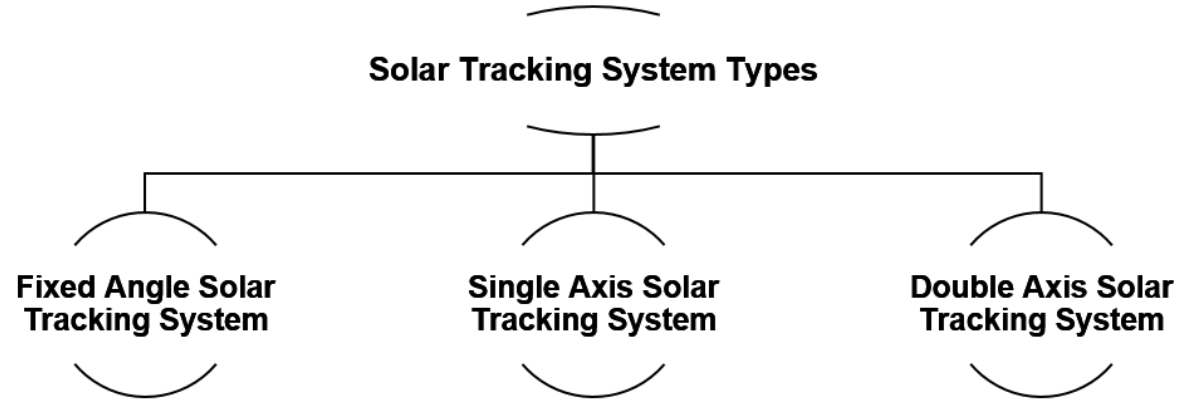

Figure 3.27. Solar tracking systems used in solar PV power plants.

3.2.1. Fixed Angle Solar System

The systems in which the panels are mounted with a fixed angle, which is aimed to work with the highest efficiency by deciding as a result of the feasibility study of the angle of the sun's rays, are called fixed solar energy systems by making the calculations, the positions of the panels are prepared according to the resulting angle, the panels are fixed and their assembly is completed. Since fixed systems cannot provide movement, they constantly see the sun from different angles during the day, and in this case, the sunbathing times are greatly reduced. Since they are fixed, they do not change direction according to the movement of the sun and remain in a fixed position. This situation is explained as the reason why the efficiency of the fixed angle solar system, which is the classical system, is lower than the solar tracking systems. The fixed angle solar system is also shown in Figure 3.28.

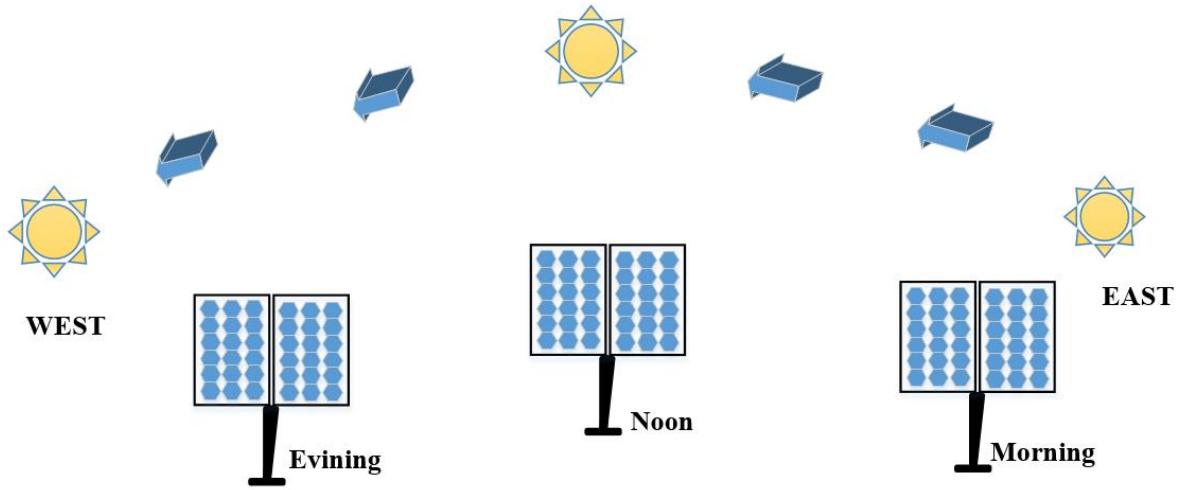

Figure 3.28. The fixed-angle solar system

3.2.2. Single-Axis Solar Tracking System

Systems that allow the panels to follow the sun based on the angle of the sun through some methods are called solar tracking systems. Systems that follow the sun in one direction in the east-west direction are called single-axis solar tracking systems. It is stated that these unidirectional systems are 25-30% more efficient than conventional systems that work stationary. In these systems, where the panels are controlled as a single axis, the panels are placed on the north-south line and the movement takes place in the east-west axis. Thus, the panel increases production by catching the sun at the steepest angle throughout the day. Since the panel that receives the sun at the best angle throughout the day will increase the energy production, this system is more efficient than the fixed angle solar system. The single axis solar tracking system is shown in Figure 3.29

