T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

DYNAMIC OPTIMIZATION OF SOLAR PANEL SYSTEM AND ITS DEMANDED SIDE MANAGEMENT

MASTER'S THESIS

Khodr HAJ ALI

Department of Mechanical Engineering

FEBRUARY, 2024

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Department of Mechanical Engineering

Thesis Advisor: Prof. Dr. Hasan Alpay HEPERKAN

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APPROVAL PAGE

DECLARATION

I hereby declare with the respect that the study " Dynamic optimiztation of Solar Panel System and it Demnaded Side Mangement ", which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References. (13/2/2024)

Khodr HAJ ALI

FOREWORD

Initially, I wish to extend my boundless gratitude to the divine for shaping me into the individual I am today and for bestowing upon me the perseverance and inner fortitude needed to complete this thesis. My heartfelt appreciation extends to my family, whose encouragement to pursue a master's degree overseas has been matched by their teachings to relentlessly pursue aspirations and persist in the face of challenges.

I consider myself exceptionally fortunate to have been under the guidance of Prof. Dr. HASAN HEPERKEN as my supervisor. I am deeply grateful for his patient and effective mentorship throughout the entirety of the research journey. Moreover, Dr. KENAN KAYA not only exudes professionalism in his field but also embodies a compassionate spirit that continues to uplift and motivate me.

Lastly, I must acknowledge the pivotal role that Istanbul Aydin University has played in my life. The impact is not limited to the academic realm; the institution has introduced me to remarkable individuals who consistently inspire, challenge, and provide unwavering support, thus keeping my motivation alive.

February, 2024 Khodr HAJ ALI

DYNAMIC OPTIMIZTATION OF SOLAR PANEL SYSTEM AND ITS DEMANDED SIDE MANGEMENT

ABSTRACT

Turkey has increasingly turned its attention towards solar renewable energy as a pivotal component of its sustainable future. The country's abundant sunlight resources and growing energy demands have paved the way for significant investments in solar power projects. With a strategic focus on reducing dependence on fossil fuels, promoting environmental well-being, and achieving energy security, Turkey's solar renewable energy sector is rapidly evolving. This shift not only aligns with global clean energy goals but also contributes to Turkey's economic growth while mitigating the environmental impact of traditional energy sources.

The adoption of solar panel systems is gaining momentum worldwide due to their remarkable significance in sustainable energy solutions. Integrating solar panel systems holds the potential to greatly reduce reliance on fossil fuels, curb greenhouse gas emissions, and pave the way for a greener future. By harnessing the abundant and renewable energy of the sun, these systems contribute to energy independence, cost savings, and environmental preservation.

Beyond the immediate economic benefits, embracing solar panel systems showcases a commitment to responsible energy consumption and addresses the pressing global challenge of climate change. As individuals, businesses, and communities seek to embrace cleaner and more efficient energy alternatives, the application of solar panel systems emerges as a pivotal step towards creating a cleaner and more resilient energy future.

The primary goal of this study was to enhance the efficient utilization of solar radiation captured by the solar panels integrated into Istanbul Aydin University's solar energy framework. The research aimed to determine the most advantageous tilt angle for these panels, accounting for different time periods such as hourly, seasonal, and semi-annual performance intervals. To achieve this, the study utilized the Photovoltaic Geographical Information System (PVGIS) to evaluate solar radiation exposure and implemented PVGIS methodology to identify the optimal angles at which the panels should be inclined.

This project further expands on these efforts by focusing on the dynamic optimization of solar panel systems. By analyzing the performance of a movable solar panel, oriented towards six horizontal directions and moving between five pre-defined angles, the project aims to understand the optimal directions and angles for solar energy absorption throughout each hour. The steps involve panel movement, data collection, comparison with current solar panels that is already been implemented in Isantbul Aydin University, and results analysis, contributing valuable insights to harness solar energy more effectively.

Keywords: Solar Panel System, Optimum Tilt Angle, Solar Radiation, PVGIS, Dynamic optimization

GÜNEŞ PANELİ SİSTEMİNİN DİNAMİK OPTİMİZASYONU VE TALEP YÖNETİMİ

ÖZET

Türkiye, sürdürülebilir geleceğinin önemli bir bileşeni olarak dikkatini giderek yenilenebilir güneş enerjisine çeviriyor. Ülkenin güneş ışığı kaynaklarının bol olması ve artan enerji talebi, güneş enerjisi projelerine önemli yatırımların yapılmasının önünü açmıştır. Fosil yakıtlara bağımlılığın azaltılması, çevre refahının desteklenmesi ve enerji güvenliğinin sağlanmasına stratejik olarak odaklanan Türkiye'nin yenilenebilir güneş enerjisi sektörü hızla gelişiyor. Bu değişim, yalnızca küresel temiz enerji hedefleriyle uyumlu olmakla kalmıyor, aynı zamanda geleneksel enerji kaynaklarının çevresel etkilerini azaltarak Türkiye'nin ekonomik büyümesine de katkıda bulunuyor.

Sürdürülebilir enerji çözümlerindeki dikkate değer önemi nedeniyle güneş paneli sistemlerinin benimsenmesi dünya çapında ivme kazanıyor. Güneş paneli sistemlerinin entegre edilmesi, fosil yakıtlara olan bağımlılığı büyük ölçüde azaltma, sera gazı emisyonlarını azaltma ve daha yeşil bir geleceğin yolunu açma potansiyelini taşıyor. Güneşin bol ve yenilenebilir enerjisinden yararlanan bu sistemler, enerji bağımsızlığına, maliyet tasarrufuna ve çevrenin korunmasına katkıda bulunur.

Doğrudan sağlanan ekonomik faydaların ötesinde, güneş paneli sistemlerini benimsemek, sorumlu enerji tüketimine olan bağlılığı gösterir ve iklim değişikliğinin acil küresel sorununa çözüm getirir. Bireyler, işletmeler ve topluluklar daha temiz ve daha verimli enerji alternatiflerini benimsemeye çalışırken, güneş paneli sistemlerinin uygulanması daha temiz ve daha dayanıklı bir enerji geleceği yaratmaya yönelik önemli bir adım olarak ortaya çıkıyor.

Bu çalışmanın temel amacı, İstanbul Aydın Üniversitesi'nin güneş enerjisi çerçevesine entegre edilen güneş panelleri tarafından yakalanan güneş ışınımının verimli kullanımını arttırmaktır. Araştırmada saatlik, mevsimsel ve altı aylık performans aralıkları gibi farklı zaman dilimleri dikkate alınarak bu paneller için en avantajlı eğim açısının belirlenmesi amaçlandı. Bunu başarmak için çalışmada, güneş radyasyonuna maruz kalma durumunu değerlendirmek üzere Fotovoltaik Coğrafi Bilgi Sistemi (PVGIS) kullanılmış ve panellerin eğilmesi gereken en uygun açıları belirlemek için PVGIS metodolojisi uygulanmıştır.

Bu proje, güneş paneli sistemlerinin dinamik optimizasyonuna odaklanarak bu çabaları daha da genişletiyor. Proje, altı yatay yöne yönlendirilmiş ve önceden tanımlanmış beş açı arasında hareket eden hareketli bir güneş panelinin performansını analiz ederek, her saat boyunca güneş enerjisi emilimi için en uygun yönleri ve açıları anlamayı amaçlamaktadır. Adımlar panel hareketini, veri toplamayı, İsantbul Aydın Üniversitesi'nde hâlihazırda uygulanmakta olan mevcut güneş panelleriyle karşılaştırmayı ve sonuç analizini içerir ve güneş enerjisinden daha etkili bir şekilde faydalanmak için değerli bilgiler sağlar.

Anahtar Kelimeler: Güneş Paneli Sistemi, Optimum Eğim Açısı, Güneş Radyasyonu, PVGIS, Dinamik optimizasyon

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LIST OF ABBREVIATIONS

PV	: Photo -Voltic
IAU	: Istanbul Aydin University
PVGIS	: Photovoltic Gergraphical Information System
LDR	: Liquid Dependent Sensor
RTC	: Real Time Clock

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I. INTRODUCTION

A. General Introduction

In the realm of sustainable energy solutions, solar panels have emerged as a beacon of innovation and environmental responsibility. As the global focus shifts towards cleaner energy alternatives, Turkey has not remained untouched by this transformative trend. The adoption of solar panel systems has gained significant traction in the country, driven by both environmental concerns and the pursuit of energy self-sufficiency. This report delves into the realm of solar panel systems in Turkey, with a special focus on their installation and utilization within the premises of Istanbul Aydin University.

B. Importance of Solar Panel Systems

Solar panel systems stand as a cornerstone of sustainable energy practices, presenting a compelling solution to the escalating challenges of climate change and energy security. As traditional energy sources continue to exert a toll on the environment and deplete finite resources, solar panels offer a way forward. Their installation has the power to significantly reduce dependence on fossil fuels, mitigate greenhouse gas emissions, and create a cleaner energy landscape. In Turkey, where the abundant sunlight resources align harmoniously with the goal of energy diversification, solar panel systems play a pivotal role in fostering both environmental well-being and energy independence.

C. Benefits of Solar Panel Systems

The Benefits of solar panel systems are multifaceted. Beyond their contributions to reducing carbon footprints and promoting a greener planet, these systems offer considerable economic benefits. They provide a reliable and renewable source of energy, thereby reducing electricity bills and generating potential revenue through excess energy production that can be fed back into the grid. Furthermore, solar panels necessitate minimal maintenance, have a long lifespan, and contribute to energy stability by reducing strain on conventional power infrastructure during peak demand periods.

D. Study on Solar Panel System in Istanbul Aydin University

This thesis report centres on a comprehensive study conducted at Istanbul Aydin University, where solar panel systems have been harnessed to tap into the potent solar radiation available. The focal point of the investigation was to optimize the performance of these solar panels through an exploration of the ideal tilt angle. The study encompassed various temporal dimensions, ranging from hourly to seasonal and semi-annual performance cycles. The methodology employed the Photovoltaic Geographical Information System (PVGIS) as a robust tool to evaluate solar radiation levels across different timeframes. By adopting the PVGIS approach, the study aimed to precisely determine the optimal tilt angles for the solar panels installed within the confines of Istanbul Aydin University.

In essence, this report encapsulates the journey of leveraging solar energy through panel systems in Turkey, with a spotlight on Istanbul Aydin University as a case study. It underscores the significance of solar panels in the country's energy landscape, elucidates their advantages, and delves into the intricate investigation that seeks to unlock the utmost potential of solar panel systems. As shown in figure 1, where the research will be done on those thirty solar panels.

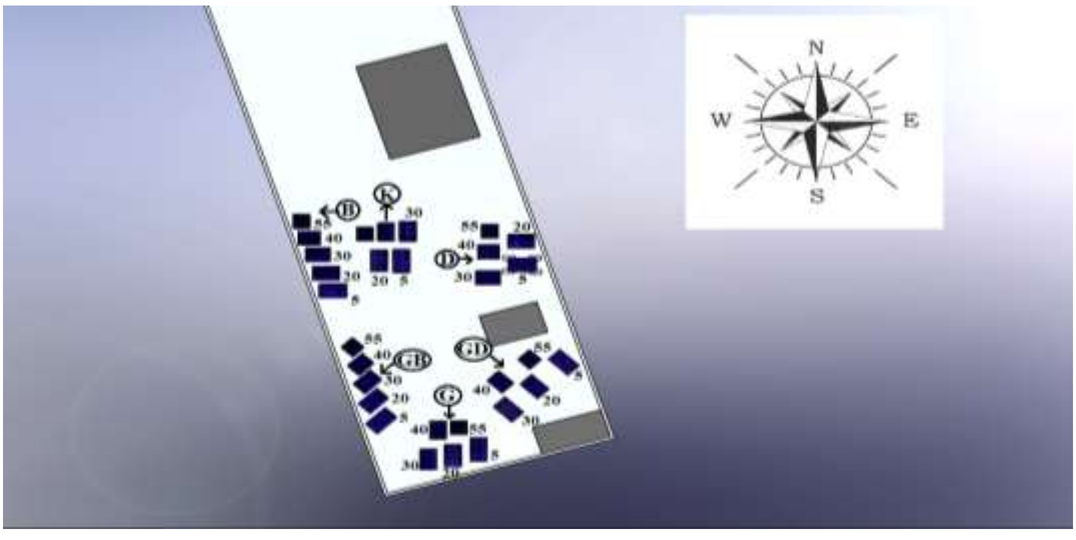

Figure 1 Shows the thirty different solar panel that has different angels and orientation in Istanbul Aydin University.

E. Introduction to PVGIS

PVGIS is a web site that gives you information about solar radiation and Photovoltaic (PV) system performance. You can use PVGIS to calculate how much energy you can get from different kinds of PV systems at nearly any place in the world.

Since 2001, the European Commission Joint Research Centre has been diligently developing PVGIS at its site in Ispra, Italy. PVGIS is a research initiative focused on the assessment of solar resources, studies on photovoltaic (PV) performance, and the widespread dissemination of insights and data concerning solar radiation and PV efficiency. While the online PVGIS web application is the most recognizable facet of our efforts, a substantial body of research underpins its precision and accuracy.

As shown in figure 2 and over the years, the PVGIS web application has evolved through multiple iterations, culminating in its current rendition, PVGIS 5. With each successive version, the system's capabilities have grown, and the geographical coverage of our data has expanded, aligning with our commitment to enhance accuracy and broaden the scope of our offerings.

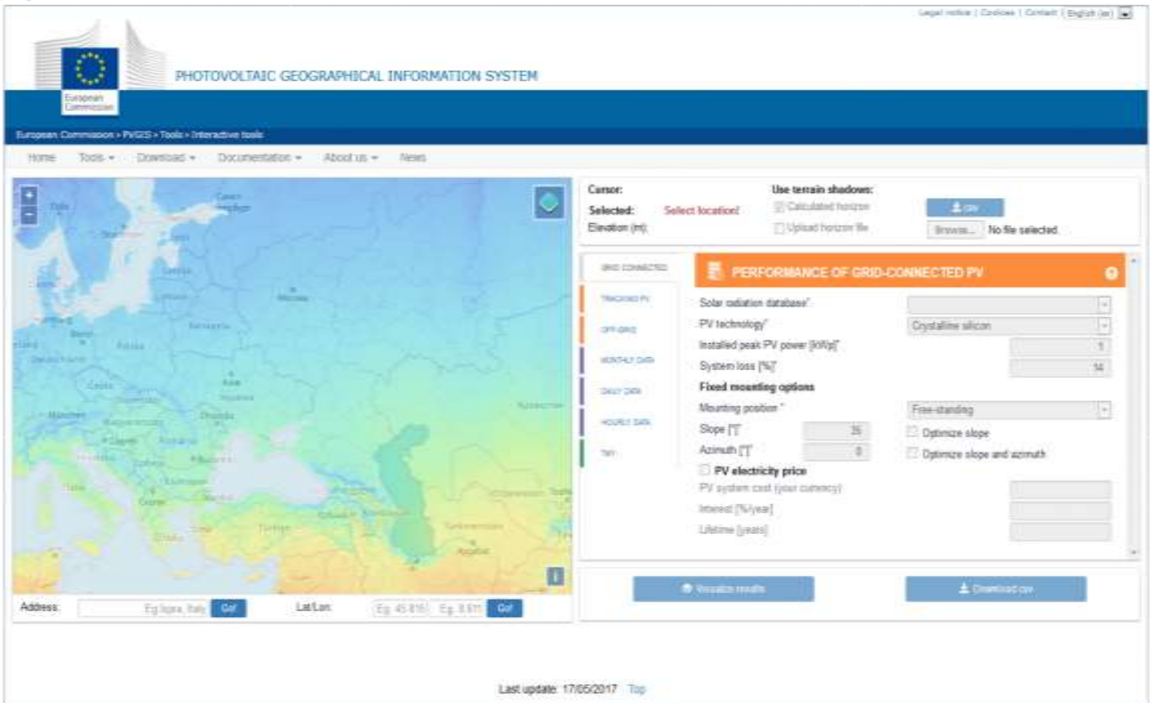

Figure 1 Shows the PVGIS web interface.

II. LITERATURE REVIEW

A. History of Solar Panel System

The history of solar panel systems traces back to the mid-19th century when the principle of converting sunlight into electricity was first recognized. In 1839, French physicist Alexandre Edmond Becquerel discovered the photovoltaic effect, demonstrating that certain materials generate an electric current when exposed to sunlight. However, it wasn't until the 1950s that practical advancements began to take shape.

In 1954, Bell Laboratories engineers Calvin Fuller, Daryl Chapin, and Gerald Pearson created the first functional silicon solar cell, marking a significant milestone in solar technology. This breakthrough achieved a solar conversion efficiency of around 6%, setting the stage for further developments.

During the following decades, solar panel systems experienced gradual improvements, finding applications primarily in space missions and remote locations. The 1970s saw the emergence of terrestrial applications, driven by the oil crisis and growing environmental concerns. Governments and research institutions started investing in solar technology, resulting in incremental efficiency gains and cost reductions.

