T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

OPERATION AND MAINTENANCE OPTIMIZATION OF AN ON-GRID SOLAR FARM IN JORDAN

MASTER’S THESIS

Mohamed Sallam Abdel latif ALDAWOUDI

Department of Mechanical Engineering
Energy Technologies Program

APRIL, 2024

T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

OPERATION AND MAINTENANCE OPTIMIZATION OF AN ON-GRID SOLAR FARM IN JORDAN

MASTER'S THESIS

Mohamed Sallam Abdel latif ALDAWOUDI
Y2112.023003

Department of Mechanical Engineering
Energy Technologies Program

Thesis Advisor: Assist. Prof. Dr. Cem Savaş AYDIN

APRIL, 2024

ONAY FORMU

DECLARATION

I hereby declare with respect that the study Operation and Maintenance Optimization of an On-Grid Solar Farm in Jordan, 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 Bibliography. (27/03/2024)

Mohamed Dawoudi

FOREWORD

I want to say a big thank you to Dr. Cem Savaş AYDIN, my academic supervisor, for all their help and support during this research project. Their knowledge and encouragement helped me a lot and played a huge role in shaping this thesis. I am very grateful for their guidance and advice, which helped me navigate through the challenges of this project. Without their support, this thesis wouldn't have been possible.

I want to express my deep thanks to my dad, Eng. Salam Dawoudi, for his constant support and encouragement throughout my time in school. He always believed in me and was ready to help whenever I needed it. Without his guidance and advice, I wouldn't have been able to complete this thesis. I'm truly grateful for everything he's done for me, from cheering me on during late-night study sessions to offering valuable advice on my research. His unwavering faith in my abilities has been a constant source of strength.

I want to thank my mom, my sisters, and my partner for always supporting and understanding me during my studies. Their encouragement has kept me going. Lastly, a big thank you to my brother Eng. Omar Ghazal, and everyone who took part in this study or helped in any way. Your involvement was essential to finishing this research.

April, 2024 Mohamed Dawoudi

OPERATION AND MAINTENANCE OPTIMİZATION OF AN ON-GRID SOLAR FARM IN JORDAN

ABSTRACT

The critical need to guarantee sustainable energy futures and reduce climate change has led to an expanded global search for renewable energy sources (RES) in recent years. Solar energy is one of the most abundant, easily accessible, and environmentally friendly forms of renewable energy. On the other hand, careful consideration of several variables and elements impacting system performance is necessary for the best possible use of solar energy in grid-connected systems. Using solar power has a lot of promise to satisfy energy demands and lessen reliance on fossil fuels in areas like Jordan, which has plenty of sunshine and an increasing need for electricity.

Within this framework, the goal of this thesis is to progress grid-connected solar systems by the creation of a thorough mathematical model (MM) that maximizes both system economic viability and efficiency. The emphasis is on two critical factors that are necessary to improve energy production and performance ratio: the pace of soil mitigation and the installation of a vertical-axis tracking device. Stakeholders in solar energy projects can make decisions more easily when the MM creates an objective function that weighs possible earnings against installation and maintenance expenses. Making use of the model's non-linearity, a Particle Swarm Optimisation (PSO) technique is used to determine the ideal parameter values, which results in a well-balanced system performance and cost-effectiveness.

In addition, the study utilizes actual data obtained from solar system factories located in Jordan, guaranteeing the model's suitability for regional circumstances. The use of a daily tracking method based on a single axis and the modification of tilt angles to conform to ideal circumstances in Amman, Jordan, highlight the study's dedication to practical relevance and practical effect. In addition, to address the problem of dirt mitigation, the suggested regular cleaning schedule seeks to reduce annual loss factors, which in turn improves system lifetime and efficiency. This thesis aims to educate policymakers, energy planners, and industry stakeholders on methods to optimize the use of solar energy resources in Jordan and comparable areas by providing insights into the optimization of grid-connected solar systems.