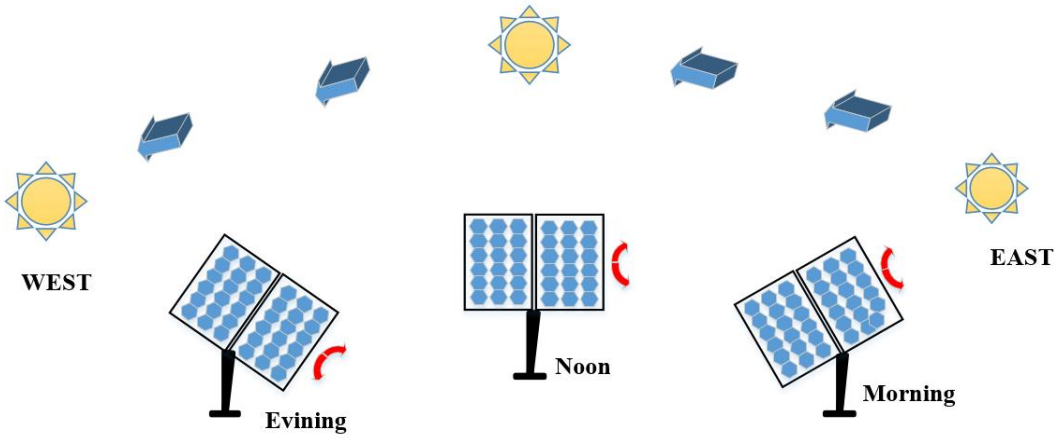

Figure 3.29. The single-axis solar tracking system

3.2.3. Double-Axis Solar Tracking System

The detection of the movement of the sun both in the azimuth axis and in the zenith axis and accordingly the tracking of the sun in the dual axis of the panel is provided by dual axis tracking systems. With the dual-axis solar tracking system, the energy production efficiency is 30-40% higher than the fixed systems. It is 7-15% more than single-axis solar tracking systems. To make efficient use of the sun throughout the day, the panel is moved north-south and east-west to capture the best possible angles of the sun. The dual axis solar tracking system is shown in Figure 3.30.

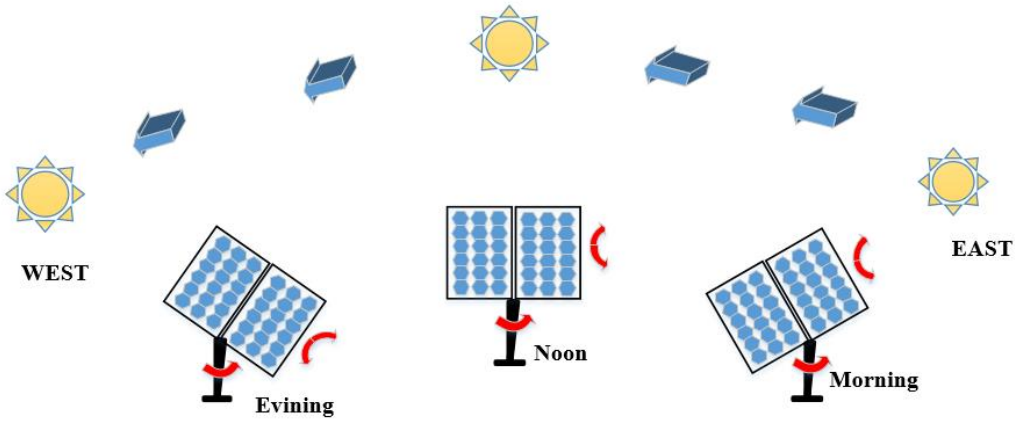

Figure 3.30. The single-axis solar tracking system

3.3. Mathematical Modeling of The Solar Tracker System

First of all, the parts to be used for the system where the application will be made were created and the materials were prepared. These materials to be used are mathematically modeled so that the data is correct and valid. These models are calculated and explained separately for each part.

3.3.1. DC Motor Modeling

DC motors are electrical elements used in almost every field in industry, whose input is electrical energy and output is motion energy. In this project, it will be used in the part that provides the movement of the panel used in order to follow the sun in line with the calculated data. DC motor modeling was done as follows. Here V is the armature voltage. w indicates motor shaft. θ is the motor shaft angle. Figure 3.31. shows the circuit diagram of the DC motor to be used.

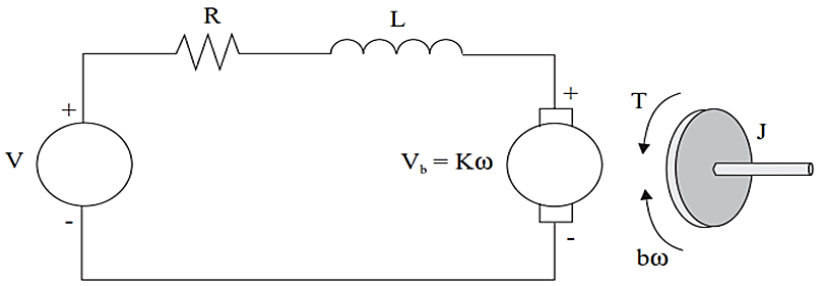

Figure 3.31. Circuit diagram of DC motor (Ort, 2016).

$$Js^2\theta(s) + bs\theta(s) = K\frac{V_{(s)} - Ks\theta(s)}{R + Ls} \tag{1}$$

$$T = K.i \tag{2}$$

Depending on the DC motor, the Torque equation can be defined using Equations 1 and 2. In this information, we have obtained the above equation.

3.3.2. Modelling of Sunlight Absorb Sensors

In this project, LDR sensors that detect sunlight are used to ensure the movement of the sun. By using the voltage divider circuits of these sensors, the voltages of the light falling on them were also changed. Therefore, the radiation dependent variation of an LDR sensor connected to the voltage divider circuit can be defined as follows:

$$V_{LDR} = V_g \frac{R}{R + R_{LDR}G_{LDR}} \tag{3}$$

In Equation 3, VLDR is the output voltage of the sensor; Vg is the input voltage of the voltage divider (6V); R is the series resistance in the voltage divider circuit (100W); RLDR, sensor resistance and GLDR are the effective radiation values falling on the sensor. The effective radiation value falling on the sensor is defined as the radiation value falling perpendicular to the sensor surface. The data related to the calculation of the effective radiation value are as in Equation 4.

$$G_{LDRi} = G * \cos[\alpha - (\theta - \beta_i)] i = 1,2 \quad (4)$$

3.3.3. Sun Modeling and Movement Control

In this model, the angle that the sunlight makes with the PV panel,

$$\alpha = \gamma * t + \phi \quad (5)$$

In Equation 5, α is the angle that the sun makes with the PV panel; γ, change of angle of the sun in one second; t is the system time (at one-second intervals) and başlangıç the starting angle of the sun.