The late 20th century witnessed a surge in photovoltaic research, leading to innovations like thin-film solar cells and amorphous silicon panels. As economies of scale improved, solar panel systems became more accessible for residential and commercial use. Subsidies and incentives introduced by governments in various countries further accelerated their adoption.

The 21st century has witnessed a remarkable transformation in solar energy. Advancements in materials, manufacturing techniques, and cell design have significantly increased efficiency and lowered costs. This progress, coupled with heightened awareness of climate change and the need for sustainable energy, has led to a global solar boom. Solar panel systems have become a mainstream energy source, integrated into power grids and making remarkable strides towards achieving grid parity with conventional energy sources.

In summary, the history of solar panel systems spans over a century, evolving from scientific discoveries to practical applications, and eventually becoming a pivotal player in the global energy landscape. The journey continues as researchers and engineers strive to make solar technology even more efficient, affordable, and integral to our sustainable future.

B. History of Solar Panel System in Turkey

The history of solar panel systems in Turkey reflects the country's journey towards embracing renewable energy solutions. While the adoption of solar technology in Turkey began relatively modestly, it has gained momentum in recent years due to increasing environmental awareness and efforts to diversify the energy mix.

Solar energy initiatives in Turkey can be traced back to the 2000s when the government introduced incentives and regulations to promote renewable energy sources. The Renewable Energy Law of 2005 marked a significant milestone, encouraging private investment in solar projects through feed-in tariffs and guaranteed purchase agreements. This legal framework laid the groundwork for the expansion of solar energy projects across the country.

In the subsequent years, Turkey witnessed a growing interest in solar panel systems, particularly in the commercial and industrial sectors. The gradual reduction in solar technology costs, coupled with the increasing electricity demand, further fueled the uptake of solar power solutions. The government's commitment to achieving its renewable energy targets added impetus to this transition.

By the 2010s, Turkey had made substantial strides in solar energy deployment. Large-scale solar power plants began to emerge, contributing significantly to the national energy capacity. The country's geographical advantage of abundant sunlight resources played a crucial role in driving solar projects in various regions.

Government initiatives, such as the Solar Energy Roadmap 2023, underscored Turkey's commitment to achieving its renewable energy goals. The roadmap aimed to increase solar capacity and enhance domestic production of solar components.

Auctions and tenders for renewable energy projects further facilitated the growth of solar energy installations.

The years leading up to the present day have witnessed substantial growth in Turkey's solar energy sector. Solar panel systems have become increasingly commonplace in residential, commercial, and industrial settings. The cumulative solar capacity has experienced substantial growth, contributing to the country's efforts to diversify its energy sources and reduce dependence on fossil fuels.

In summary, the history of solar panel systems in Turkey reflects a journey of gradual adoption, spurred by government policies, environmental concerns, and the economic viability of solar technology. As Turkey continues to prioritize sustainable energy, the solar sector is expected to play an increasingly significant role in the nation's energy landscape.

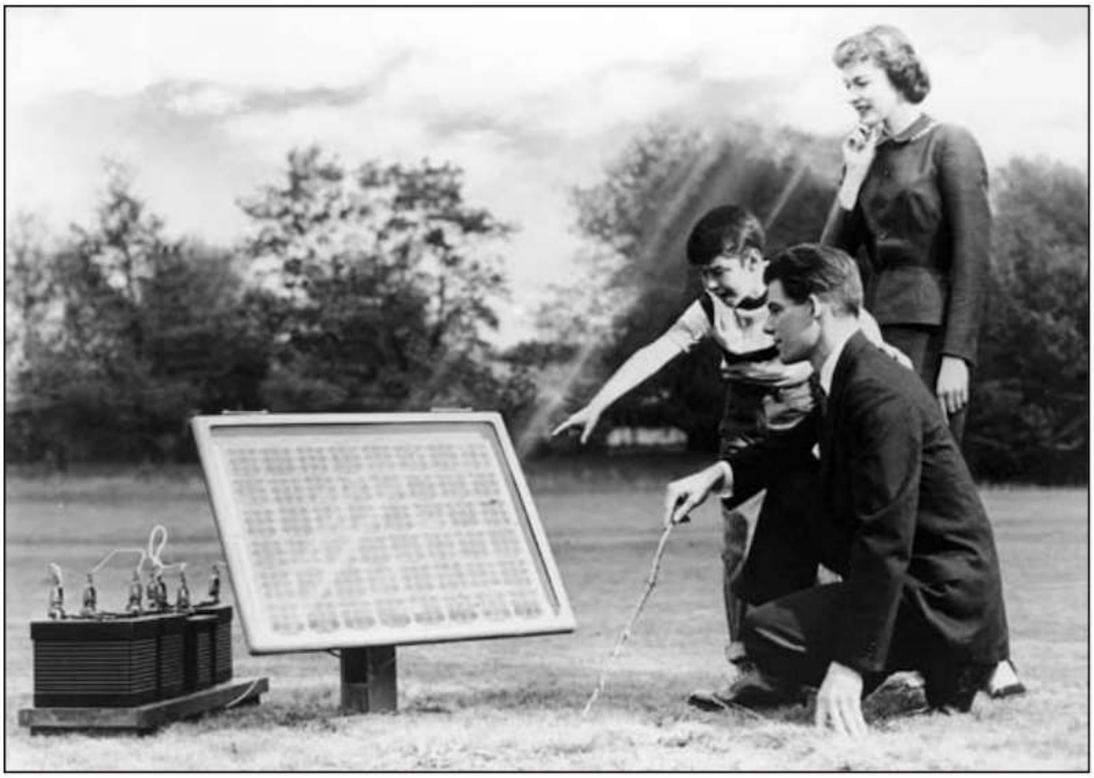

Figure 3 Shows an advertisement photo that appeared in the 1956 issue of Look Magazine, show off the “Bell Solar Battery”.

C. Photovoltaic Geographical Information System (PVGIS)

Researchers employ a variety of techniques to estimate and utilize specialized software for simulation to determine the most advantageous orientation for solar panels. This systematic strategy seeks to maximize the utilization of solar radiation.

This method greatly simplifies the process of performing realistic and applicable analyses. In the scope of the current project, the calculation approach is founded on the incorporation of the PVGIS method.

PVGIS, recognized as the Photovoltaic Geographical Information System, serves as a web-centric application developed by the Institute for Energy and Transport (IET) operating under the Joint Research Center (JRC). Its central purpose revolves around equipping users with the capability to anticipate the electrical output achievable from any photovoltaic (PV) system. The crux of determining PV system performance lies in possessing prior knowledge of the comprehensive solar energy absorbed by the PV module.

D. PVGIS Methodology

This module typically assumes an inclined configuration, chosen deliberately to optimize the absorption of solar radiation. This optimization can be achieved through a stationary incline or a mechanism that tracks the sun's movement. Regardless of the chosen arrangement, it demands accurate information concerning the holistic solar radiation that reaches the PV plane. Unfortunately, this specific data is rarely available through direct measurement, necessitating the reliance on estimations. Within the realm of scientific literature, an array of models exists to approximate the global solar radiation on titled surfaces, termed as G_T.

These models leverage input data encompassing the total solar radiation on the horizontal plane (G), in conjunction with its beam (G_b) and diffuse (G_d) components.

$$G_T = G_{bT} + G_{dT} + G_{rT} \tag{1}$$

As illustrated in Equation 1 provided above:

- The cumulative solar radiation on an inclined plane is denoted as G_T.
- It encompasses the combined values of beam irradiance known as G_{bT}.
- Diffuse irradiance is represented by G_{dT}.
- Additionally, there's a contribution stemming from ground reflections, denoted as G_{rT}.

Considering that the beam component emanates directly from the solar disk, once the value of beam irradiance on the horizontal plane (G_b) is determined, the computation of beam irradiance reaching an inclined surface is contingent on a geometric relationship. This relationship is intricately linked to variables such as the tilt and orientation angles of the surface, alongside the coordinates of the sun, as elucidated in Equation 2.

$$G_{bT} = G_b \frac{cos\xi}{cos\sigma_z} \tag{2}$$

The magnitude of G_{bT}, as demonstrated in Equation 2, is susceptible to alteration contingent upon the sun's location, the incline angle of the surface, and its azimuthal orientation. Within Equation 2:

- G_b signifies the direct solar radiation received on the horizontal plane [W/m²],
- ξ symbolizes the angle at which the direct radiation impinges upon the surface [°],
- Consequently, σz indicates the zenith angle [°].

$$G_{rt} = G \frac{(1-cos\beta)}{2} \tag{3}$$

Considering these factors and careful deliberations, the solar radiation that is reflected, known as G_{rT}, is assumed to spread evenly in all directions, a property described as "isotropic." The calculation of G_{rT} is conducted using Equation 3, where the ρ symbolizes the ground's albedo. Furthermore, the angle β signifies the surface's inclination with respect to the horizontal plane.

Diffuse irradiance arises as a result of solar radiation scattering through elements in the atmosphere, leading to an uneven distribution across the celestial dome. Nevertheless, some models simplify this by assuming uniformity and isotropy, disregarding the nuanced impacts of cloud cover and atmospheric scattering.

Although cloud effects are commonly disregarded, alternative models strive to represent scattering outcomes by supplementing the isotropic background with diffuse irradiance originating from both the surrounding solar region and the band along the horizon.

As a result, models tailored for estimating GT can be categorized into two primary groups: those assuming isotropy and those with anisotropic characteristics. Within the latter category, models can be further classified based on whether they encompass both the surrounding solar region and the horizon band or exclusively focus on irradiance from the surrounding solar region. Moving forward, anisotropic models will be grouped based on their utilization of either three or two distinct "components" related to diffuse irradiance.

Within PVGIS, Equation 4 becomes relevant when addressing situations involving shading or cloudiness, whereas Equation 5 assumes significance during periods of sunlight under clear sky conditions.

$$G_{dT} = G_d.\left[\left(\frac{1+cos\beta}{2}\right) + 0{,}25227.\left(sin\beta - \beta.cos\beta - \pi.\left(sin\frac{\beta}{2}\right)^2\right)\right] \tag{4}$$

$$G_{dT} = G_d.\left[\left(\left(\frac{1+cos\beta}{2}\right) + \left(sin\beta - \beta.cos\beta - \pi.\left(sin\frac{\beta}{2}\right)^2\right).\left(0{,}00263 - 0{,}712.\frac{G_b}{G_0} - 0{,}6883.\left(\frac{G_b}{G_0}\right)^2\right)\right).\left(1 - \frac{G_b}{G_0}\right) + \left(\frac{G_b}{G_0}.\frac{cos\xi}{cos\sigma_z}\right)\right] \tag{5}$$

- G_d signifies the horizontal plane's receipt of diffuse solar radiation [W/m²], whereas G_o stands for the complete solar radiation outside the Earth's atmosphere [W/m²].
- When the sun's rise angle, represented by αs, is below 0.1 radians,
- The computation for GdT is enacted utilizing Equation 6, as detailed below.

$$G_{dT} = G_d.\left[\left(\left(\frac{1+cos\beta}{2}\right) + \left(sin\beta - \beta.cos\beta - \pi.\left(sin\frac{\beta}{2}\right)^2\right).\left(0{,}00263 - 0{,}712.\frac{G_b}{G_0} - 0{,}6883.\left(\frac{G_b}{G_0}\right)^2\right)\right).\left(1 - \frac{G_b}{G_0}\right) + \left(\frac{G_b}{G_0}.\frac{sin\beta.\cos(\gamma-\gamma_S)}{0{,}1-0{,}008.\alpha_S}\right)\right] \tag{6}$$

The methodology adopted by PVGIS entails simulating the comprehensive solar radiation on the basis of the solar panel's tilt angle and the azimuth angle γs [°]. In the context of this research, a distinct site in Istanbul, pinpointed by latitude 40.922° and longitude 28.797°, was selected as the central point of attention.

In the process of utilizing the PVGIS methodology to determine the most advantageous tilt angle, the approach involved identifying the angle that resulted in the highest average solar radiation on the solar panel, considering monthly, seasonal, and six-month periods. This angle was then designated as the optimal tilt angle for the given month, season, or half-year span. The results were organized in a tabular format and visually presented through Microsoft Excel, employing graphing features to enhance comprehension.

For instance, the PVGIS technique was applied to compute the optimal tilt angles aiming to maximize solar radiation in June, July and August within Istanbul. This methodology aids in establishing the angles that guarantee the greatest potential for energy capture.

E. PVGIS Calculation Method

The PVGIS web starts as shown in figure 2. Therefore, PVGIS offers a multitude of choices, many of which are accompanied by helpful explanations accessible by clicking on the respective option. As an example, if you click on the text "Lat/Lon" located beneath the map, a guidance text related to that specific aspect will be provided.

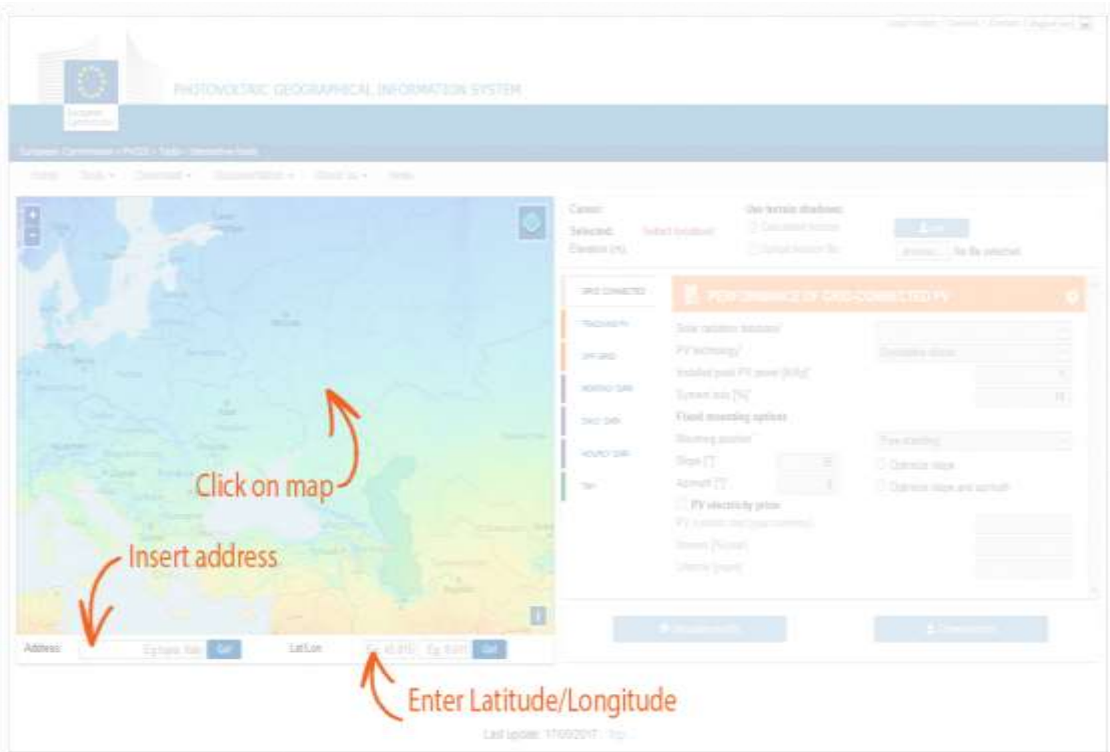

Figure 4 Shows how to insert the location on the map of the PVGIS Program.

Currently, you're unable to perform any calculations since you haven't selected the location you intend to calculate for. You have three distinct options for choosing a location:

- By clicking on the map, allowing you to zoom in and navigate as usual.
- By inputting the name of a location (such as a town or street) in the "Address" field beneath the map.
- By entering the latitude and longitude coordinates in the provided boxes below the map.

PVGIS offers a variety of calculation options for you to explore. You determine the specific type by clicking on the tabs located to the right of the map (as shown in the following figure 5). Each calculation type comes with its own guidance, accessible by clicking on the title of the corresponding calculation tab.