Keywords: Jordan, Solar farm, operation and maintenance, Optimization

ÜRDÜN'DE BİR AĞ BAĞLANTILI GÜNEŞ ÇİFTLİĞİNİN İŞLETME VE BAKIMININ OPTİMİZASYONU

ÖZET

Sürdürülebilir enerji geleceklerini garanti altına almak ve iklim değişikliğini azaltmak için kritik bir ihtiyaç, son yıllarda yenilenebilir enerji kaynaklarının genişletilmiş küresel arayışına yol açmıştır. Güneş enerjisi, yenilenebilir enerjinin en bol, kolay erişilebilir ve çevre dostu formlarından biridir. Öte yandan, güneş enerjisinin grid bağlantılı sistemlerde en iyi şekilde kullanılabilmesi için sistem performansını etkileyen birkaç değişken ve unsura dikkatli bir şekilde gözden geçirilmesi gerekmektedir. Güneş enerjisinin kullanımı, Ürdün gibi güneş ışığı bol ve elektrik ihtiyacı artan bölgelerde enerji taleplerini karşılamak ve fosil yakıtlara olan bağımlılığı azaltmak için büyük bir vaat taşımaktadır. Bu çerçevede, bu tezin amacı, sistem ekonomik uygunluğunu ve verimliliğini maksimize eden kapsamlı bir matematiksel model (MM) oluşturarak grid bağlantılı güneş sistemlerinin ilerlemesini sağlamaktır. Enerji üretimini ve performans oranını iyileştirmek için gereken iki temel faktöre vurgu yapılır: toprak azaltım hızı ve dikey eksenli izleme cihazının kurulumu. Güneş enerjisi projelerinde paydaşlar, MM'nin mümkün olan kazançları kurulum ve bakım masrafları karşısında değerlendiren bir amaç fonksiyonu oluşturduğunda karar verme süreçlerini daha kolay hale getirebilirler. Modelin doğrusal olmayanlığını kullanarak, bir Parçacık Sürü Optimizasyonu (PSO) tekniği, ideal parametre değerlerini belirlemek için kullanılır, bu da dengeli bir sistem performansı ve maliyet etkinliği sağlar. Ayrıca, çalışma Ürdün'deki güneş enerjisi fabrikalarından elde edilen gerçek verilerden yararlanarak, modelin bölgesel koşullara uygunluğunu garanti altına alır. Günlük izleme yönteminin tek bir eksen üzerine dayandığı ve Amman, Ürdün'deki ideal koşullara uygun eğim açılarının değiştirilmesi, çalışmanın pratik öneme ve etkiye olan bağlılığını vurgular. Ayrıca, kir azaltma sorununu ele almak için önerilen düzenli temizlik programı, yıllık kayıp faktörlerini azaltmayı amaçlar, bu da sistem ömrünü ve verimliliğini artırır. Bu tez, Ürdün ve benzer bölgelerde güneş enerjisi kaynaklarının kullanımını optimize etme yöntemleri hakkında politika yapıcılarına, enerji planlayıcılarına ve endüstri paydaşlarına içgörüler sunarak grid bağlantılı güneş sistemlerinin optimizasyonuna dair bilgi sağlamayı amaçlamaktadır.

Anahtar Kelimeler: Ürdün, Güneş Çiftliği, İşletme Ve Bakim, Optimizasyonu

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The use of renewable energy sources has accelerated recently on a global scale, providing promising answers to the world's energy and environmental problems. Solar energy is unique among these sources because of its sustainability and wide availability. Solar farms are becoming more common in sunny locations like Jordan to harness abundant sunshine for energy. Establishing these farms is vital for sustainable energy production, but regular maintenance is crucial for long-term operation efficiency. Well-maintained solar farms generate more electricity and require less frequent downtime, ultimately increasing profitability.

The primary objective does not lie in the direct development of the photovoltaic (PV) panel design, as there exist specialized companies equipped with numerous engineers dedicated to such tasks. Jordan, being one of the growing nations, presents a unique context. In my role as an engineer in the Middle East, the principal focus is directed towards the maintenance and operational continuity of the solar power system. The dynamic growth of Jordan necessitates a strategic allocation of responsibilities, where my role is not to replicate the efforts of design-focused entities but rather to ensure the robust and uninterrupted functioning of the existing system. By dedicating efforts to system reliability, we contribute to the sustained energy infrastructure of a growing country so this thesis focuses on optimizing the O&M practices of a specific on-grid solar farm located in Jordan. The aim is to determine and execute tactics that increase the farm's efficacy and guarantee its enduring viability.

This study looks at possible ways to improve present practices and seeks to:

- Enhance operational efficiency: This involves optimizing equipment performance and maximizing solar energy capture.
- Implement effective maintenance practices: This includes preventative measures and timely repairs to minimize downtime and ensure smooth operation.

Optimizing these aspects of the solar farm's O&M can significantly contribute to increased electricity production for Jordan, promoting a more sustainable and reliable energy sector.