3.3.4. Effective Radiation Modelling

Correctly detecting the sun's rays will ensure that the movement of the panel works correctly. For this purpose, solar modeling is very important. In order to correctly perceive the movement of the sun throughout the day, it is very important to transfer the radiation from the sun to the control part of the information correctly. In short, correctly estimating the movement of the sun throughout the day will ensure that the panel follows the sun correctly. This will directly affect the production data. The effective radiation value produced by the radiation value obtained from the solar model on the panel can be calculated with the following Equation 6.

$$G_{PV\_panel} = G * \cos(\alpha - \theta) \quad (6)$$

4. RESULTS AND DISCUSSIONS

A portable solar tracking system study was carried out for the solar tracking system, which is one of the most important studies to increase efficiency in solar energy systems. The content of the study includes a fixed system, single axis solar tracking system and dual axis solar tracking system. A portable product is designed for each of them separately. It is aimed to have an idea about which system is more successful in terms of efficiency by comparing the daily production data of these 3 separate systems consisting of 400 watt solar panels in the same environment and conditions. In the systems, there are 400 watt solar panels, solar tracker actuator, 600 watt solar inverter, 20 amp solar charge controller, ardiuno software and circuit elements to control the tracker system, an analyzer to measure energy and LDR sensors to track the sun. used. Chapter 3 provides detailed information about these materials.

In the study, it was aimed to benefit more from solar energy and increase its efficiency in electricity production, and in this direction, systems were installed in Adana Seyhan province Zeytinli Mahallesi between 10 - 24 September 2021 and production data were obtained. Since the first of these 3 systems is a fixed system, a solar panel was mounted on a fixed carrier and measurements were taken with the help of an inverter and charge controller. In the second system, the movement of the panel in the east and west directions is provided with the help of the mechanical part mounted on the carrier and the solar tracking actuator (linear motor). In the third system, it is provided to move according to the sun in the east, west and north-south directions with the help of mechanical equipment specially designed for this system and 2 solar tracker actuators. These motion systems are specially written and controlled with ardiuno.

With the applied study, it has been revealed that more production can be achieved in electricity production from solar energy systems by using the sun more efficiently. In this study, three different systems were compared, and which system would be more efficient and production differences in percentage were stated. In the light of all these data, it is thought that the tracker system would be more suitable for the solar power plants planned to be built in the Çukurova region, where the study was conducted, instead of the fixed system. Between the tracker systems, there is a 7% difference between the production obtained from the dual-axis system and the production obtained from the single-axis system. Since this production difference will be insufficient to cover the cost that will occur if biaxial systems are preferred, it has been suggested that the preference be used in favor of a single-axis system.

Since the land structure of the Çukurova region is mostly flat areas, the installation and operation of uniaxial systems for the planned solar power plants will be easy. Considering the roof angles of the solar power plants planned for the roofs for industrial zones, it is recommended to re-work the roof models to be applied for the tracker system.

4.1. Parameters of The Material of The Solar Tracking System

The parameters of the materials used in the Solar Tracking System, which is installed portable and where application data are obtained, are presented in tables below.

Table 4.1. Panel Electrical parameters used in the Solar Tracking System

Electrical Characteristics						
Module						
Maximum Power at STC (Pmax)	380 W	385 W	390 W	395 W	400 W	405 W
Open-Circuit Voltage (Voc)	48.3 V	48.4 V	48.5 V	48.6 V	48.7 V	48.8 V
Short-Circuit Current (Isc)	10.34 A	10.47 A	10.55 A	10.67 A	10.79 A	10.91 A
Optimum Operating Voltage (Vmp)	39.9 V	40.1 V	40.3 V	40.5 V	40.7 V	40.9 V
Optimum Operating Current (Imp)	9.55 A	9.61 A	9.68 A	9.76 A	9.84 A	9.91 A
Module Efficiency	%18.9	%19.1	%19.4	%19.6	%19.9	%20.1
Power Tolerance	0 ~ + 5 W					
Maximum System Voltage	1000 V / 1500 V DC (UL/IEC)					
Maximum Series Fuse Rating	15 /20 A					
Operating Temerature	- 40 °C to + 80 °C					

Table 4.2. Panel mechanical parameters used in the Solar Tracking System

Mechanical Characteristics	
Solar Cells	Monocrystalline 158.75 × 158.75mm
No.of Cells	72 (6 × 12)
Dimensions	2008mm×1002mm×35mm
Weight	22.5kg
Front Glass	High transmission tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP68
Cable	4mm² (UL/IEC) Length:1200mm
Connectors	MC4 Compatible
Packaging Configuration	30pcs / box, 715pcs / 40'HQ Container

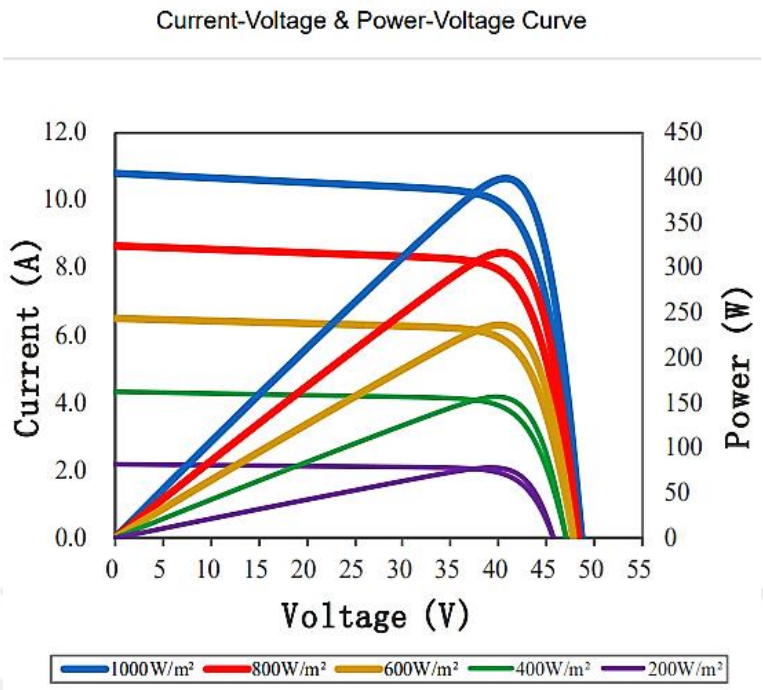

Figure 4.1. I-V Curves of Panel

Table 4.3. Inverter parameters used in Solar Tracking System

Normal Output Power:	600 Watt
Continuous Output Power	600 Watt
Maximum Power	1200 W
Normal Input Volt	12 Volt DC / 24 Volt DC
Normal Output Volts	220 V AC
Frequency	50 HZ
Output Layout	+ - % 5
Sine Output	Modifiye Sinüs
Voltage Alarm Range	10.5 + / - 0.5 Volt
Cut-off Voltage Range	10.5 + / - 0.5 Volt
Efficiency Ratio	85 - 90 %
Heat Preservation	65 C + / - 5 C
Short Circuit Protection	There is
Insurance Protection	There is
Short Circuit Protection	There is
Cooling fan	There is
European Type Socket	There is
Fuse	Available