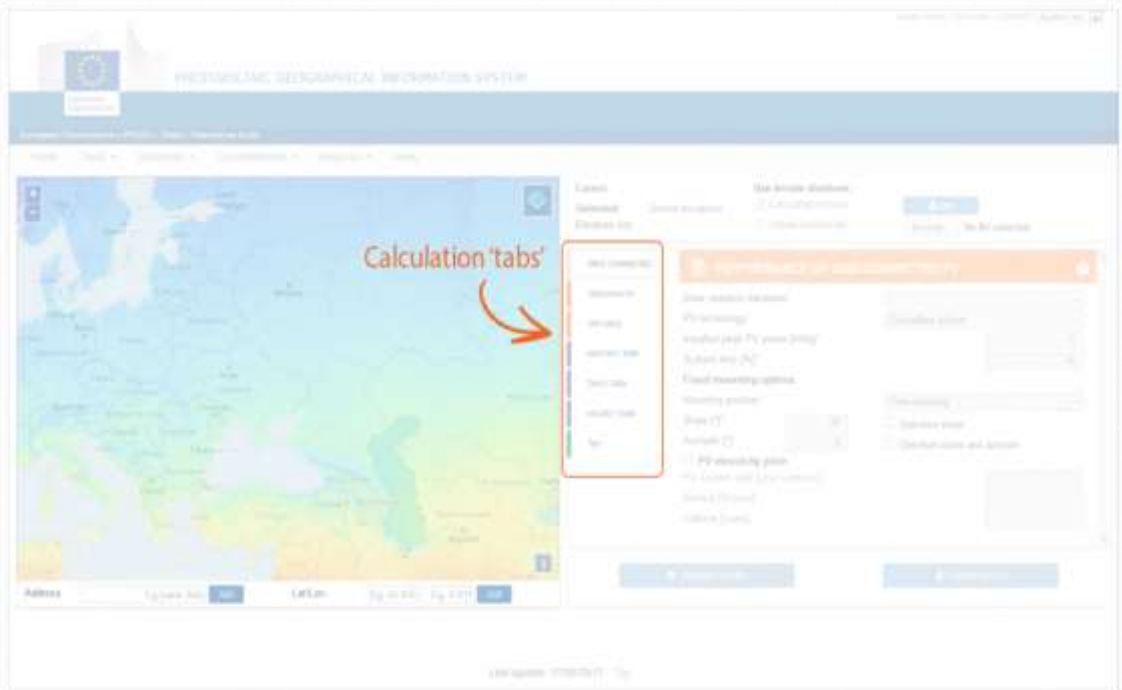

Figure 5 Shows the calculation tab in order for the PVGIS program to calculate.

Currently, PVGIS provides the capacity for various calculations, which include:

Grid-Connected PV Performance: This function enables the computation of the long-term average energy production from photovoltaic systems linked to the power grid. This applies to stationary PV setups where modules are affixed in a fixed position, whether on a standalone structure or a building.

Tracking PV Systems Performance: Here, you can evaluate the long-term average energy output of grid-connected PV systems employing sun-tracking mounts for enhanced sunlight exposure. This category allows you to select from different types of tracking mechanisms.

Off-Grid PV Systems Performance: This tool facilitates calculations for PV systems that operate independently from the electricity grid, relying on battery storage for energy.

Monthly Radiation: This tool provides monthly averages of radiation and temperature data across multiple years.

Daily Radiation: Calculate the average solar irradiance and temperature for a typical day in each month.

Hourly Radiation: This utility enables the downloading of hourly solar radiation and/or PV power time series data.

TMY (Typical Meteorological Year) Generation: This tool generates TMY data encompassing solar radiation, temperature, and other meteorological variables. TMY data is widely used across various fields, such as energy performance calculations for buildings.

For every calculation category, you need to input specific details regarding the desired computation type. Once this is completed, you have two options:

- You can view the outcomes of the calculation presented as graphs and numerical values directly on the PVGIS webpage. These results will be visible underneath the map and input sections.
- Alternatively, you can download the computed data in CSV format, suitable for utilization in spreadsheets and other software applications. The precise data formats for each calculation alternative are outlined in this context.
- To accomplish this, you simply need to click on either of the two buttons situated at the bottom of each calculation tab.

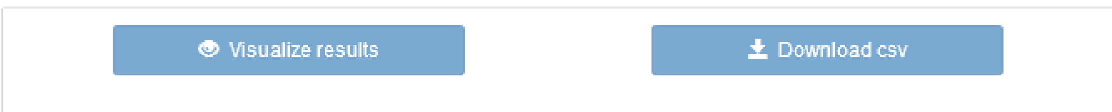

Figure 6 shows the button in order to view to download the result for in solar panel system.

III. DYNAMIC OPTIMIZTATION OF SOLAR PANEL SYSTEM AND ITS DEMANDED SIDE MANGEMENT

A. Project Detail

This project delves into the intricate study of optimal directions and angles to enhance solar energy absorption through the meticulous evaluation of a movable solar panel. Strategically oriented towards six horizontal directions (North, South, East, West, Southeast, and Southwest), the solar panel dynamically adjusts its position across five pre-defined angles (5, 20, 30, 40, 55 degrees). This report provides a comprehensive exploration of system components, their functions, and the detailed process governing the solar panel's hourly movements and performance analysis.

The objective of dynamic analysis of movable solar panel is to gain a nuanced understanding of the optimal directions and angles for efficient solar energy absorption throughout each hour. As shown in the figure below, the solar panel that have been used to analyis the six directions along with the angles.

Figure 7 Solar Panel system that have been built.

B. 3D Solidwork Project Drawing

Introducing a cutting-edge solar energy optimization project designed using SolidWorks, this initiative is meticulously crafted to address the pivotal challenge of maximizing solar panel efficiency.

The project is ingeniously divided into three integral components, each playing a crucial role in the overall functionality. First and foremost, the base serves as the robust foundation, providing stability and support to the entire structure. This foundational element is intricately designed to withstand varying environmental conditions and ensure the durability of the solar panel system.

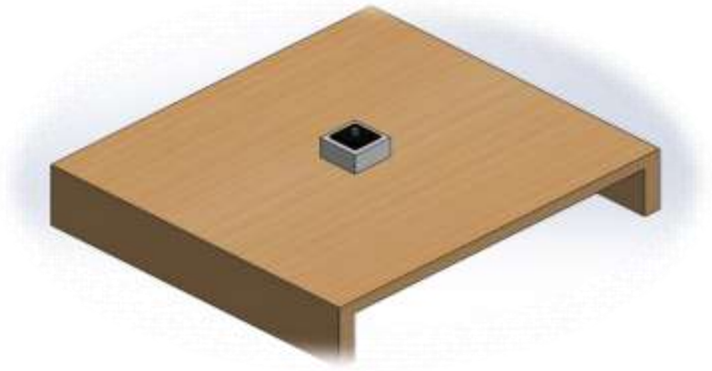

Figure 8 Solar Panel Base (Front view)

Shows the base in Front view.

Figure 9 Solar Panel Base (Top view)

Shows the base of the solar panel project in top view.

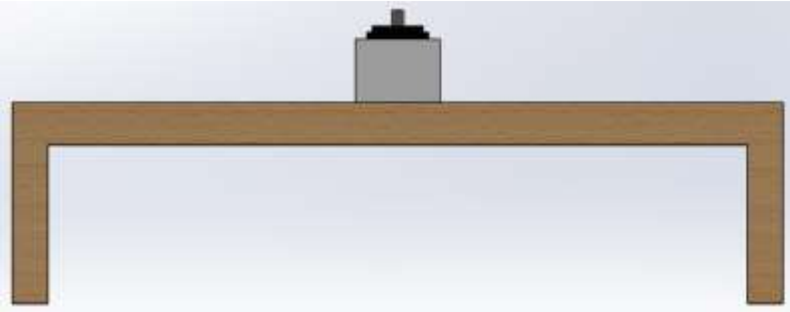

Figure 10 Solar Panel Base (Right view)

Shows the base of the solar panel project in right view.

Moving on to the second component, the solar panel holder or stand, this critical part is engineered for dynamic movement and precise orientation. Utilizing SolidWorks' advanced design capabilities, this holder allows the solar panel to pivot horizontally towards six cardinal directions (North, South, East, West, Southeast, and Southwest). Additionally, it facilitates vertical movement, enabling adjustments to five pre-defined angles (5, 20, 30, 40, and 55 degrees). The holder's design ensures optimal exposure to sunlight throughout the day, enhancing the overall performance of the solar panel system.

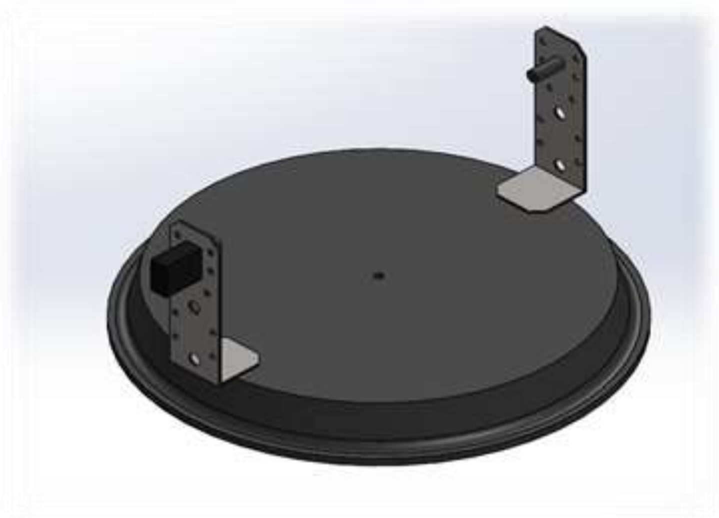

Figure 211 Solar Panel Stand/ Holder (Front view)

Shows the Solar panel holder/ stand in front view.

Figure 12 Solar Panel Stand/ Holder (Right view)

Shows the Solar panel holder/ stand in right view.

Figure 13 Solar Panel Stand/ Holder (Top view)

Shows the Solar panel holder/ stand in top view.

The third component, the solar panel itself, represents the pinnacle of innovation in harnessing solar energy. Designed with meticulous attention to detail, the solar panel integrates seamlessly with the holder, maximizing its exposure to sunlight at different orientations and angles. The use of SolidWorks allows for precision in modeling and simulation, ensuring that the solar panel functions optimally to capture and convert solar energy into usable electricity.

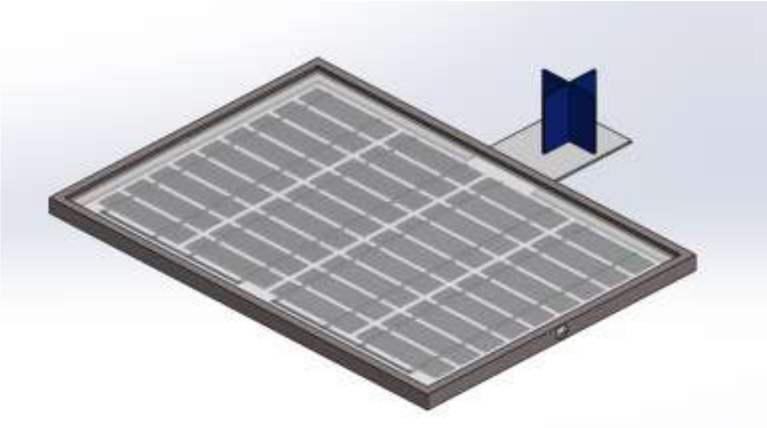

Figure 14 Solar Panel Plate (Front view)

Shows the solar panel plate that have been used in the project front view.

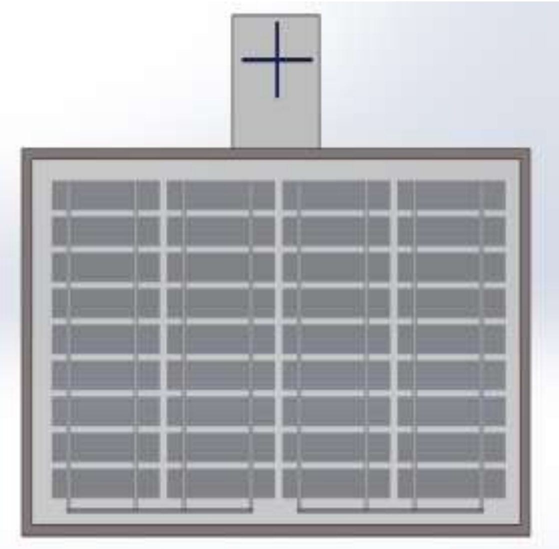

Figure 15 Solar Panel Plate (Top view)

Shows the solar panel plate in top view.

Figure 16 Solar Panel Plate (Right view)

Shows the solar panel in right view.

In figure 17 shows the assembly of all parts that are assembled together.

Furthermore, this SolidWorks-designed solar energy optimization project is a testament to technological innovation and engineering excellence. By combining a robust base, a dynamic solar panel holder, and an efficient solar panel, the project aims to revolutionize the efficiency of solar energy capture and contribute to sustainable and renewable energy practices.

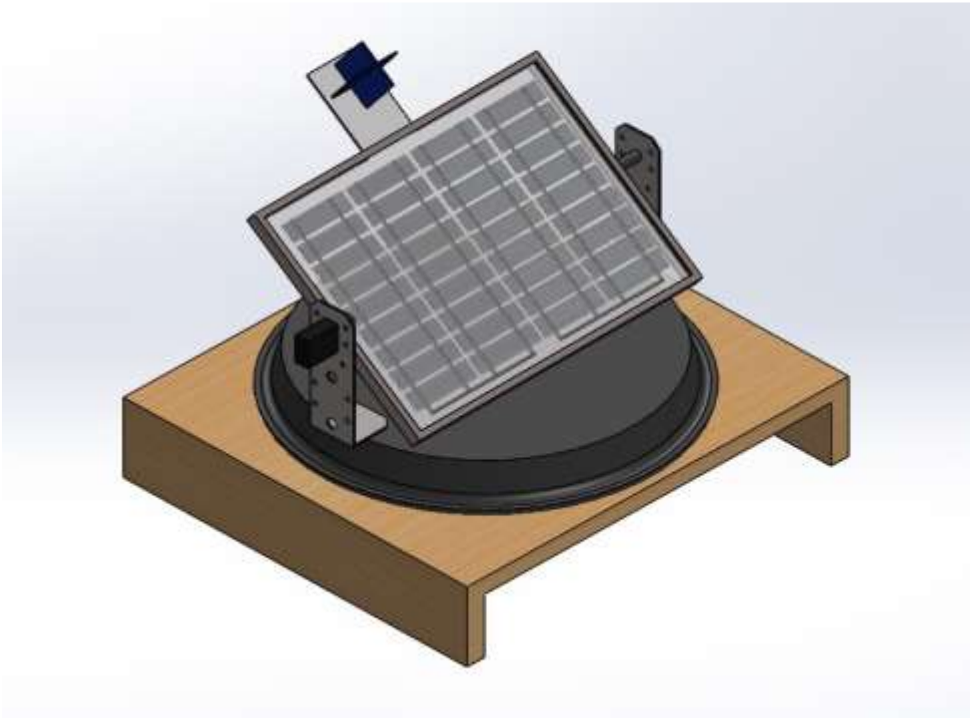

Figure 17 Solar Panel Plate (Assembly front view)

Shows the assembly of the part that has been drawn in 3D Solidwork software.

C. Mechanical Structure of the Solar Panel

1. Solar Panel Base

The solar panel is mounted on a wooden at its center. The panel's horizontal movement is facilitated by a centrally located servo motor, with a dish positioned between the solar panel and the wooden base. This dish, situated above the motor on the wooden base, is responsible for rotation on horizontal axis as shown in figure 8.

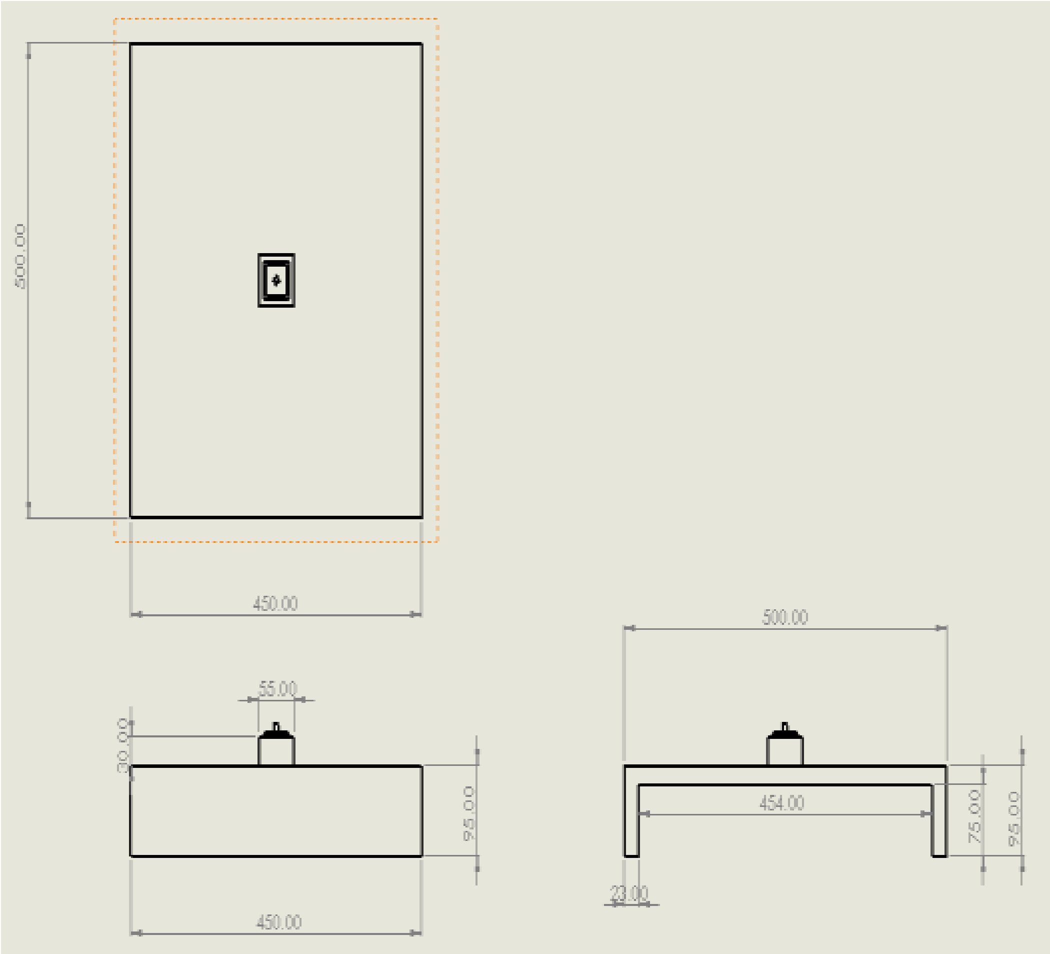

Figure 18 Solar Panel Base Dimensions

Shows the dimensions of the Solar's panel base in different views.