II. BACKGROUND AND LİTERATURE REVİEW

A. Jordan’s Current Situation

Jordan stands as one of the leaders in renewable energy adoption and clean energy growth within the Middle East and North Africa (MENA) region. Over 20% of Jordan's electrical grid currently relies on solar or wind energy, intending to reach 31% by 2030. However, surpassing this percentage proves challenging until effective storage options are developed. Moreover, factors such as surplus capacity, moderate demand growth, and non-renewable energy diversification endeavors pose limitations to the immediate potential for renewable projects soon. To address these challenges and promote overall energy security, the Jordan National Energy Strategy 2020-2030 emphasizes boosting energy efficiency measures, diversifying the energy mix, increasing the proportion of renewable energy sources in the country's overall energy consumption, reducing carbon emissions, and lowering energy prices. Furthermore, the policy aims to decrease reliance on imported fossil fuels for power generation. It sets a target where 48.5 percent of the country's electricity will be produced locally by the end of 2030. The nation of Jordan, with its abundant sunshine of 316 days per year, favorable wind speeds ranging from 7 to 8.5 m/s, and vast desert areas sparsely populated, holds great potential for long-term renewable energy expansion (The International Trade Administration, 2019).

1. National Situation

a. Location and Geography

Situated strategically in the Middle East, Jordan acts as a pivotal nexus connecting Asia, Africa, and Europe. Spanning an area of 89,318 square kilometers, the nation showcases a varied landscape, with around 75% of its expanse dominated by desert terrain. Jordan can be delineated into three principal geographical and climatic regions: the Jordan Valley, the Mountain Heights Plateau, and the Eastern Desert or Badia region. The Jordan Valley, extending down the entire western side towards the Dead Sea (referred to as the Ghor in Arabic), emerges as the most fertile sector in the nation. Boasting a year-round agricultural climate, substantial winter precipitation, and extensive summer irrigation, the Ghor stands as the agricultural hub of Jordan. The Mountain Heights Plateau serves as the demarcation between the Jordan Valley and the eastern desert plains, receiving heightened rainfall and displaying a more luxuriant landscape. This zone harbors major population hubs like Amman, Irbid, Zarqa, Madaba, and Karak. Jordan undergoes protracted, sweltering, and arid summers, coupled with brief, temperate winters. Its climatic patterns are dictated by its strategic positioning, sandwiched between the aridity of the Arabian Desert and the humidity emanating from the eastern Mediterranean

The eastern Desert, or Badia, is part of the North Arab Desert and receives little rain, averaging fewer than 50 millimeters per year. The Badia's climate changes greatly between day and night, as well as between summer and winter, with summer temperatures surpassing 40°C and winter nights that are cold, dry, and windy (Ministry of Environment, 2021).

b. Demographic and social challenges

In 2023, the population of Jordan reached 11,337,052 people. The majority, approximately 90.3%, resided in urban areas, while the remaining 9.7% lived in rural regions. Men slightly outnumbered women with a representation of 53% and 47%, respectively. Age distribution revealed a significant presence of young individuals, as 44.3% were within the age range of 0 to 19 years old. Additionally, the working-age population (20 to 59 years) accounted for around 50.3%.

Over the past decade, Jordan's population growth rate has experienced fluctuations due to significant events like the crises in Iraq and Syria. Between 1994 and 2004, the population witnessed a steady growth of 2.6%. However, from 2004 to 2015, that growth rate surged to an impressive 5.3%, primarily driven by an unprecedented influx of refugees. By 2019, approximately 1.3 million Syrians sought refuge in Jordan, with only 664,226 officially registered as refugees according to the United Nations High Commissioner for Refugees (UNHCR).

Approximately 20% of the Syrian refugees resided in camps, while the majority lived in urban areas across Jordan. These refugees relied on the government for infrastructure and basic services, which strained Jordan's limited natural resources. Despite almost a decade since the onset of the Syrian crisis, Jordan has consistently supported these refugees, met their humanitarian needs and helped them build resilience. The government estimated that hosting the Syrian population incurred an annual cost of around US$1.4 billion, highlighting the country's dedication to assisting those in need (Ministry of Environment, 2021).

2. Energy sector

a. The Existing Electric Grid

Figure 2.1 illustrates the present electric grid, boasting a system capacity of 3168MW and a transmission network operating at 132kV and 400kV. The connectivity to Syria is facilitated by 230kV and 400kV tie lines, while ties to Egypt are established through 400kV lines. Currently, the installed grid efficiently serves 99.9% of the Jordanian population with electricity (National Electric Power Company, 2020)