Table 4.4. Linear Motor parameters used in Solar Tracking System

Datasheed of Linear Motor	
Main application	Industrial, Solar tracker
Input voltage	12V DC / 24V DC
Rated load	7,000N
Max. static load	17,100N
Max. dynamic load	9,000N
Max. speed at no load	5.5 mm/sec
Max. speed at full load	4.4 mm/sec
Stroke	450 mm (18”) / 600 mm (24”) / 900 mm (36”)
Power cord length	250 mm (with tinned wires)
Ambient operation temperature	-25°C ~ +65°C

Table 4.5. Solar Charge Controller parameters used in the Solar Tracking System

Electrical Parameters	
Maximum Working Current	20 A
System Voltage	12 Volt / 24 Volt
Battery Max. Charging Voltage	13.7 Volt / 27,4 Volt
Battery Low Voltage Protection	10,7 Volt / 21,4 Volt

Table 4.6. Software parameters controlling the Solar Tracking System

```
#define ldrlt A0   // top left
#define ldrrt A1   // top right
#define ldrld A2   //bottom left
#define ldrrd A3   // bottom right

#define M1_A 2
#define M1_Y 3
#define M2_A 4
#define M2_Y 5

void setup()
{
  // put your setup code here, to run once:
```

```
  Serial.begin(9600);              // Serial Display

  pinMode(2,OUTPUT);
  pinMode(3,OUTPUT);
  pinMode(4,OUTPUT);
  pinMode(5,OUTPUT);
}

void loop(){

  // put your main code here, to run repeatedly:
  int lt = analogRead(ldrlt);   // top lefft
  int rt = analogRead(ldrrt);   // top right
  int ld = analogRead(ldrld);   // bottom left
  int rd = analogRead(ldrrd);   // bottom right

   int dtime = 10;
   int tol = 50;

   int avt = (lt + rt) / 2; // Avarage Upper Value
   int avd = (ld + rd) / 2; // Avarage Lower Value
   int avl = (lt + ld) / 2; // Avarage Left Value
   int avr = (rt + rd) / 2; // Avarage Right Value

   int dvert = avt - avd; //Difference between top and bottom

   int dhoriz = avl - avr;// difference between right and left

 digitalWrite(M1_A,LOW);
 digitalWrite(M1_Y,LOW);
 digitalWrite(M2_A,LOW);
 digitalWrite(M2_Y,LOW);

    if (-1*tol > dvert || dvert > tol)
    {

        if (avt > avd)// HIGH AVERAGE HIGH VALUE THAN AVERAGE LOWER
VALUE

        {

          digitalWrite(M1_A,HIGH);
          digitalWrite(M1_Y,LOW);

        }
```

```
      else if (avt < avd)// LOWER AVERAGE VALUE AVERAGE GREATER THAN
UPPER VALUE

      {

        digitalWrite(M1_A,LOW);
        digitalWrite(M1_Y,HIGH);
      }

      else if (avt = avd)

      {
        digitalWrite(M1_A,LOW);
        digitalWrite(M1_Y,LOW);
      }

  }

   if (-1*tol > dhoriz || dhoriz > tol)

  {
      if (avl > avr)// IF AVERAGE LEFT VALUE IS GREATER THAN AVERAGE
RIGHT VALUE

      {

        digitalWrite(M2_A,HIGH);
        digitalWrite(M2_Y,LOW);

      }

      else if (avl < avr) {

        digitalWrite(M2_A,LOW);
        digitalWrite(M2_Y,HIGH);

      }

      else if (avl = avr)

      {
        digitalWrite(M2_A,LOW);
        digitalWrite(M2_Y,LOW);
      }

   }
```

4.2. Meteorological Data

Detailed information about the meteorological data in the Seyhan district of Adana province, where the portable system prepared for the application was established, is given below.

Table 4.7. Temperature, precipitation and wind parameters of September 2021 for many years comparison with values

Temperature (°C)						Precipitation (mm)				Wind (m/s)	
Long Year Average	Last Month Average	Long Year Maximum	Last Month Maximum	Long Year Minimum	Last Month Minimum	Long Year Months Total Average	Last Month Total	Long Year Maximum	Last Month Maximum	Long Year Maximum	Last Month Maximum
25,8	27,2	43,2	37,3	9,3	17,1	17,1	0	129	0	25,5	9,8

Table 4.8 Meteorological Data for September 2021

Meteorological Data for September 2021					
Day	**Temperature Maximum**	**Temperature Minimum**	**Precipitation Probability %**	**Humidity %**	**Wind (km/h)**
1	32	25	0	50	21
2	33	25	0	46	21
3	32	25	10	47	19
4	32	25	0	43	21
5	32	25	10	46	20
6	32	25	0	46	19
7	32	25	0	46	19
8	32	25	10	46	18
9	32	25	10	46	19
10	33	24	0	43	21
11	32	25	0	46	19
12	32	25	0	50	21
13	31	24	0	54	20
14	31	24	10	41	19
15	31	24	10	50	20
16	31	24	20	54	19
17	30	24	20	55	19
18	30	24	10	51	19
19	30	23	20	51	18
20	29	23	30	55	19
21	29	23	40	54	19
22	29	22	20	52	19
23	29	23	30	50	15
24	29	23	0	43	17
25	29	23	10	44	16
26	29	23	10	50	15
27	28	23	10	57	18
28	29	22	10	43	19
29	29	23	10	43	18
30	29	22	10	38	18

4.3. Analysis of Solar Tracker Systems Application

In order to maximize energy production by making more use of solar energy, 3 different portables have been created to show which system is the most accurate. The first is the fixed system where no movement has taken place, the second is the single axis tracker system moving in the east and west directions, and the last is the dual axis tracker system moving in the east-west and north-south directions. LDR sensor, linear motor and Arduino software were used to provide the movement of the second and third systems. With the help of the software written with Arduino, it has been tried to ensure that the panels produce more energy by tracking the sun through the information received from the LDR sensors. The size information of the designed systems are shown in the Table 4.9.