Table 1 Solar panel base Specifications

Dimensions(mm)	500*450*23
Material	Wood

2. Solar Panel Holder/Stand

The solar panel stand is designed with the capability to rotate in a clockwise (rotation-wise) direction. Its primary function is to securely hold the solar panel. The stand is affixed or fixed firmly to the base, ensuring stability and preventing any unintended movement. As shown in figure 11, This design allows the solar panel to be strategically positioned to follow the sun's movement throughout the day, optimizing energy capture and overall system efficiency.

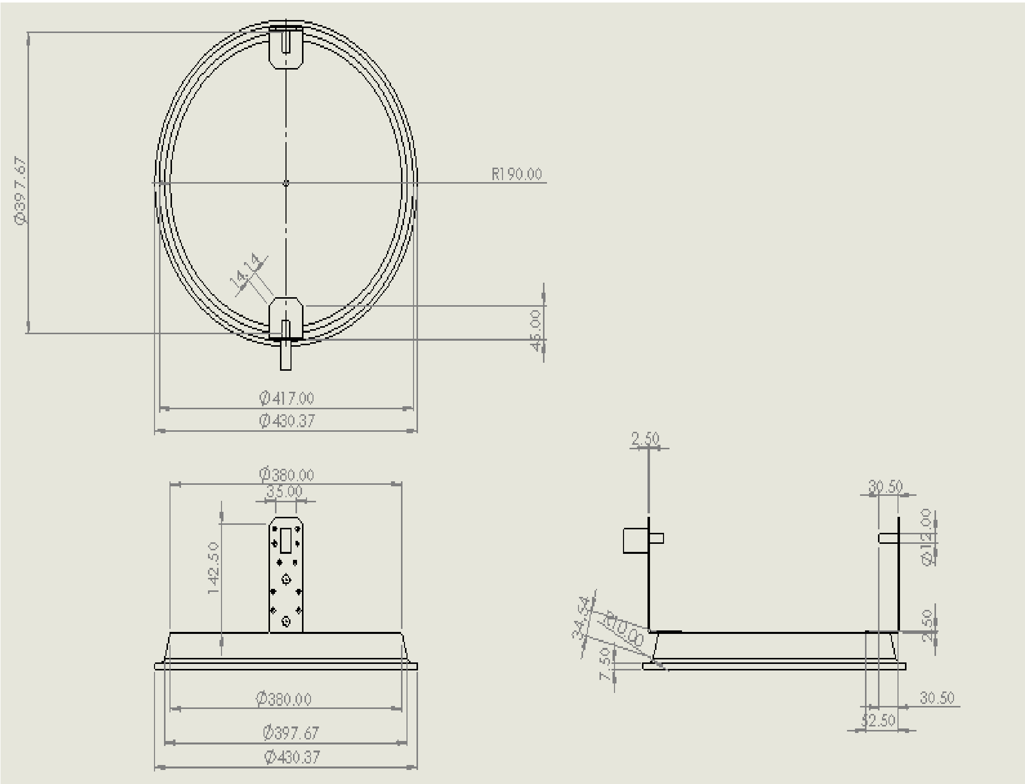

Figure 19 Solar Panel Holder/Stand Dimensions

Shows the dimensions of the Solar's panel holder/stand in different views.

Table 2 Solar panel hold/stand material specifications

Tray Material	Aluminium
90° Bracket corner joint	Stainless Steel

3. Solar Panel Plate

The solar panel plate a shown in figure 14 is securely attached to the stand, enabling controlled movement along the vertical axis. This design allows the solar panel to tilt or adjust its position in response to the changing angle of the sun. By being fixed to the stand, the solar panel plate can efficiently move in the vertical direction, ensuring that it maintains an optimal orientation to maximize sunlight exposure and enhance overall energy capture .

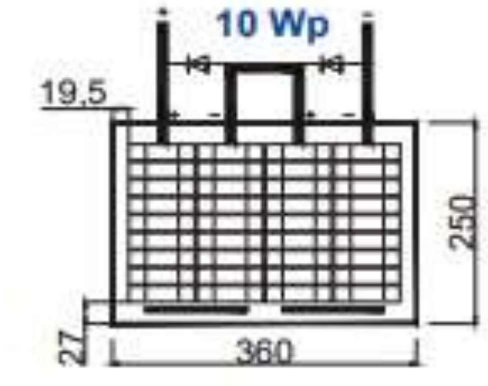

Figure 20 Solar Panel Plate Dimensions

Shows the dimensions of the Solar's panel dimensions different views.

Model Type	TT5-18P	TT10-36P	TT22-36P	TT42-36P	TT55-36P	TT85-36P	TT110-36P	TT170-36P
Peak Power (P_{max})	5 Wp	10 Wp	22 Wp	42 Wp	55 Wp	85 Wp	110 Wp	170 Wp
Maximum Power Voltage (V_{mp})	9,86	19,73	19,73	19,73	19,73	19,73	19,73	19,73
Maximum Power Current (I_{mp})	0,51	0,51	1,12	2,13	2,83	4,31	5,58	8,62
Open Circuit Voltage (V_{oc})	11,61	23,22	23,22	23,22	23,22	23,22	23,22	23,22
Short Circuit Current (I_{sc})	0,54	0,54	1,19	2,26	3,00	4,51	5,81	9,02
Cell per Module	18(2x9)	36(4x9)	36(4x9)	36(4x9)	36(4x9)	36(4x9)	36(4x9)	36(4x9)
Cell Dimensions (mm)	20x78	20x78	39x78	39x157	52,25x157	78x157	97x157	157x157
Panel Dimensions (mm)	204x254x16	364x254x16	365x425x16	680x430x20	680x554x20	680x790x20	680x1025x25	680x1504x30
Weight (kg)	0,68	1,13	1,9	3,32	4,2	5,87	7,53	11,7
Voltage (v)	9V	12V	12V	12V	12V	12V	12V	12V
Operating Temperature	-40 ~ +85°C							

MECHANICAL SPECIFICATIONS			
Solar Glass	3,2mm Low iron, Tempered Glass		
Frame	Anodized Aluminum		
Junction Box	IP65 (5-85 Wp)		
Junction Box	IP67 (110-170 Wp)		
Cable	$4mm^2$		
Cable Length	55Wp 430mm	85Wp 475mm	170 Wp 1000mm

TEMPERATURE CHARACTERISTICS	
Temp. Coeff. of Isc	0.06%/°C
Temp. Coeff. of Voc	-0.31%/°C
Temp. Coeff. of Pmax	-0.38%/°C
Nominal Working Cell Temperature (NOCT)	45°C±2°C

Figure 21 Solar Panel Plate Specifications

Shows solar panel plate specifications.

D. Electrical components installed in the solar panel system

1. Arduino Mega Controller

The Arduino Uno serves as the brain of your project. It controls and coordinates the movements of the solar panels based on the input from sensors. You program it to read data from sensors, make decisions, and control the servo motors accordingly.

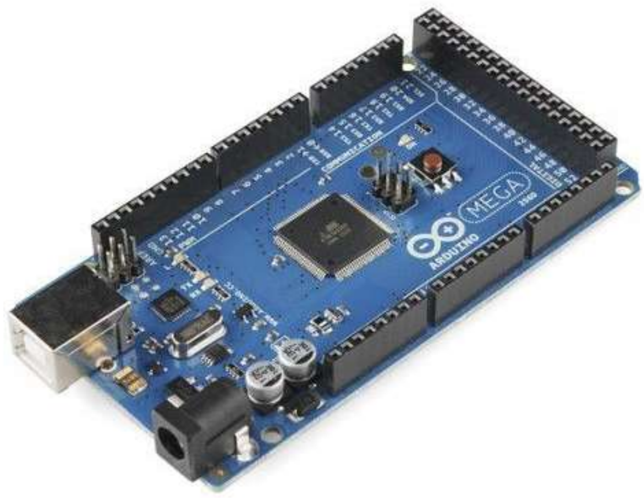

Figure 22 Arduino Mega Controller.

2. Breadboard

The breadboard is used for prototyping and organizing the circuit connections. It allows you to connect various components, such as sensors and actuators, without soldering. In your project, it helps create a flexible and adjustable circuit layout.

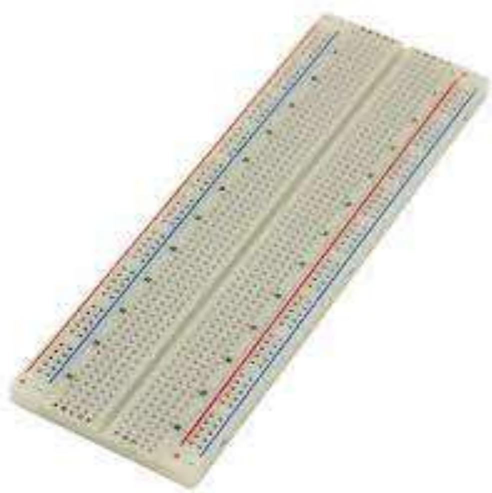

Figure 23 Bread board.

3. Jumping Wires

Jumping wires provide electrical connections between components on the breadboard. They enable the flow of signals and power between different parts of your circuit, facilitating the communication and interaction between the Arduino and other components.

Figure 24 Jumping wires.

4. Servo Motor

Servo motors control the movement of the solar panels along both the horizontal and vertical axes. In your dual-axis solar tracking system, servo motors adjust the position of the solar panels to face the sun, optimizing energy capture throughout the day.

Figure 25 Servo motor.

5. Solar Panel Plate

The solar panel plate contains solar cells that convert sunlight into electrical energy. Its role is to capture solar energy and provide power to your system. The dual-axis movement ensures that the solar panels are always facing the sun for maximum efficiency.

Figure 26 Solar Panel TT10-36P.

6. SD Memory Card Sensor

The SD memory card sensor allows you to log and store data related to your solar panel system. This can include information about energy production, tracking efficiency, and other relevant parameters. It adds a data logging capability to your project.

Figure 27 SD Memory card sensor.

7. Potentiometer

The potentiometer provides a way to customize and calibrate the sensitivity of the LDR sensor based on the specific requirements of the solar panel project. It gives you control over when certain actions or operations should be initiated, depending on the amount of light detected by the LDR.

Figure 28 Potentiometer.

8. Real Time Clock (RTC)

An RTC in a solar panel is like a little clock that keeps track of time, even when the solar panel is not actively producing electricity. This clock helps in scheduling tasks, logging data accurately, and managing energy more efficiently. It ensures that the solar panel system operates effectively by knowing when to do certain things, like adjusting positions or storing energy, based on the time of day or specific conditions. It's like a timekeeper for the solar panel to make sure everything happens at the right time.

Figure 29 RTC sensor.

9. Light Dependent Resistor

The LDR (Light Dependent Resistor) sensor plays a crucial role in the solar panel tracking system, contributing to the intelligent adjustment of the solar panel based on real-time light conditions.

Figure 30 Light Dependent Resistor.

E. Solar Panel System

The investigation centers around the performance analysis of a dynamically movable solar panel, strategically oriented towards six cardinal horizontal directions—North, South, East, West, Southeast, and Southwest. Moreover, the solar panel undergoes vertical movement between five carefully chosen pre-defined angles, namely 5, 20, 30, 40, and 55 degrees. The systematic approach of this study encompasses various key steps.

Firstly, the solar panel undergoes controlled movements every hour towards the specified directions, simultaneously adjusting its inclination according to the predetermined angles. Subsequently, a meticulous data collection process is implemented, recording the solar panel's performance metrics, including angle and direction, at each hourly interval. The gathered data is then subjected to a comparative analysis with existing solar panels currently in operation on the surfaces of university buildings. This comparative study aims to contribute valuable insights for determining the optimal conditions for solar energy absorption.

Lastly, a rigorous results analysis will be conducted to discern the most effective directions and angles that facilitate maximum harnessing of solar energy. This research is poised to shed light on innovative approaches to enhance the efficiency of solar panels in diverse environmental conditions, with potential implications for sustainable energy practices and resource utilization

F. System Components and Functions

Arduino Mega

- Function: Acts as the main controller for the entire system, managing the input and output to control the positioning of the solar panel.

SD Sensor

- Function: Stores data regarding solar panel angles, directions, and other relevant information for analysis or future use.

RTC (Real-Time Clock) Sensor

- Function: Keeps track of the current date and time to accurately determine the position of the sun. This information is crucial for the solar panel to adjust its position accordingly.

Breadboard

- Function: Provides a platform for connecting and prototyping the various electronic components in a temporary setup.

Potentiometer (for LDR Sensor)

- Function: Adjusts the sensitivity of the LDR sensor, allowing manual calibration of the system based on ambient light conditions.

LDR Sensor (Light Dependent Resistor)

- Function: Measures the ambient light intensity to determine the current sunlight conditions, helping the system decide when and how to adjust the solar panel.

Solar Panel

- Function: Absorbs sunlight and converts it into electrical energy. The angle and direction adjustments are made to optimize the energy absorption based on the sun's position.

Servo Motor

- Function: Actuates the movement of the solar panel by adjusting its tilt angle. The servo motor's rotation is controlled by the Arduino based on the input from sensors and algorithms.

The Real-Time Clock (RTC) sensor plays a crucial role in the solar panel positioning system by continuously updating the system with the current date and time. This information forms the basis for accurately determining the position of the sun at any given moment, providing the necessary temporal context for optimizing solar energy absorption.

In tandem with the Light Dependent Resistor (LDR) sensor, the potentiometer serves as a vital component for monitoring ambient light levels. The LDR sensor, coupled with the potentiometer, enables the system to assess sunlight conditions with precision. The potentiometer acts as a manual adjustment tool, allowing users to fine-tune the sensitivity of the LDR sensor. This manual calibration capability ensures an accurate evaluation of sunlight conditions, contributing to the overall efficiency of the solar tracking system.

The Arduino Mega, serving as the central controller, processes data obtained from both the RTC and LDR sensors. This integrated data processing mechanism enables the Arduino to calculate the optimal position for the solar panel based on the current date, time, and ambient light conditions. The system utilizes predefined angles and directions, strategically oriented towards North, South, East, West, Southeast, and Southwest, to formulate the calculations necessary for the solar panel's optimal orientation.

Upon completing the angle calculations, the Arduino orchestrates the required movements of the servo motor. The servo motor, a key actuator in the system, precisely adjusts the solar panel to the calculated angle, facilitating maximum sunlight absorption. This dynamic adjustment mechanism ensures that the solar panel is continually positioned for optimal energy capture throughout the day.

To facilitate analysis and future adjustments, a Secure Digital (SD) sensor is incorporated into the system. This sensor functions as a data storage unit, recording relevant information about solar panel angles, directions, and other pertinent details. The stored data can be utilized for performance analysis, system optimization, or future enhancements to the solar tracking system.

In summary, the integration of these components and their coordinated functions enhances the efficiency and adaptability of the solar panel positioning system.

G. System Operation Overview

The solar panel positioning system is designed to efficiently harness solar energy by dynamically adjusting the orientation of the solar panel based on real-time environmental conditions. The system initiates its operation by initializing the Real-Time Clock (RTC) sensor, which provides accurate information about the current date and time. Simultaneously, the Light Dependent Resistor (LDR) sensor, in collaboration with the potentiometer, continually monitors ambient light levels. The potentiometer allows manual calibration, enabling users to fine-tune the sensitivity of the LDR sensor for precise assessment of sunlight conditions.

The Arduino Mega, serving as the central controller, processes the data collected from the RTC and LDR sensors. Utilizing this information, the system calculates the optimal position for the solar panel, factoring in the current date, time, and ambient light conditions. This calculation is based on predefined angles and directions strategically oriented towards North, South, East, West, Southeast, and Southwest.