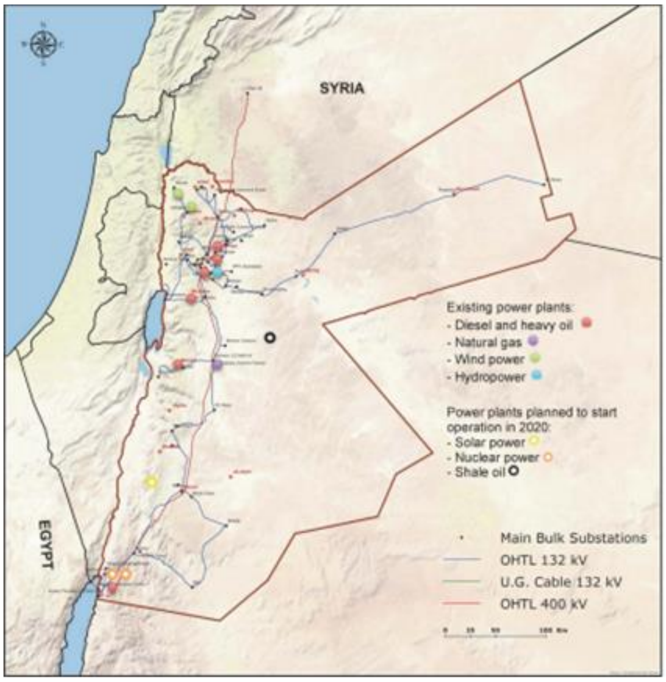


Figure 1 The transmission lines of the Jordanian grid (National Electric Power Company, 2020)

b. Renewable Energy Potentials

Jordan's ability to generate a minimum of 1000 GWh annually is underscored by (Zafar, 2021) study. A recent examination by the International Renewable Energy Agency (IRENA) in 2012 suggests that the cost of harnessing energy from concentrated solar power (CSP) could potentially drop to $0.14/kWh, assuming a storage duration of less than six hours. In contrast, traditional natural gas combustion turbines are priced at \$0.13/kWh, offshore wind turbines at \$0.20/kWh, and advanced nuclear power at approximately \$0.1/kWh. The conjunction of cost-effective solar power generation and Jordan's extensive solar potential establishes the viability of transitioning to renewable energy. Figure 2.2 visually encapsulates Jordan's solar irradiation.

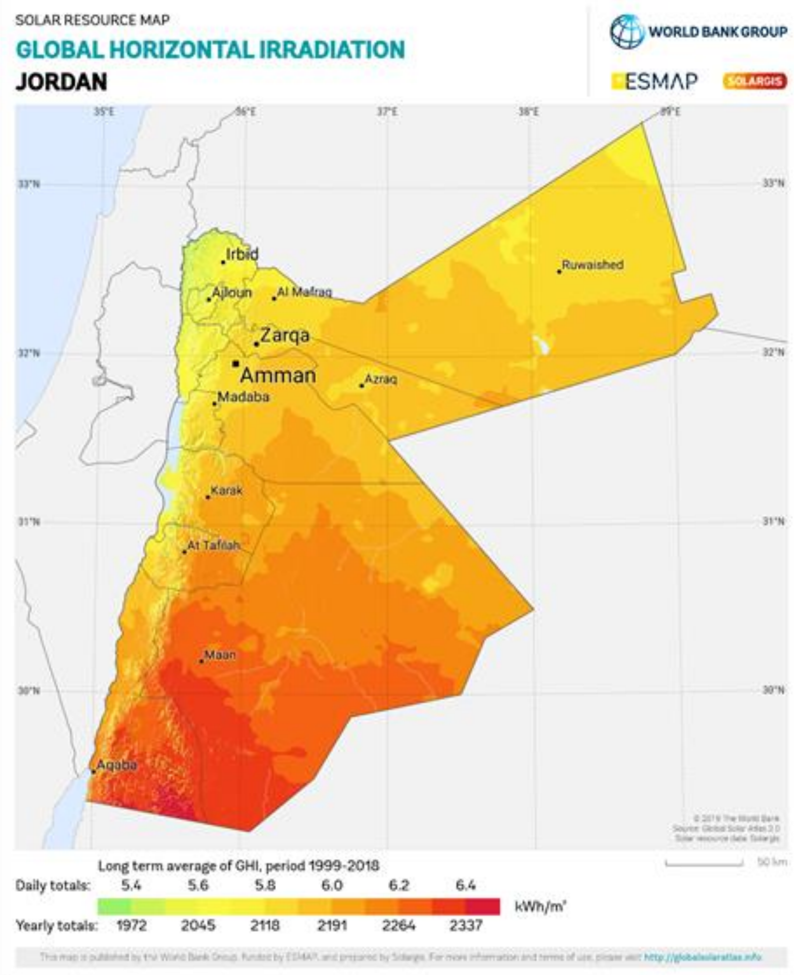


Figure 2 map of Jordan showing solar irradiation (Global Solar Atlas, 2019)