Table 4.9. Dimensions of portable systems

System Name	Weight (kg)	Height (cm)	Dimensions of Panel (cm)
Fixed System	24	158	202*102
Single Axis System	39	158	202*102
Double Axis System	51	158	202*102

For these systems created for the purpose of comparison, first of all, 3 identical 400-watt solar panels were arranged. For the positioning of these panels, 3 mechanical materials consisting of legs and stands were arranged. As shown in Figure 4.5, the panels were mounted on the stands. Afterward, linear mounting was made to 2 systems for the operation of the system, which we call solar tracker. A single motor was installed on the system considered as a single axis solar tracker, and 2 linear motors were mounted on the system considered as a dual axis solar tracker. LDR sensors used to determine the angle of the sun were installed in 2 systems considered for solar tracker. Two LDR sensors, north and south, for the single-axis solar tracker system, and 4 LDR sensors, north, south, west and east, to the dual-axis LDR system, were installed and connected to the digital inputs of the Arduino Uno card.

Figure 4.2. Mechanical parts of the dual axis solar tracker system

Figure 4.3. Mechanical parts of the single axis solar tracker system

Figure 4.4. General view of the triple portable system

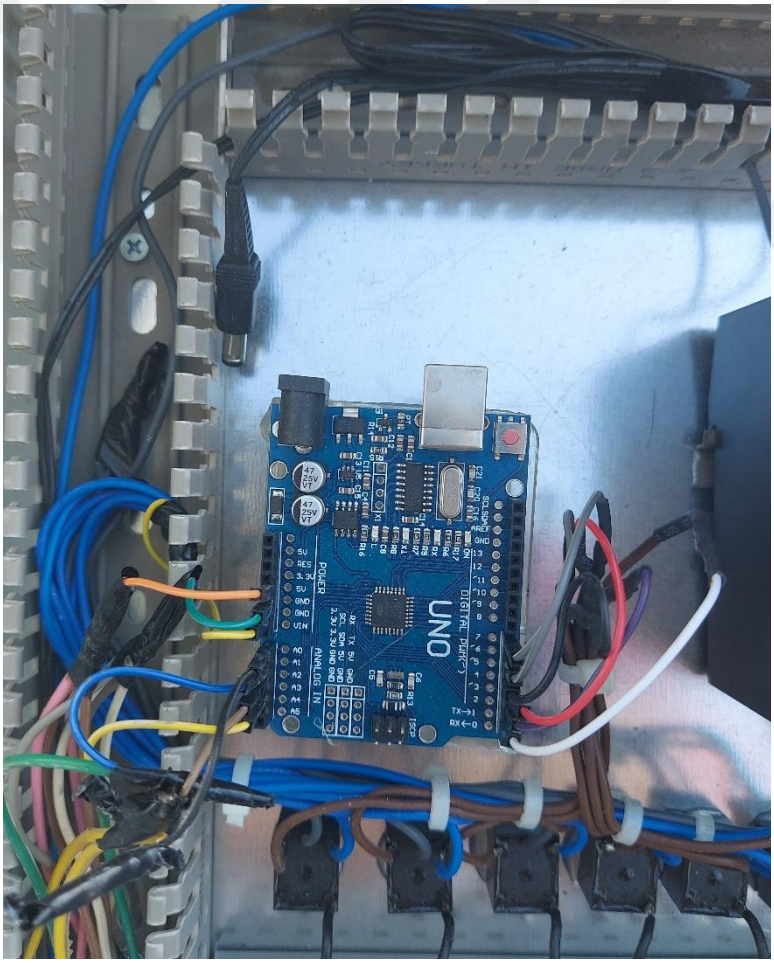

Figure 4.5. Arduino board and connection used in the system

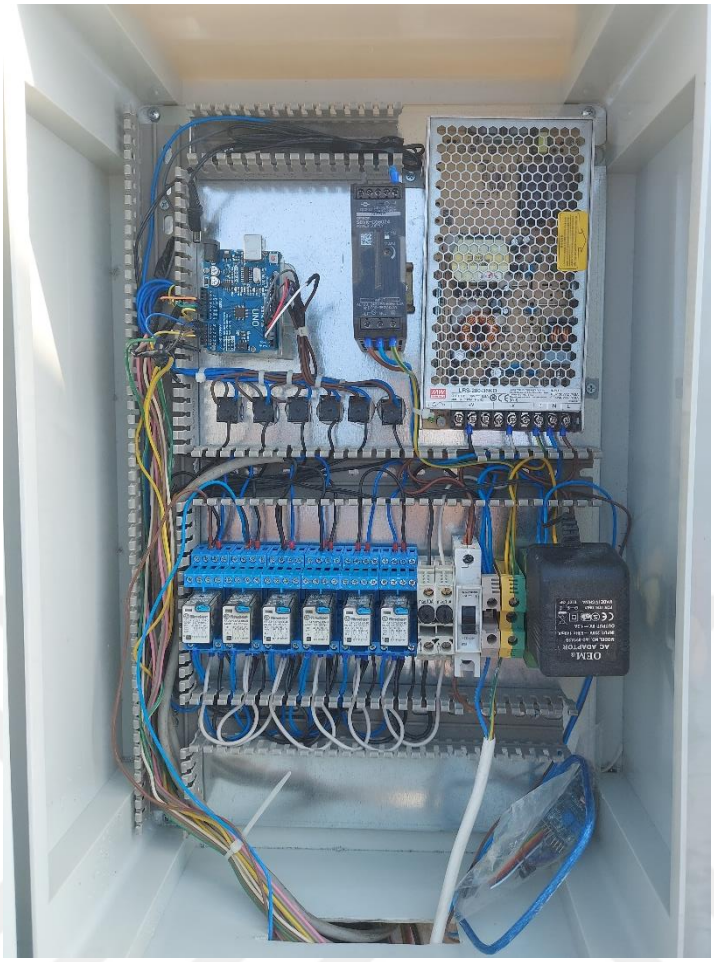

Figure 4.6. Control panel and connections of the Solar Tracker system

Figure 4.7. Datasheet of linear motor used in Solar Tracker system

Figure 4.8. Assembled linear motor used in Solar Tracker system

Figure 4.9. The assembled version of the LDR sensor used in the Solar Tracker system

Figure 4.10. Energy analyzers that record production data in each portable system

The three prepared systems were moved to their predetermined location so that they would not cast shadows on each other and fixed. For each of them, the cables of the panels were connected and assembled. The energy cables of the panels were first connected to the solar charger, from the solar charger to the solar inverter and from the inverter to the consumption point. A connection was made to the energy analyzer with the help of current transformers from the inverter output, and thus, the production data was started to be followed with the help of the analyzer. The LDR sensors used for the two systems with the mobile system were connected to the digital inputs of the Arduino UNO card. Thus, the LDR sensor transferred the data it received from the movement of the sun to the Arduino. Thanks to this data, Arduino enabled the panel to follow the sun by changing the direction by giving output to linear motors. Calculations of LDR sensor data coming through Arduino IDE software were made and outputs