The servo motor, a critical actuator in the system, receives commands from the Arduino to dynamically adjust the solar panel's tilt angle. This adjustment ensures that the solar panel remains optimally positioned throughout the day, aligning with the calculated angle for maximum sunlight absorption. Concurrently, a Secure Digital (SD) sensor records relevant data, such as solar panel angles and directions, for analysis, system optimization, or future adjustments.

The system operates with continuous monitoring and adaptation, responding to changing environmental conditions in real-time. It offers a seamless and sustainable solution for harnessing solar power, combining precise calculations, dynamic adjustments, and user-interaction through the potentiometer for manual calibration when needed. In summary, the solar panel positioning system demonstrates efficiency and adaptability, making it an effective tool for optimizing solar energy absorption.

H. Project System Coding

The heart of this system lies in the Arduino platform, serving as the central intelligence orchestrating precise movements of servo motors, timekeeping with the DS3231 RTC module, environmental feedback from a light sensor, and data storage capabilities using an SD card. The Arduino code, a pivotal component of this project, encapsulates algorithms and control logic that enable real-time adjustments based on environmental conditions.

By leveraging Arduino's open-source and customizable nature, this project empowers users to delve into the intricacies of solar energy optimization. The flexibility of the Arduino code allows for easy experimentation, modification, and adaptation to diverse geographical locations and environmental variables.

In this exploration of sustainable energy harvesting, the Arduino-Powered Solar Panel Positioning System not only showcases the potential of Arduino in facilitating complex control systems but also serves as an educational tool for those keen on understanding and implementing smart solutions in renewable energy.

```
#include <Servo.h>
#include <SPI.h>
#include <SdFat.h>
#include <Wire.h>
#include <DS3231.h>
DS3231 clock;
RTCDateTime dt;

const int servo1Pin = 9;
const int servo2Pin = 10;
const int lightSensorPin = A0;
const int chipSelectPin = 53;

Servo servo1;
Servo servo2;
SdFat SD;
File dataFile;


void setup() {
  Serial.begin(9600);
  servo1.attach(servo1Pin);
  servo2.attach(servo2Pin);

  clock.begin();



  clock.setDateTime( __DATE__ , __TIME__ );



```

Figure 31 Arduino code.

```
  if (!SD.begin(chipSelectPin)) {
    Serial.println("SD Initialization failed!");
    return;
  }

  dataFile = SD.open("data.csv", O_WRITE | O_CREAT);

  if (dataFile) {
    Serial.println("File opened successfully");
  } else {
    Serial.println("Error opening file!");
  }
}

void loop() {
   if (!SD.begin(chipSelectPin)) {
    Serial.println("SD Initialization failed!");
    return;
  }

  dataFile = SD.open("data.csv", O_WRITE | O_APPEND);

  if (dataFile) {
    Serial.println("File opened successfully");
  } else {
    Serial.println("Error opening file!");
  }

  performOperations();

  delay(3600000);
}
```

Figure 32 Arduino Code.

```
void performOperations() {
  int angles1[] = {1,45, 90, 135, 178};
  int angles2[] = {5, 20, 30, 40, 55};

  dt = clock.getDateTime();
    dataFile.println("");
    dataFile.println("");
  dataFile.print(dt.year);   dataFile.print("-");
  dataFile.print(dt.month);  dataFile.print("-");
  dataFile.print(dt.day);    dataFile.print(" ");
  dataFile.print(dt.hour);   dataFile.print(":");
  dataFile.print(dt.minute); dataFile.print(":");
  dataFile.print(dt.second); dataFile.println("");

  for (int i = 0; i < 5; i++) {
    int angle1 = angles1[i];









    moveServo1(angle1);

    for (int j = 0; j < 5; j++) {
      int angle2 = angles2[j];
      moveServo2(angle2);

      int lightPercentage = readLightPercentage();

```

Figure 33 Arduino Code.

```
      Serial.print("Direction: ");
      Serial.print(angle1);
      Serial.print(", Angle2: ");
      Serial.print(angle2);
      Serial.print(", Light Percentage: ");
      Serial.println(lightPercentage);


      if (dataFile) {
        if (i == 0) {
      dataFile.println("Direction: West");
    }
    if (i == 1) {
      dataFile.println("Direction:Southwest");
    }
    if (i == 2) {
      dataFile.println("Direction: South");
    }
    if (i == 3) {
      dataFile.println("Direction: Southeast");
    }
    if (i == 4) {
      dataFile.println("Direction: East");
    }
        dataFile.print("Direction: ");
        dataFile.print(angle1);
        dataFile.print(", Angle2: ");
        dataFile.print(angle2);
        dataFile.print(", Light Percentage: ");
        dataFile.println(lightPercentage);
      } else {
        Serial.println("Error writing to file!");
```

Figure 34 Arduino Code.

```
      }

      delay(1000);
    }
  }


  int servo2Angles[] = {75, 90, 100, 110, 125};
  Serial.println("Direction:North ");
  for (int i = 0; i < 5; i++) {
    moveServo1(90);

    int angle2 = servo2Angles[i];
    moveServo2(angle2);
    delay(1000);
    int lightPercentage = readLightPercentage();

    Serial.print("Angle1: 90, Angle2: ");
    Serial.print(angle2);
    Serial.print(", Light Percentage: ");
    Serial.println(lightPercentage);


    if (dataFile) {
      dataFile.println("Direction:North ");
      dataFile.print("Direction:North, Angle1: 90, Angle2: ");
      dataFile.print(angle2);
      dataFile.print(", Light Percentage: ");
      dataFile.println(lightPercentage);
    } else {
      Serial.println("Error writing to file!");
    }
  }
```

Figure 35 Arduino Code.

```
  dataFile.close();
}

void moveServo1(int angle) {
  servo1.write(angle);
  delay(500);
}

void moveServo2(int angle) {
  servo2.write(angle);
  delay(500);
}

int readLightPercentage() {
  int sensorValue = analogRead(lightSensorPin);
  int lightPercentage = map(sensorValue, 0, 1023, 0, 100);
  return lightPercentage;
}
```

Figure 36 Arduino Code.

This Arduino code is for a solar panel positioning system that incorporates two servo motors, an RTC module (DS3231), a light sensor, and an SD card for data storage. The system aims to optimize solar energy absorption by adjusting the solar panel across different angles and directions, recording relevant data to an SD card.

In the setup function, serial communication is initiated, and connections to the servos, RTC, and SD card are established. The RTC is initialized and set with the current date and time. The SD card is checked for successful initialization, and a data file named "data.csv" is opened for writing.

The loop function begins with an attempt to initialize the SD card and open the data file. If successful, it calls the performOperations function, which orchestrates the movement of the two servos through predefined angles. The system records the date, time, direction, servo angles, and light percentage to the data file during each movement. The delay(3600000) introduces a one-hour delay between operations.

The moveServo1 and moveServo2 functions control the movement of the two servos, introducing a delay after each movement for stability. The readLightPercentage function reads the light sensor's analog value, maps it to a percentage, and returns the result.

The system performs a series of movements for both servos across specified angles, recording data for each combination of angles and directions. The recorded data includes timestamped information about the direction, servo angles, and light percentage. This data is valuable for analyzing the system's performance in different conditions. Note that the code uses the DS3231 library for RTC and the SdFat library for SD card communication.

IV. DATA AND ANALYSIS

In this Chapter, the investigation utilized PVGIS software for a comprehensive analysis of solar energy potential, covering six cardinal directions: north, south, east, west, southeast, and southwest. Within each direction, data was systematically collected at five specific angles, presenting a detailed examination of solar radiation patterns. The study spans the years 2018, 2019, and 2020, aiming to determine the maximum solar radiation in each direction and its associated angles over this three-year timeframe. This approach provides a robust understanding of the variability of solar radiation, crucial for assessing the optimal conditions for solar energy harnessing.

A. South Direction

In 2018, the graph indicates that the maximum power in the south direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 497067.56 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south direction.

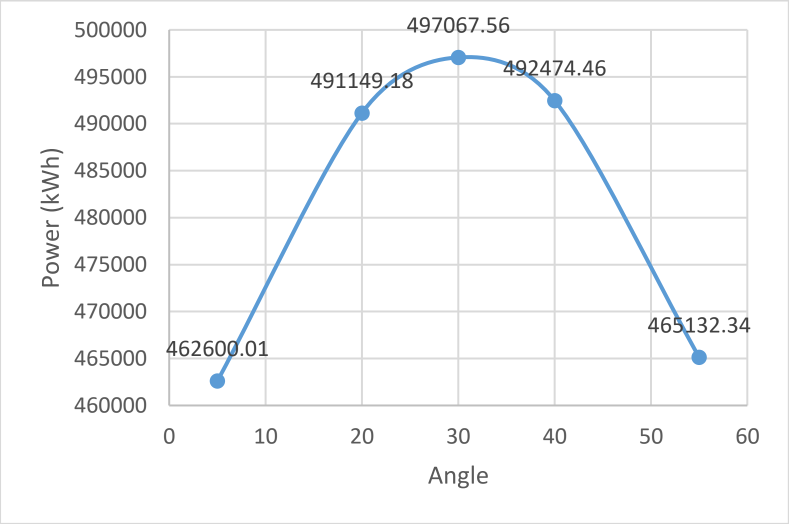

Figure 37 Shows the maximum power at 30° in the south direction in 2018.

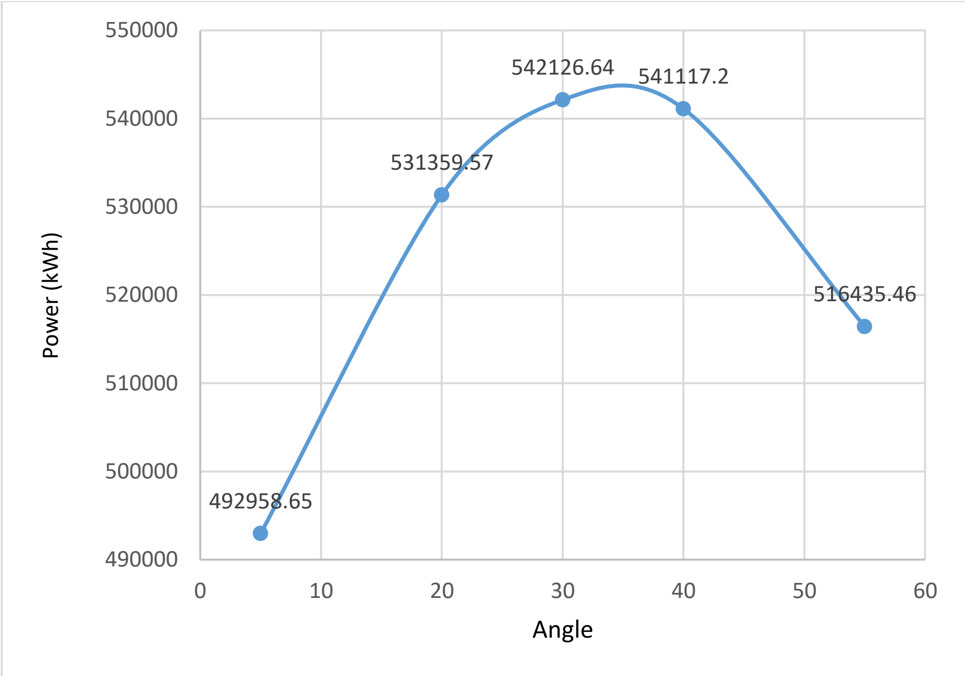

Figure 38 Shows the maximum power at 30° in the south direction in 2019.

In 2019, the graph indicates that the maximum power in the south direction occurs between angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 542126.64 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south direction.

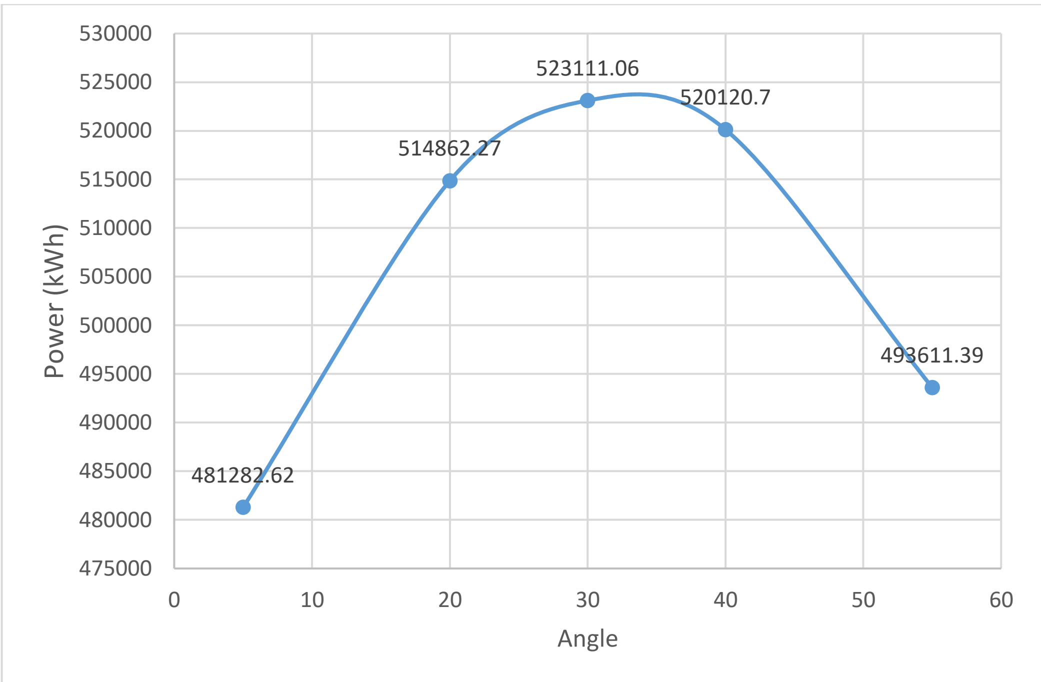

Figure 39 Shows the maximum power at 30° in the south direction in 2020.

In 2020, the graph indicates that the maximum power in the south direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55.

This peak power value is recorded at 523111.06 kWh , showcasing that angle 30 degrees yields the highest power throughout the year in the south direction.

B. West Direction

In 2018, the graph indicates that the maximum power in the west direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 448543.05 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the west direction.

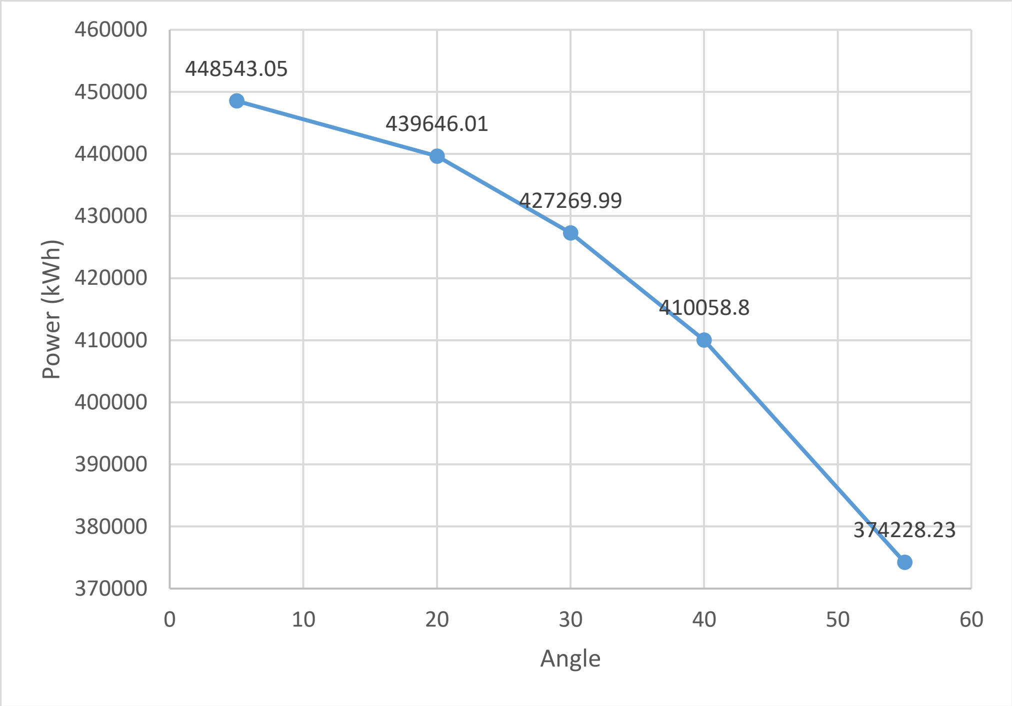

Figure 40 Shows the maximum power at 5° in the west direction in 2018.

In 2019, the graph indicates that the maximum power in the west direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 474624.03 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the west direction.

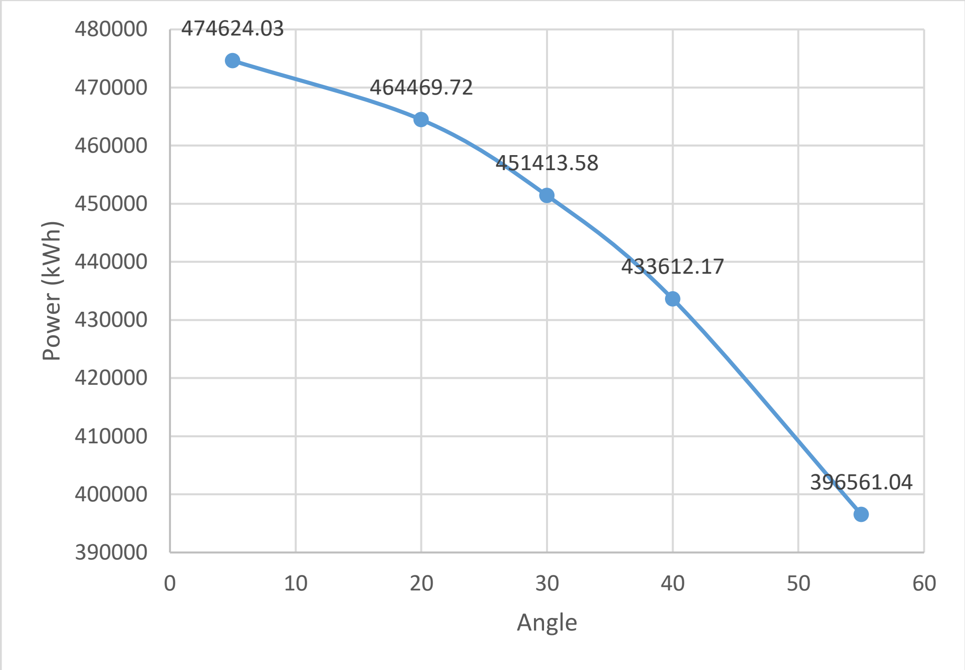

Figure 41 Shows the maximum power at 5° in the west direction in 2019.

In 2020, the graph indicates that the maximum power in the west direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 464077.62 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the west direction.

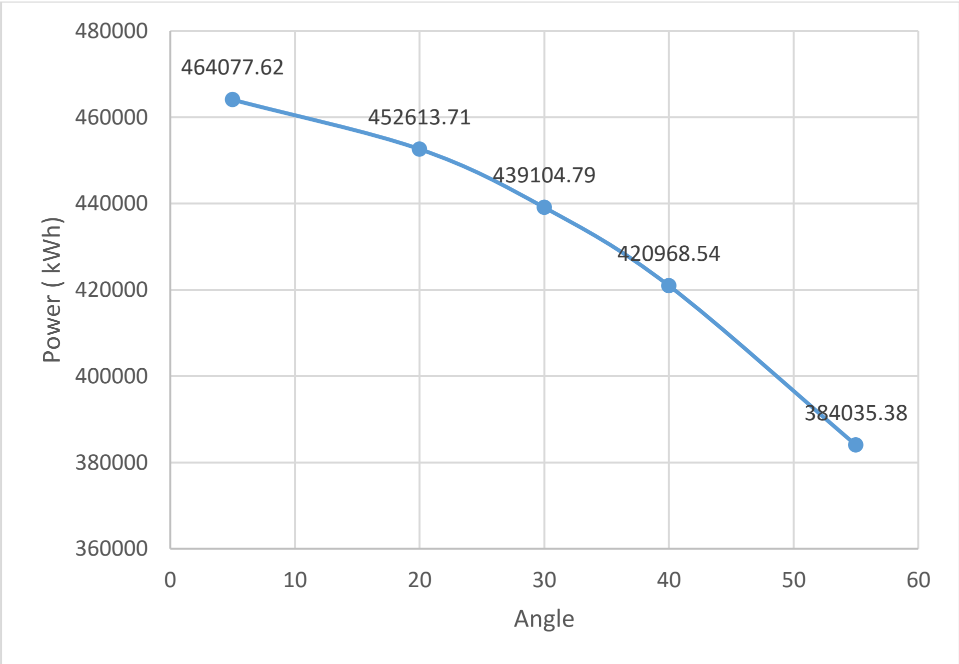

Figure 42 Shows the maximum power at 5° in the west direction in 2020.

C. North Direction

In 2018, the graph indicates that the maximum power in the north direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 430469.37 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the north direction.

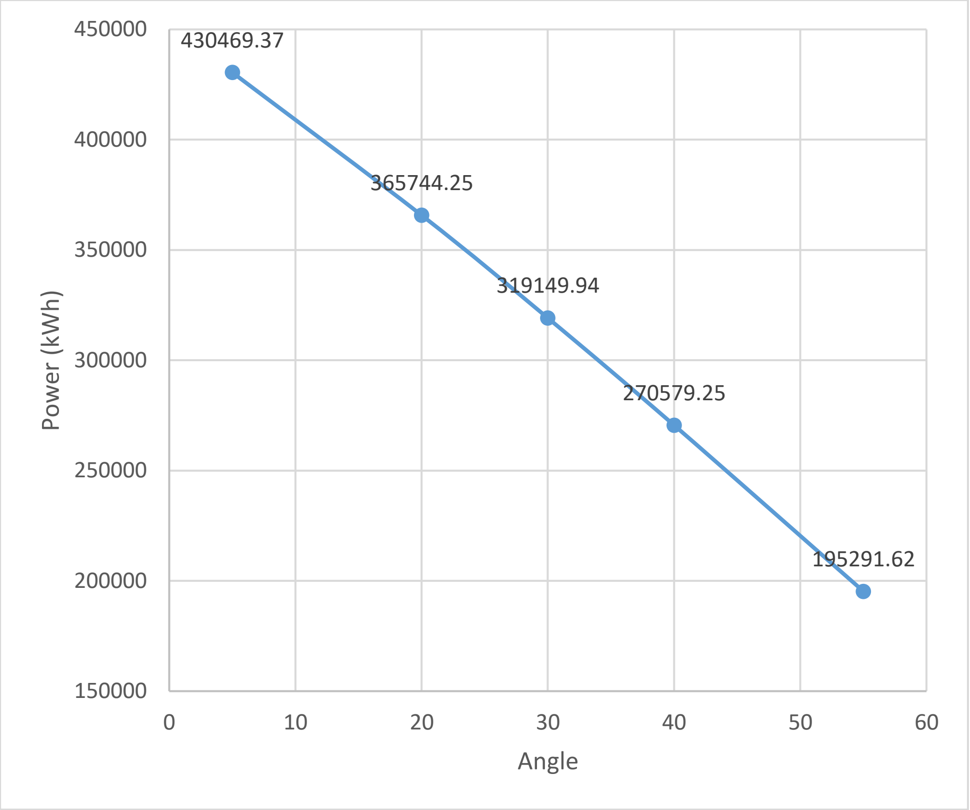

Figure 43 Shows the maximum power at 5° in the north direction in 2018.

In 2019, the graph indicates that the maximum power in the north direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 452549.73 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the north direction.

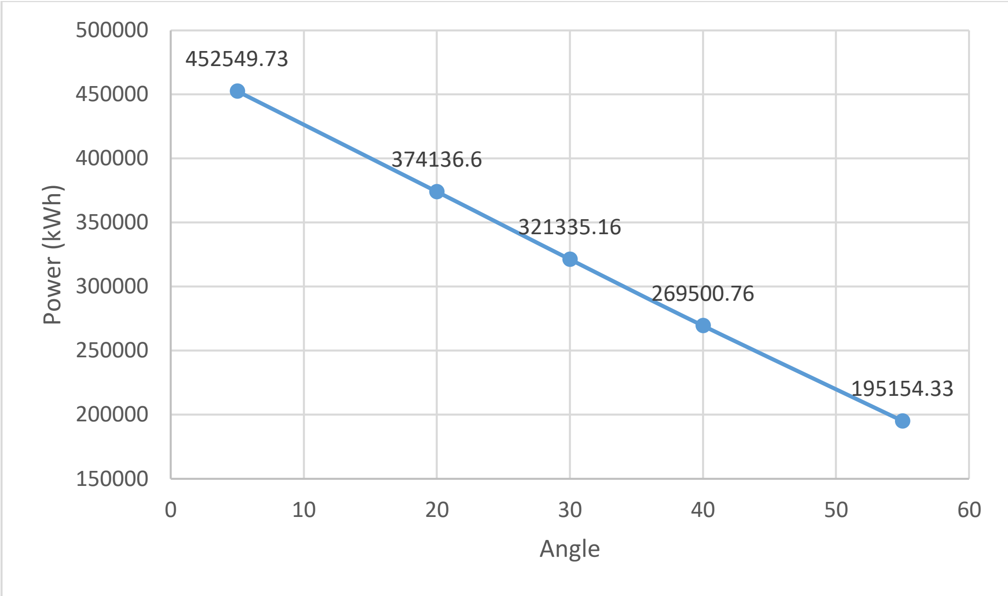

Figure 44 Shows the maximum power at 5° in the north direction in 2019.

In 2020, the graph indicates that the maximum power in the north direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 444825.23 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the north direction.

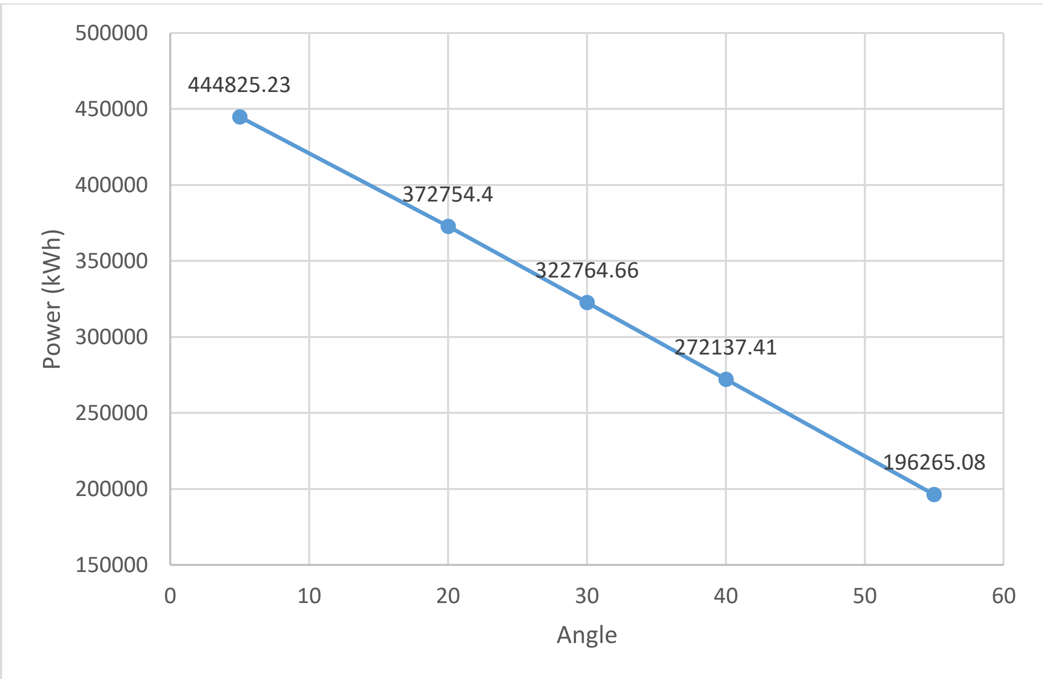

Figure 45 Shows the maximum power at 5° in the north direction in 2020.

D. East Direction

In 2018, the graph indicates that the maximum power in the east direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 444910.84 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the east direction.

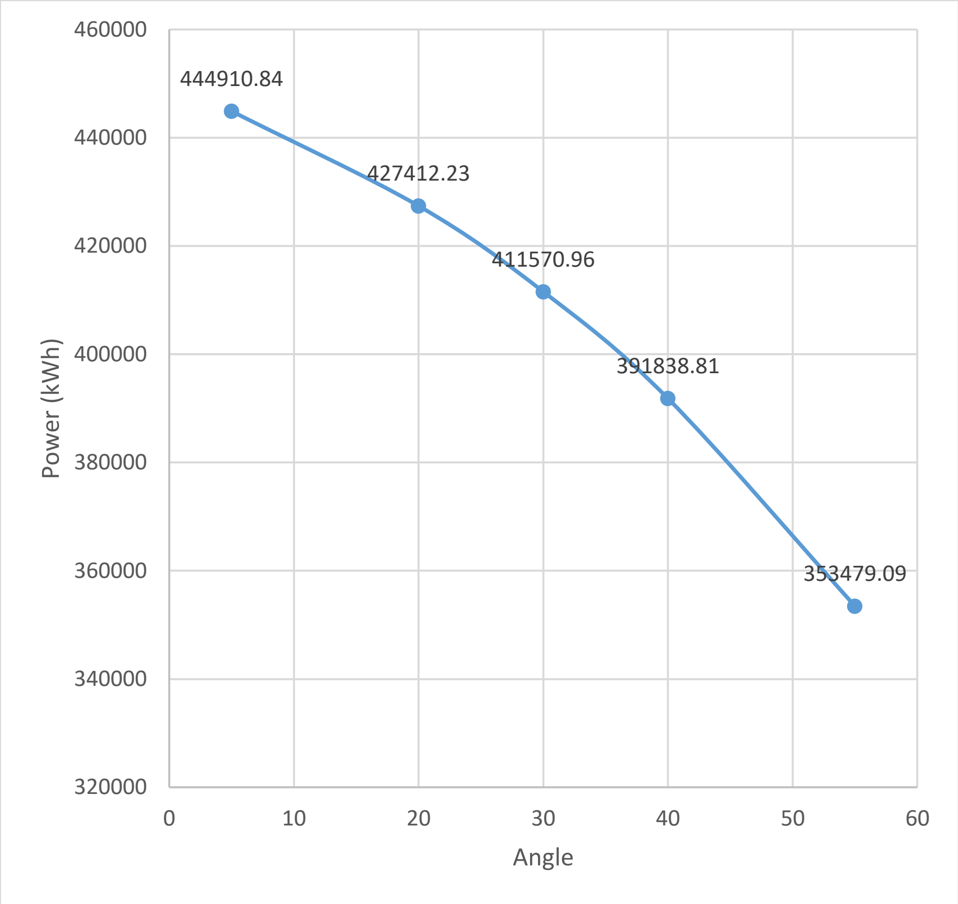

Figure 46 Shows the maximum power at 5° in the east direction in 2018.

In 2019, the graph indicates that the maximum power in the east direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 471458.5 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the east direction.

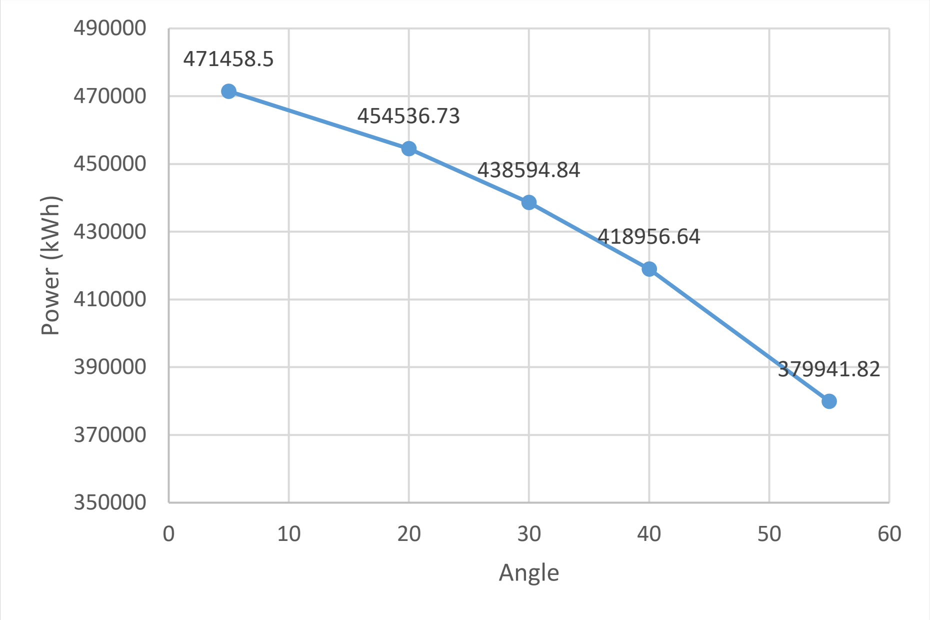

Figure 47 Shows the maximum power at 5° in the east direction in 2019.

In 2020, the graph indicates that the maximum power in the east direction occurs at an angle of 5 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 462537.18 kWh, showcasing that angle 5 degrees yields the highest power throughout the year in the east direction.