were adjusted to ensure correct movement. Since the Arduino UNO board can give 5 volts as an output, 5 volt relays are used to supply 36 volts to the motors through the power supply. The relays, which give output according to 5 volts coming from the Arduino, provide the movement by pulling a 24 volt relay through which 36 volt supply passes. In order to supply the supply voltage of the motors, a power supply with 220 volt input supply and 36 volt output is used. Thus, as a result of the data coming from the LDR sensor, the solar tracking system was operated by running linear motors thanks to the Arduino software written specifically for this system.

The next step with the operation of the system was the monitoring of production data. Daily production data was taken from each analyzer in the three systems shown in Figure 4.11 at the same time each day, and these data were recorded. The recorded records were then used to compare the efficiency of the three systems.

4.4. Comparison of Production Data of Three Different Portable Solar Systems Installed

The production data of the three solar systems installed were recorded for 15 days. The recordings were taken daily and simultaneously at the same time each day. The data related to the records received are shown in the tables below.

Table 4.10. Production data of three portable systems installed

400 W PHOTOVOLTAIC SOLAR PANEL SYSTEMS					
Date	**Fixed System(Watt)**	**Single Axis System(Watt)**	**Double Axis System(Watt)**	**Single %**	**Double %**
10.09.2021	1503,47	1867,67	1976,60	**24,224**	**31,469**
11.09.2021	1476,65	1839,23	1955,17	**24,554**	**32,406**
12.09.2021	1482,64	1842,79	1953,76	**24,291**	**31,776**
13.09.2021	1515,77	1872,29	1992,76	**23,521**	**31,468**
14.09.2021	1421,13	1759,55	1866,50	**23,813**	**31,339**
15.09.2021	1748,26	2185,26	2321,37	**24,996**	**32,782**
16.09.2021	1942,27	2421,56	2567,29	**24,677**	**32,180**
17.09.2021	2073,18	2591,59	2751,05	**25,006**	**32,697**
18.09.2021	2062,14	2580,07	2747,17	**25,116**	**33,219**

Date	Fixed System(Watt)	Single Axis System(Watt)	Double Axis System(Watt)	Single %	Double %
19.09.2021	1948,26	2428,53	2587,35	**24,651**	**32,803**
20.09.2021	1915,45	2403,95	2562,54	**25,503**	**33,783**
21.09.2021	1864,35	2308,42	2453,48	**23,819**	**31,600**
22.09.2021	1218,29	1500,79	1601,60	**23,188**	**31,463**
23.09.2021	1472,87	1819,91	1941,89	**23,562**	**31,844**
24.09.2021	2144,16	2674,28	2849,08	**24,724**	**32,876**
TOPLAM	**25788,89**	**32095,89**	**34127,61**	**24,376**	**32,247**