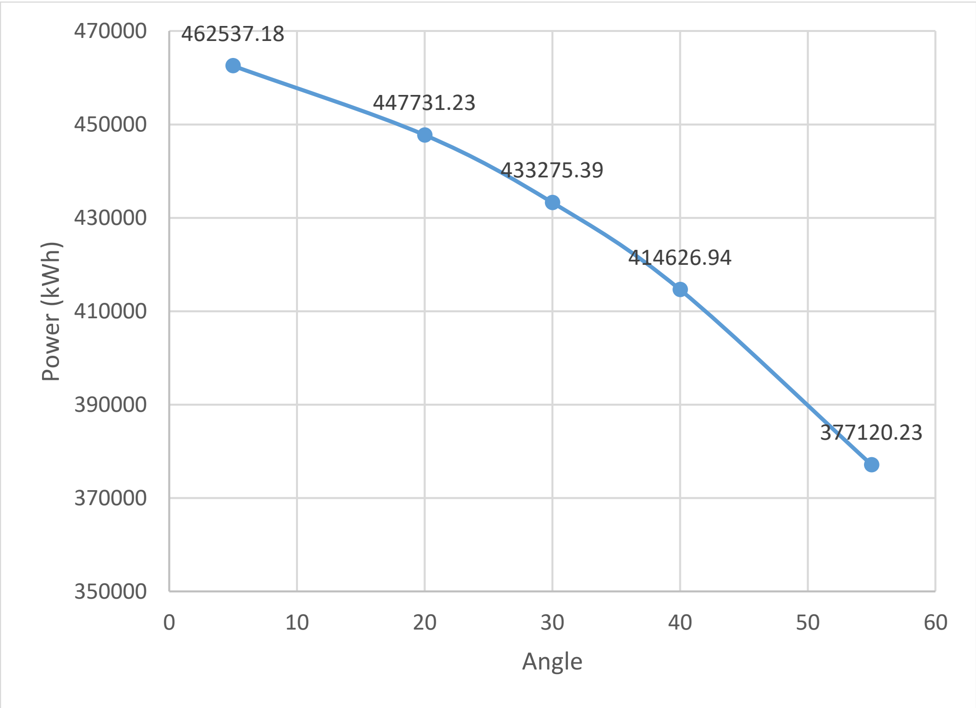

Figure 48 Shows the maximum power at 5° in the east direction in 2020.

E. South-West Direction

In 2018, the graph indicates that the maximum power in the south-west direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 481030.71 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south-west direction.

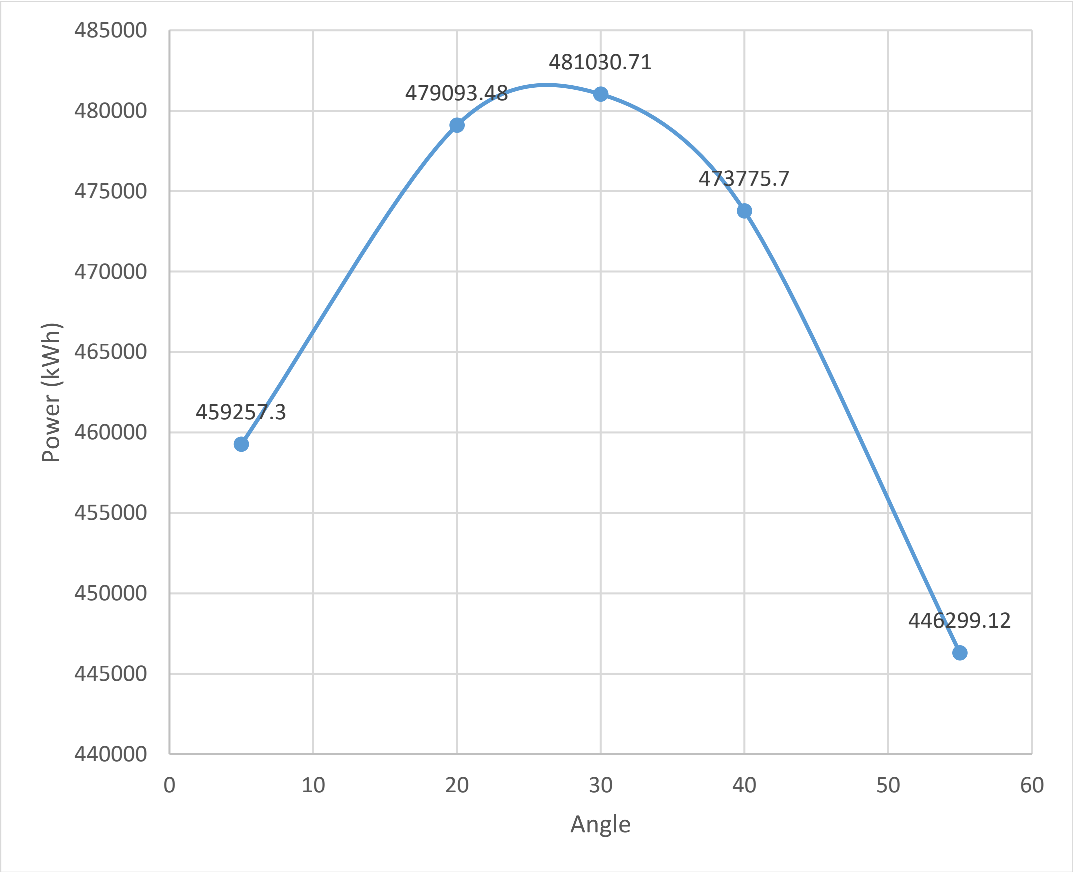

Figure 49 Shows the maximum power at 30° in the south-west direction in 2018.

In 2019, the graph indicates that the maximum power in the south-west direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 519078.27 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south-west direction.

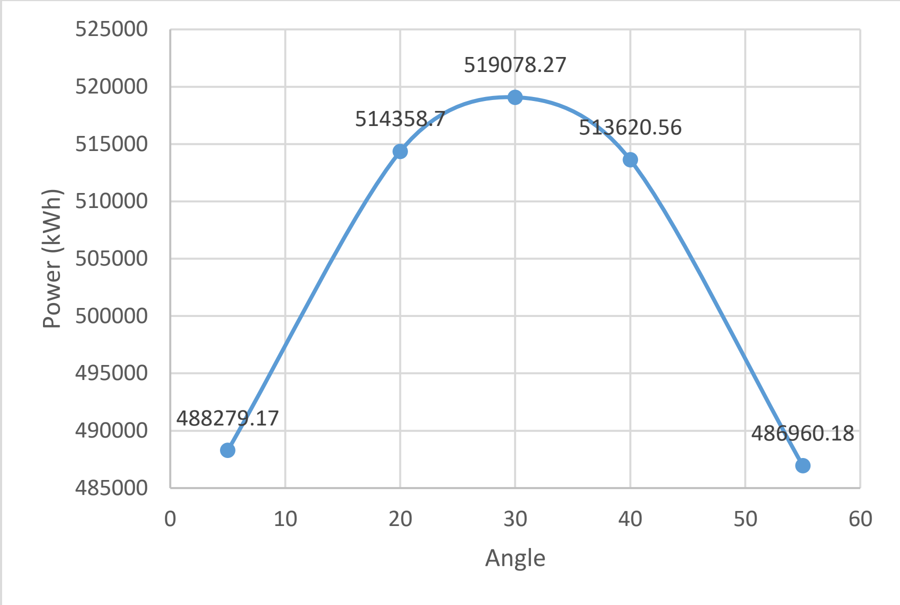

Figure 50 Shows the maximum power at 30° in the south-west direction in 2019.

In 2020, the graph indicates that the maximum power in the south-west direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 500772.07 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south-west direction.

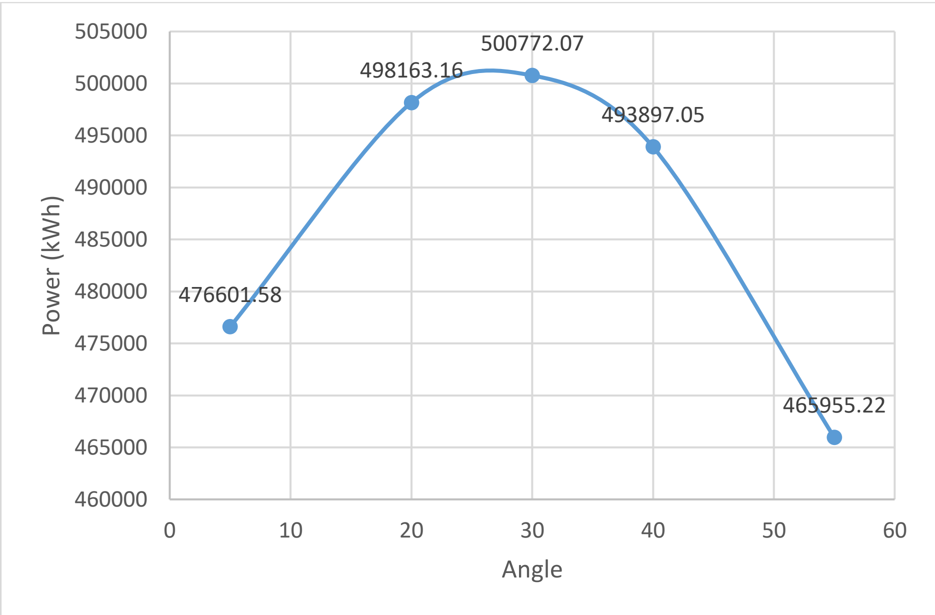

Figure 51 Shows the maximum power at 30° in the south-west direction in 2020.

F. South-East Direction

In 2018, the graph indicates that the maximum power in the south-east direction occurs at an angle of 20 degrees among the specified angles of 5, 20, 30, 40, and 55.

This peak power value is recorded at 470189.77 kWh, showcasing that angle 20 degrees yields the highest power throughout the year in the south-east direction.

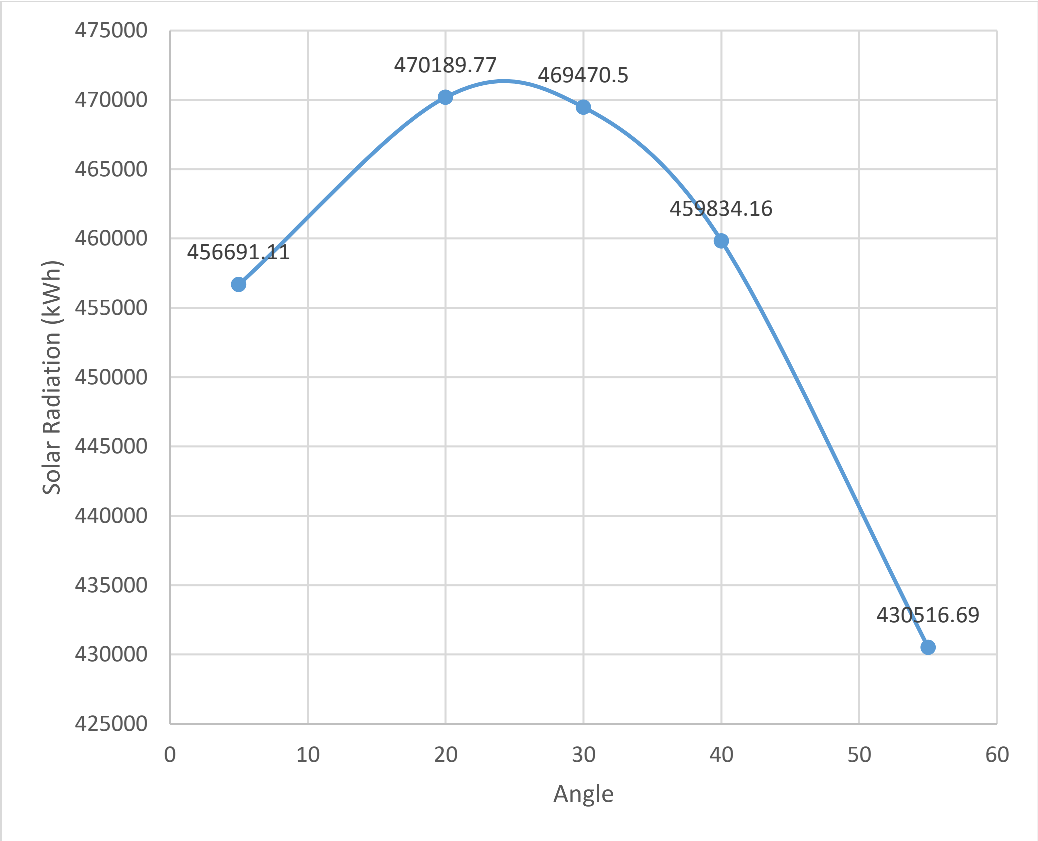

Figure 52 Shows the maximum power at 20° in the south-east direction in 2018.

In 2019, the graph indicates that the maximum power in the south-east direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 510120.5 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south-east direction.

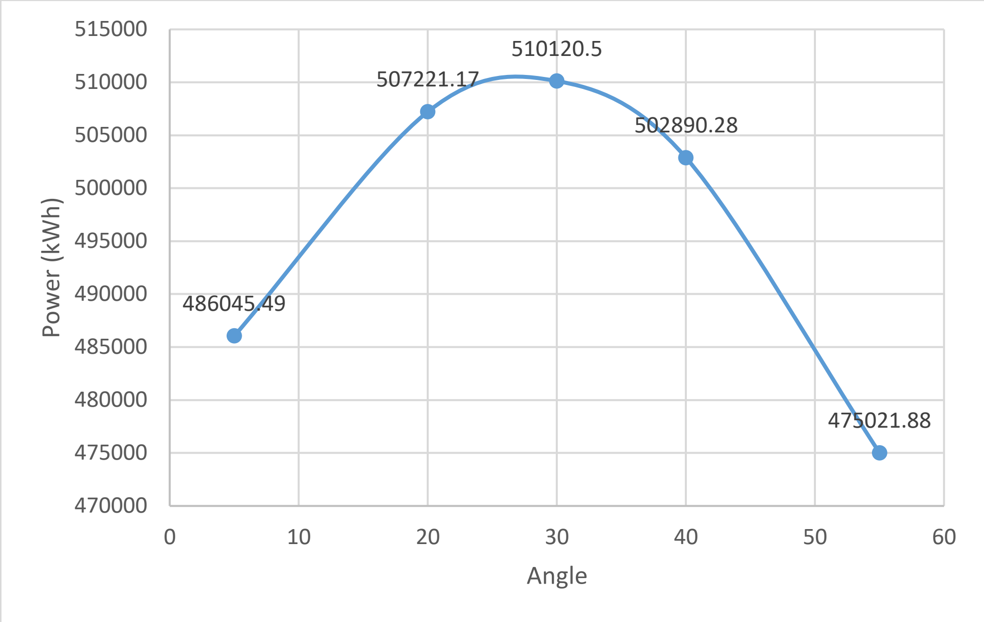

Figure 53 Shows the maximum power at 30° in the south-east direction in 2019.

In 2020, the graph indicates that the maximum power in the south-east direction occurs at an angle of 30 degrees among the specified angles of 5, 20, 30, 40, and 55. This peak power value is recorded at 496825.36 kWh, showcasing that angle 30 degrees yields the highest power throughout the year in the south-east direction.

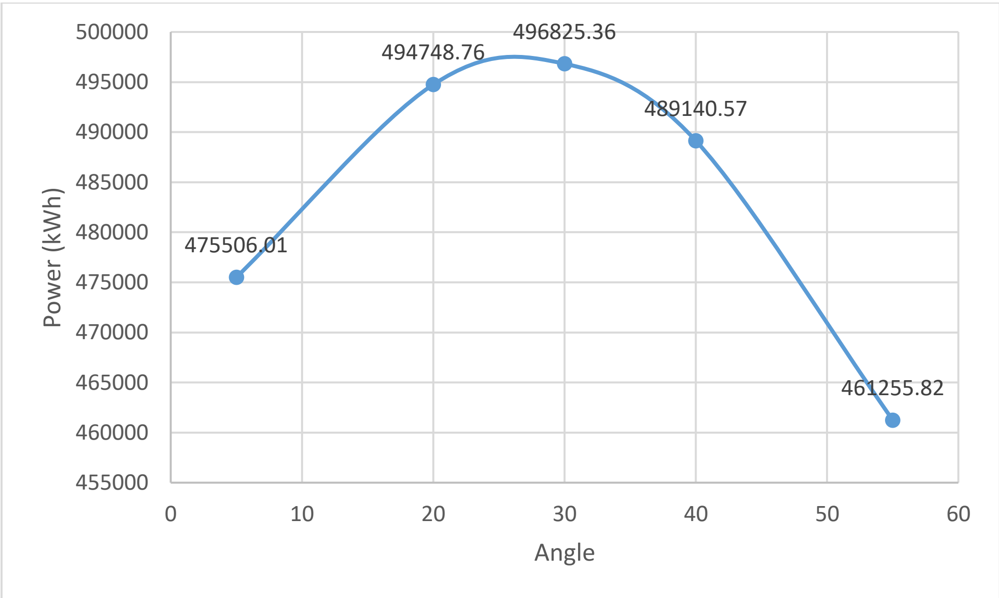

Figure 54 Shows the maximum power at 30° in the south-east direction in 2020.

G. Dynamic Analysis of Movable Solar Panel

The outcome of the Solar Panel Positioning System presents a comprehensive examination of light percentages across distinct directional settings and corresponding servo angles. Fueled by Arduino technology, the system dynamically manipulated the solar panel, exploring optimal angles to augment energy absorption.

This data-driven approach provides illuminating insights into the nuanced relationship between solar panel angles and light percentages, showcasing the system's adaptability and efficiency in response to diverse environmental conditions.

11/02/2024 08:26			
Direction: West			
Direction: 1	Angle2: 5	Light Percentage: 30	
Direction: West			
Direction: 1	Angle2: 20	Light Percentage: 33	
Direction: West			
Direction: 1	Angle2: 30	Light Percentage: 32	
Direction: West			
Direction: 1	Angle2: 40	Light Percentage: 35	
Direction: West			
Direction: 1	Angle2: 55	Light Percentage: 34	
Direction:Southwest			
Direction: 45	Angle2: 5	Light Percentage: 32	
Direction:Southwest			
Direction: 45	Angle2: 20	Light Percentage: 35	
Direction:Southwest			
Direction: 45	Angle2: 30	Light Percentage: 34	
Direction:Southwest			
Direction: 45	Angle2: 40	Light Percentage: 34	
Direction:Southwest			
Direction: 45	Angle2: 55	Light Percentage: 33	
Direction: South			
Direction: 90	Angle2: 5	Light Percentage: 35	
Direction: South			
Direction: 90	Angle2: 20	Light Percentage: 39	
Direction: South			
Direction: 90	Angle2: 30	Light Percentage: 43	
Direction: South			
Direction: 90	Angle2: 40	Light Percentage: 38	
Direction: South			
Direction: 90	Angle2: 55	Light Percentage: 40	

Figure 55 shows the recorded data from the solar panel system.

Direction: Southeast			
Direction: 135	Angle2: 5	Light Percentage: 74	
Direction: Southeast			
Direction: 135	Angle2: 20	Light Percentage: 69	
Direction: Southeast			
Direction: 135	Angle2: 30	Light Percentage: 65	
Direction: Southeast			
Direction: 135	Angle2: 40	Light Percentage: 61	
Direction: Southeast			
Direction: 135	Angle2: 55	Light Percentage: 56	
Direction: East			
Direction: 178	Angle2: 5	Light Percentage: 93	
Direction: East			
Direction: 178	Angle2: 20	Light Percentage: 87	
Direction: East			
Direction: 178	Angle2: 30	Light Percentage: 84	
Direction: East			
Direction: 178	Angle2: 40	Light Percentage: 75	
Direction: East			
Direction: 178	Angle2: 55	Light Percentage: 73	
Direction:North			
Direction:North	Angle1: 90	Angle2: 75	Light Percentage: 33
Direction:North			
Direction:North	Angle1: 90	Angle2: 90	Light Percentage: 35
Direction:North			
Direction:North	Angle1: 90	Angle2: 100	Light Percentage: 36
Direction:North			
Direction:North	Angle1: 90	Angle2: 110	Light Percentage: 34
Direction:North			
Direction:North	Angle1: 90	Angle2: 125	Light Percentage: 34

Figure 56 shows the recorded data from the solar panel system.

At 08:26 am in the West direction, the solar panel exhibited its peak light absorption at an angle of 40 degrees, achieving a remarkable 35% light percentage. Similarly, the Southwest direction showcased optimal performance at an angle of 20 degrees, yielding a highest recorded light percentage of 35%.

The South and Southeast orientations demonstrated peak light absorption at angles 30 degrees (43%) and 5 degrees (74%), respectively, underscoring the system's efficacy in capturing sunlight. In the East direction, the solar panel achieved an outstanding 93% light percentage at an angle of 5 degrees, emphasizing the system's ability to maximize energy harvesting.

The North direction, while demonstrating lesser sensitivity to angle variations, still exhibited optimization at an angle of 100 k(30) degrees with a light percentage of

36%.

Direction: West			
Direction: 1	Angle2: 5	Light Percentage: 53	
Direction: West			
Direction: 1	Angle2: 20	Light Percentage: 56	
Direction: West			
Direction: 1	Angle2: 30	Light Percentage: 64	
Direction: West			
Direction: 1	Angle2: 40	Light Percentage: 71	
Direction: West			
Direction: 1	Angle2: 55	Light Percentage: 90	
Direction:Southwest			
Direction: 45	Angle2: 5	Light Percentage: 58	
Direction:Southwest			
Direction: 45	Angle2: 20	Light Percentage: 59	
Direction:Southwest			
Direction: 45	Angle2: 30	Light Percentage: 67	
Direction:Southwest			
Direction: 45	Angle2: 40	Light Percentage: 77	
Direction:Southwest			
Direction: 45	Angle2: 55	Light Percentage: 94	
Direction: South			
Direction: 90	Angle2: 5	Light Percentage: 56	
Direction: South			
Direction: 90	Angle2: 20	Light Percentage: 60	
Direction: South			
Direction: 90	Angle2: 30	Light Percentage: 69	
Direction: South			
Direction: 90	Angle2: 40	Light Percentage: 84	
Direction: South			
Direction: 90	Angle2: 55	Light Percentage: 97	

Figure 57 show recorded data from the solar panel system.

Direction: Southeast			
Direction: 135	Angle2: 5	Light Percentage: 57	
Direction: Southeast			
Direction: 135	Angle2: 20	Light Percentage: 62	
Direction: Southeast			
Direction: 135	Angle2: 30	Light Percentage: 71	
Direction: Southeast			
Direction: 135	Angle2: 40	Light Percentage: 82	
Direction: Southeast			
Direction: 135	Angle2: 55	Light Percentage: 96	
Direction: East			
Direction: 178	Angle2: 5	Light Percentage: 60	
Direction: East			
Direction: 178	Angle2: 20	Light Percentage: 67	
Direction: East			
Direction: 178	Angle2: 30	Light Percentage: 74	
Direction: East			
Direction: 178	Angle2: 40	Light Percentage: 86	
Direction: East			
Direction: 178	Angle2: 55	Light Percentage: 97	
Direction:North			
Direction:North	Angle1: 90	Angle2: 75	Light Percentage: 51
Direction:North			
Direction:North	Angle1: 90	Angle2: 90	Light Percentage: 63
Direction:North			
Direction:North	Angle1: 90	Angle2: 100	Light Percentage: 66
Direction:North			
Direction:North	Angle1: 90	Angle2: 110	Light Percentage: 73
Direction:North			
Direction:North	Angle1: 90	Angle2: 125	Light Percentage: 87

Figure 58 shows the recorded data from the solar panel system.

At 12:26 Pm in the West direction, the solar panel showcased remarkable light absorption, reaching its peak percentage of 90% at an angle of 55 degrees. Likewise, the Southwest orientation demonstrated optimal performance, achieving a highest recorded light percentage of 94% at an angle of 55 degrees.

The South and Southeast directions exhibited peak light absorption at angles 55 degrees (97%) and 96 degrees (97%), respectively, underlining the system's efficacy in capturing sunlight. In the East direction, the solar panel achieved an outstanding 97% light percentage at an angle of 55 degrees, reaffirming the system's ability to maximize energy harvesting.

The North direction, while showing sensitivity to angle variations, exhibited optimization at an angle of 125(55) degrees, reaching a light percentage of 87%.

Direction: West			
Direction: 1	Angle2: 5	Light Percentage: 91	
Direction: West			
Direction: 1	Angle2: 20	Light Percentage: 87	
Direction: West			
Direction: 1	Angle2: 30	Light Percentage: 82	
Direction: West			
Direction: 1	Angle2: 40	Light Percentage: 79	
Direction: West			
Direction: 1	Angle2: 55	Light Percentage: 72	
Direction:Southwest			
Direction: 45	Angle2: 5	Light Percentage: 79	
Direction:Southwest			
Direction: 45	Angle2: 20	Light Percentage: 74	
Direction:Southwest			
Direction: 45	Angle2: 30	Light Percentage: 70	
Direction:Southwest			
Direction: 45	Angle2: 40	Light Percentage: 66	
Direction:Southwest			
Direction: 45	Angle2: 55	Light Percentage: 60	
Direction: South			
Direction: 90	Angle2: 5	Light Percentage: 31	
Direction: South			
Direction: 90	Angle2: 20	Light Percentage: 34	
Direction: South			
Direction: 90	Angle2: 30	Light Percentage: 39	
Direction: South			
Direction: 90	Angle2: 40	Light Percentage: 37	
Direction: South			
Direction: 90	Angle2: 55	Light Percentage: 40	

Figure 59 show the data recorded from the solar panel system.

Direction: Southeast			
Direction: 135	Angle2: 5	Light Percentage: 32	
Direction: Southeast			
Direction: 135	Angle2: 20	Light Percentage: 36	
Direction: Southeast			
Direction: 135	Angle2: 30	Light Percentage: 39	
Direction: Southeast			
Direction: 135	Angle2: 40	Light Percentage: 39	
Direction: Southeast			
Direction: 135	Angle2: 55	Light Percentage: 42	
Direction: East			
Direction: 178	Angle2: 5	Light Percentage: 32	
Direction: East			
Direction: 178	Angle2: 20	Light Percentage: 36	
Direction: East			
Direction: 178	Angle2: 30	Light Percentage: 36	
Direction: East			
Direction: 178	Angle2: 40	Light Percentage: 35	
Direction: East			
Direction: 178	Angle2: 55	Light Percentage: 38	
Direction:North			
Direction:North	Angle1: 90	Angle2: 75	Light Percentage: 32
Direction:North			
Direction:North	Angle1: 90	Angle2: 90	Light Percentage: 35
Direction:North			
Direction:North	Angle1: 90	Angle2: 100	Light Percentage: 37
Direction:North			
Direction:North	Angle1: 90	Angle2: 110	Light Percentage: 37
Direction:North			
Direction:North	Angle1: 90	Angle2: 125	Light Percentage: 38

Figure 60 show the data that is recorded from the solar panel system.

At 17:26 Pm in the West direction, the solar panel exhibited impressive light absorption, achieving its highest recorded light percentage of 91% at an angle of 5 degrees. Conversely, the Southwest orientation showcased optimal performance with a peak light percentage of 79% at an angle of 5 degrees, illustrating the system's versatility.

The South and Southeast directions demonstrated variations in light absorption, reaching peak percentages at angles 30 degrees (39%) and 55 degrees (42%), respectively. In the East direction, the solar panel achieved a notable 38% light percentage at an angle of 55 degrees, underlining its adaptability to diverse angles.

The North direction exhibited lower sensitivity to angle variations, with a gradual increase in light percentages up to 38% at an angle of 125 degrees. These findings underscore the Arduino-powered system's capacity to dynamically position the solar panel for optimal energy absorption, showcasing its adaptability and effectiveness across diverse environmental scenarios.

V. CONCLUSION

In conclusion, a comprehensive study has been conducted on 30 solar panels implemented at Istanbul Aydin University, utilizing the PVGIS software for analysis. The study spanned across three different years, namely 2018, 2019, and 2020, providing a longitudinal perspective on the performance of the solar panel installations over time.

This research was further augmented by the implementation of a solar panel system project, designed to record the efficiency of each solar panel across various directions and angles. The project, leveraging Arduino technology, dynamically adjusted the solar panels to optimize their orientations for enhanced energy absorption.

The culmination of this effort has yielded valuable insights into the solar panel system's adaptability and efficiency under diverse environmental conditions. The collected data, exemplified by the three datasets provided, underscores the significance of precise angle adjustments in maximizing light absorption. The recorded light percentages, varying across different directional orientations and servo angles, serve as a testament to the effectiveness of the implemented solar panel system.

Through the combination of real-world solar panel installations and systematic data collection, this study not only contributes to the broader understanding of solar energy utilization but also provides practical insights for optimizing solar panel performance in the specific context of Istanbul Aydin University. This research lays the groundwork for informed decision-making and potential enhancements in future solar energy projects, further advancing the sustainable energy landscape.

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APPENDICES

```
#include <Servo.h>
#include <SPI.h>
#include <SdFat.h>
#include <Wire.h>
#include <DS3231.h>
DS3231 clock;
RTCDateTime dt;

const int servo1Pin = 9;
const int servo2Pin = 10;
const int lightSensorPin = A0;
const int chipSelectPin = 53;

Servo servo1;
Servo servo2;
SdFat SD;
File dataFile;


void setup() {
  Serial.begin(9600);
  servo1.attach(servo1Pin);
  servo2.attach(servo2Pin);

  clock.begin();



  clock.setDateTime( __DATE__ , __TIME__ );



```

Figure 61 Arduino code.

```
  if (!SD.begin(chipSelectPin)) {
    Serial.println("SD Initialization failed!");
    return;
  }

  dataFile = SD.open("data.csv", O_WRITE | O_CREAT);

  if (dataFile) {
    Serial.println("File opened successfully");
  } else {
    Serial.println("Error opening file!");
  }
}

void loop() {
   if (!SD.begin(chipSelectPin)) {
    Serial.println("SD Initialization failed!");
    return;
  }

  dataFile = SD.open("data.csv", O_WRITE | O_APPEND);

  if (dataFile) {
    Serial.println("File opened successfully");
  } else {
    Serial.println("Error opening file!");
  }

  performOperations();

  delay(3600000);
}
```

Figure 62 Arduino Code.

```
void performOperations() {
  int angles1[] = {1,45, 90, 135, 178};
  int angles2[] = {5, 20, 30, 40, 55};

  dt = clock.getDateTime();
    dataFile.println("");
    dataFile.println("");
  dataFile.print(dt.year);    dataFile.print("-");
  dataFile.print(dt.month);   dataFile.print("-");
  dataFile.print(dt.day);     dataFile.print(" ");
  dataFile.print(dt.hour);    dataFile.print(":");
  dataFile.print(dt.minute);  dataFile.print(":");
  dataFile.print(dt.second);  dataFile.println("");

  for (int i = 0; i < 5; i++) {
    int angle1 = angles1[i];









    moveServo1(angle1);

    for (int j = 0; j < 5; j++) {
      int angle2 = angles2[j];
      moveServo2(angle2);

      int lightPercentage = readLightPercentage();

```

Figure 63 Arduino Code.

```

      Serial.print("Direction: ");
      Serial.print(angle1);
      Serial.print(", Angle2: ");
      Serial.print(angle2);
      Serial.print(", Light Percentage: ");
      Serial.println(lightPercentage);


      if (dataFile) {
        if (i == 0) {
      dataFile.println("Direction: West");
    }
    if (i == 1) {
      dataFile.println("Direction:Southwest");
    }
    if (i == 2) {
      dataFile.println("Direction: South");
    }
    if (i == 3) {
      dataFile.println("Direction: Southeast");
    }
    if (i == 4) {
      dataFile.println("Direction: East");
    }
        dataFile.print("Direction: ");
        dataFile.print(angle1);
        dataFile.print(", Angle2: ");
        dataFile.print(angle2);
        dataFile.print(", Light Percentage: ");
        dataFile.println(lightPercentage);
      } else {
        Serial.println("Error writing to file!");
```

Figure 64 Arduino Code.

```
      }

      delay(1000);
    }
  }


  int servo2Angles[] = {75, 90, 100, 110, 125};
  Serial.println("Direction:North ");
  for (int i = 0; i < 5; i++) {
    moveServo1(90);

    int angle2 = servo2Angles[i];
    moveServo2(angle2);
    delay(1000);
    int lightPercentage = readLightPercentage();

    Serial.print("Angle1: 90, Angle2: ");
    Serial.print(angle2);
    Serial.print(", Light Percentage: ");
    Serial.println(lightPercentage);


    if (dataFile) {
      dataFile.println("Direction:North ");
      dataFile.print("Direction:North, Angle1: 90, Angle2: ");
      dataFile.print(angle2);
      dataFile.print(", Light Percentage: ");
      dataFile.println(lightPercentage);
    } else {
      Serial.println("Error writing to file!");
    }
  }
```

Figure 65 Arduino Code.

```


  dataFile.close();
}

void moveServo1(int angle) {
  servo1.write(angle);
  delay(500);
}

void moveServo2(int angle) {
  servo2.write(angle);
  delay(500);
}

int readLightPercentage() {
  int sensorValue = analogRead(lightSensorPin);
  int lightPercentage = map(sensorValue, 0, 1023, 0, 100);
  return lightPercentage;
}

```

Figure 66 Arduino Code.

RESUME

KHODR HAJ ALI

EDUCATION:

- Master in Mechanical Engineering at Istanbul Aydin University. 2021-2023
- Bachelor of Engineering in Mechanical Engineering AUSTRILLIAN UNIVERSITY OF KUWAIT (AUK) 2018-2021, KUWAIT

SKILLS AND INTEREST:

- Design and Simulation Technologies: AutoCAD, Solid Works, and Vibration Matlab. .
- Microsoft Office (Excel, Word, PowerPoint.)
- Areas of Interest: Strength of material, Material science, C.F.D., Design and Optimization.

LANGUAGES:

- Arabic: Native
- English: Full Professional Proficiency
- Turkish: Starter