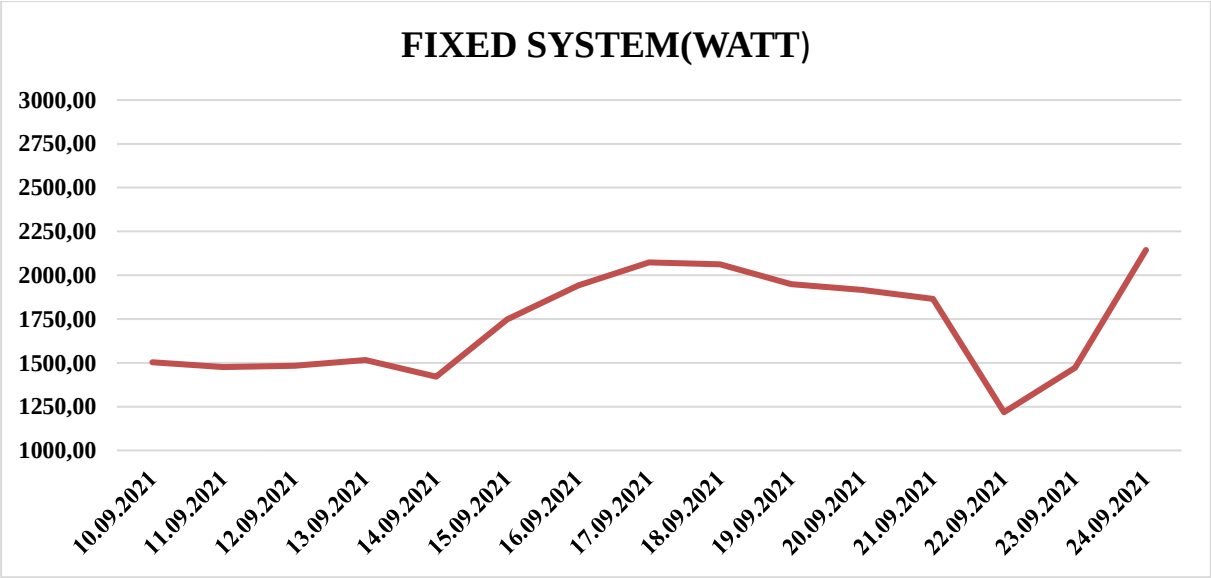

Figure 4.11. 15-day production data graph of the fixed system

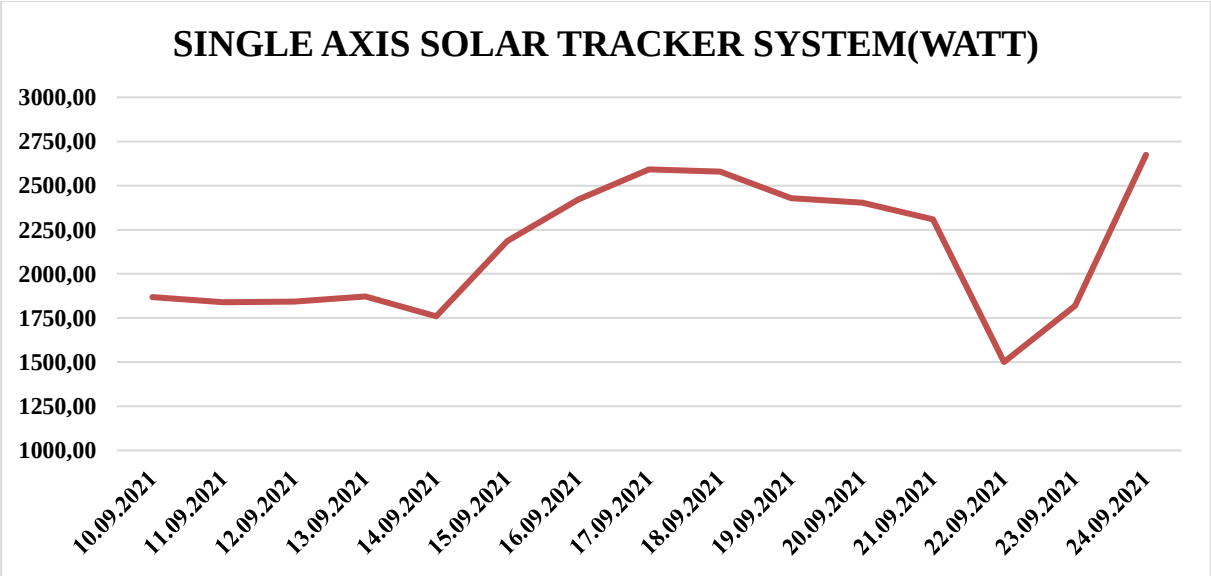

Figure 4.12. 15-day production data graph of the single axis solar tracker system

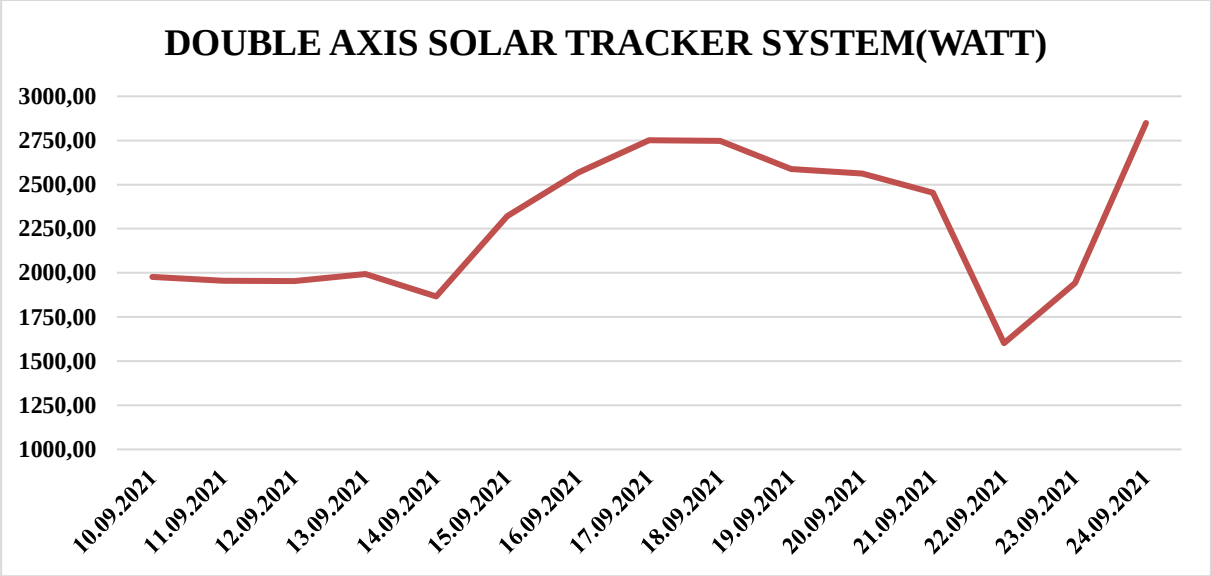

Figure 4.13. 15-day production data graph of the double axis solar tracker system

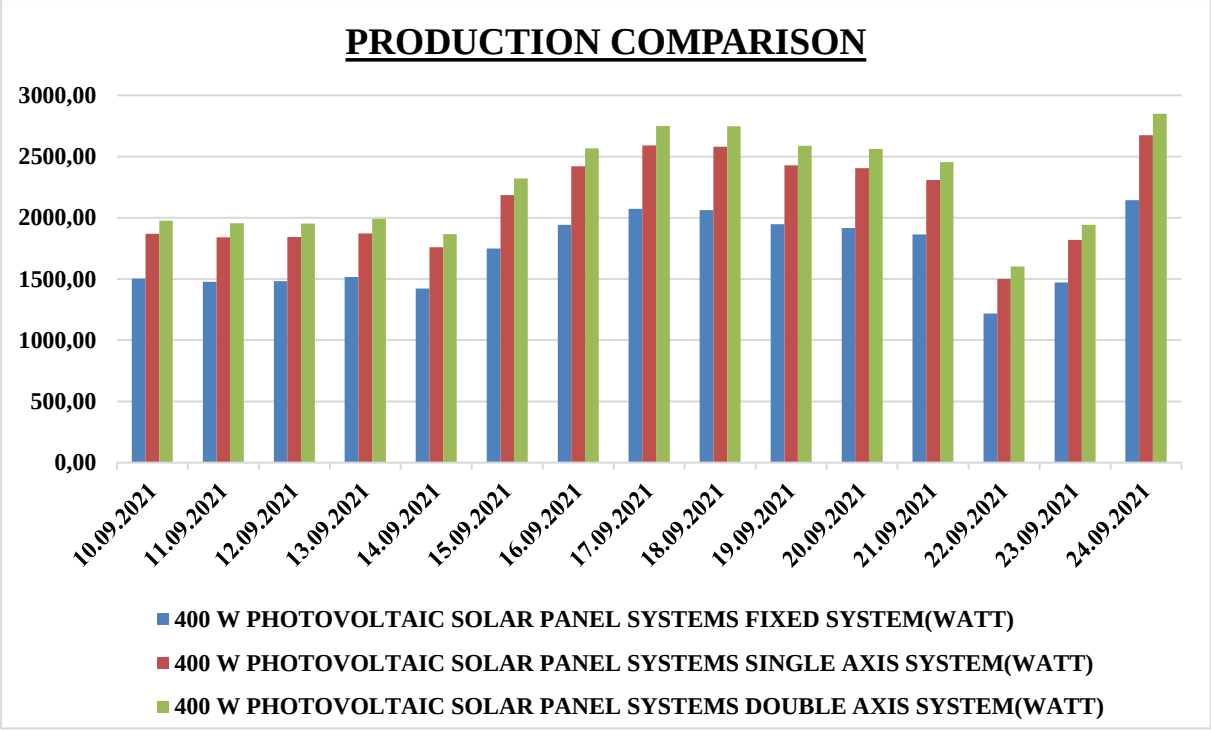

Figure 4.14. 15-day production comparison chart of the three systems

5. CONCLUSIONS

In order to meet the energy consumption needs of human beings, which are increasing day by day, there are serious increases in energy production. As a result of these increases, fossil fuels, which are the most used source to produce energy, leave damage that will be difficult to return to the environment and humanity. In addition, fossil fuels, which are non-renewable energy sources, have come to the point of exhaustion due to this production rate. Recognizing all these, human beings have started studies to use renewable energy sources in order to meet this energy need. As a result of these studies, electrical energy production has started worldwide, especially by using solar energy and wind energy. Considering the depletion rate of fossil fuels, the demand for renewable energy sources is increasing day by day. In particular, there has been a great interest in solar energy. A lot of solar power plants have been installed all over the world due to their environmental friendliness and low installation costs compared to other systems. Solar power plants, which have lower operating and maintenance costs compared to other power plants, have started to attract great attention. With the developing technology, the new type of solar panels have more energy production power and the dimensions are more ergonomic, which has increased this interest even more. Today, solar energy has an important place among renewable energy sources in the world due to its high energy potential. For this reason, the share of solar energy in electricity production is gradually increasing. Obtaining maximum efficiency from fixed-angle solar PV panels is difficult as they cannot make efficient use of solar radiation. Some studies have been initiated in order to generate more energy from the established solar power plants. Solar tracker systems are at the forefront of these studies. Thanks to this system, which enables more electricity to be produced by following the sun all day long, the more instantaneous power is produced from the same installed power plant. Developing technology has enabled more efficient work in energy production.

In this thesis, the solar tracker systems developed to keep the electrical energy produced from the solar energy panels at the maximum level are compared. Three different systems have been established. These are the first installed systems, the fixed solar system, the second one is the single-axis solar tracker system moving in the east and west directions, and the third is the dual-axis solar tracker system that moves in the east, west, north and south directions. These systems are placed in the same location with panels of the same conditions and features. Production data

were taken from these panels for 15 days and compared. Thus, some results emerged from the comparison of the obtained data. The results of these studies are presented below;

- When the energy production of the installed systems is compared, it is seen that the solar tracker system is more efficient than the fixed systems.

- Ratios to fixed systems are seen that the single-axis solar tracker system produces 24.367% more electricity, while the dual-axis solar tracker system produces 32.247% more electricity.

- When solar tracker systems are compared among themselves, it is seen that the dual-axis system produces 7,871% more electricity than the single-axis system.

- It has been observed that the installation and operation of the solar tracker system do not bring much additional load compared to normal fixed systems.

- Sun tracking was carried out thanks to the Arduino software and card, and it was verified with the production results that the sun was tracked correctly.

- As a result of this study, the increase in the amount of energy to be produced from solar energy, thanks to the solar tracking device, will increase the interest in solar energy and provide ease of investment. Thus, the number of solar power plants will increase. In this case, it will reduce the use of fossil fuels and therefore the damage to the environment will decrease.

6. RECOMMENDATIONS

Considering the results obtained by comparing the production data of the designed portables, it is seen that solar tracker systems produce 25-35% more than fixed systems. In line with the results, this study suggests that it will inspire the new solar power plants to be established and that they should make system designs and feasibility studies by considering solar tracker systems. Thus, increasing production by making more use of the sun, which is one of the renewable energy sources, will contribute to both the return on investment and the overproduction of energy. It is recommended that a detailed feasibility study be made in the regions where the power plants will be installed, and a decision should be made during the choice of single-axis and dual-axis systems.

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