c. Renewable Energy and The Energy Efficiency

The Ministry of Energy and Mineral Resources has successfully established a legal and procedural framework for renewable energy. As a result, the use of renewable energy sources in the overall energy mix has significantly increased. This achievement is attributed to the ministry signing energy purchase agreements through Direct Proposal Schemes and harnessing solar energy through netmetering and wheeling systems. By the end of 2018, the contribution of solar and wind power to electricity generation reached approximately 1130 MW, accounting for 10.8% of the total power generated. These initiatives have sparked economic growth in the local investment sector, especially in regions hosting renewable energy projects. The development of these projects has generated numerous job opportunities both directly and indirectly, while also revitalizing supporting industries across various sectors. Established under Law N. (13) of 2012, the Jordan Renewable Energy and Energy Efficiency Fund (JREEEF) stands as a key supporter of renewable energy and energy efficiency initiatives. In tandem with the Ministry of Energy and the private sector's focus on more extensive investment projects, JREEEF assumes a vital role in backing smaller-scale projects across various sectors. This holistic approach not only enhances energy efficiency but also advocates for the integration of renewable energy sources. Moreover, the Ministry's collaboration with Rural Fils has made significant strides in advancing renewable energy adoption, particularly through the implementation of 2 kW solar systems in qualifying economically disadvantaged households. The primary goal of this initiative is to alleviate the financial strain of electricity expenses for these families.

In line with the government's renewable energy objectives, the approved National Energy Efficiency Action Plan (NEEAP) for the period 2020-2018 is strategically being implemented by the Ministry in collaboration with partners. This comprehensive plan encompasses sector-specific goals aligned with renewable energy targets and involves the active participation of both public and private institutions. The overarching objective is to achieve a 20% reduction in energy consumption by 2020 compared to the average consumption during the 2010-2006 period. Additionally, it aims to contribute to global initiatives focused on reducing greenhouse gas emissions (The Ministry of Energy and Mineral Resources, 2020)

d. Irradiance

Total irradiance may be separated into two parts: direct beam and diffuse. Direct beam radiation is radiation that comes straight from the sun and does not disperse in the atmosphere. Diffuse radiation refers to radiation that has been spread by clouds, rain, or any other possible threat. As radiation moves through the atmosphere, its incidence angle changes, causing it to diffuse rather than direct. The direct beam fraction refers to the ratio of direct beam to total radiation. Previous research on the effects of different real-world direct beam fractions on PV array power production under different irradiance circumstances is limited. To achieve maximum power generation, the PV array must catch as much irradiance as feasible.

To catch the most irradiance, the array must be oriented toward the sun, increasing the effective area and providing direct beam radiation with an incidence angle of 0°. Different methods can be used to aim toward the sun for most of the day, including permanent mounting systems with optimum tilts and azimuth angles, single-axis tracking systems with optimized tilt, and dual-axis tracking systems. The more advanced a system's tracking capabilities, the more likely it is to catch the maximum amount of irradiance. This research analyzed the measured performance benefits associated with tracking technology(Fraunhofer ISE, 2019) .

B. Photovoltaic solar cells

1. Historical Overview

The first experimental demonstration of the photovoltaic (PV) phenomena is assigned to French physicist Edmond Becquerel, who carried it out in his father's lab. Willoughby Smith later explained the light effect on selenium on February 20, 1873, by monitoring the current flow through the substance when it was exposed to light. In 1883, Charles Fritts improved upon these findings by creating the first solid-state PV solar cell. Creating junctions involved applying a thin layer of gold onto a semiconductor layer of selenium, albeit with an efficiency of only around 1%. In 1888, Aleksandr Stoletov, a Russian scientist, built upon Heinrich Hertz's 1887 work by introducing the utilization of the outer photoelectric effect for electricity generation (Gevorkian, 2007). In a landmark paper in 1905, Albert Einstein evolved a new idea of mild quanta and defined the photoelectric impact. He changed into provided the Nobel Prize in Physics in 1921 for this invention. In 1941, Vadim Lashkaryov invented p-n junctions between Cu2O and silver sulfide, marking an important milestone in the development of photocells(Korsun, 2020). Then, in 1946, Russell Ohl obtained a patent for a new semiconductor junction PV solar cell.

2. PV Solar Cell Definition

Illustrated in Figure 2.3, a basic photovoltaic (PV) cell is a device characterized by various electrical traits that respond to radiation, such as voltage, current, or resistance. This compact electrical apparatus effectively converts solar radiation into electricity through the photovoltaic effect phenomenon. (Sarah et al., 2020)

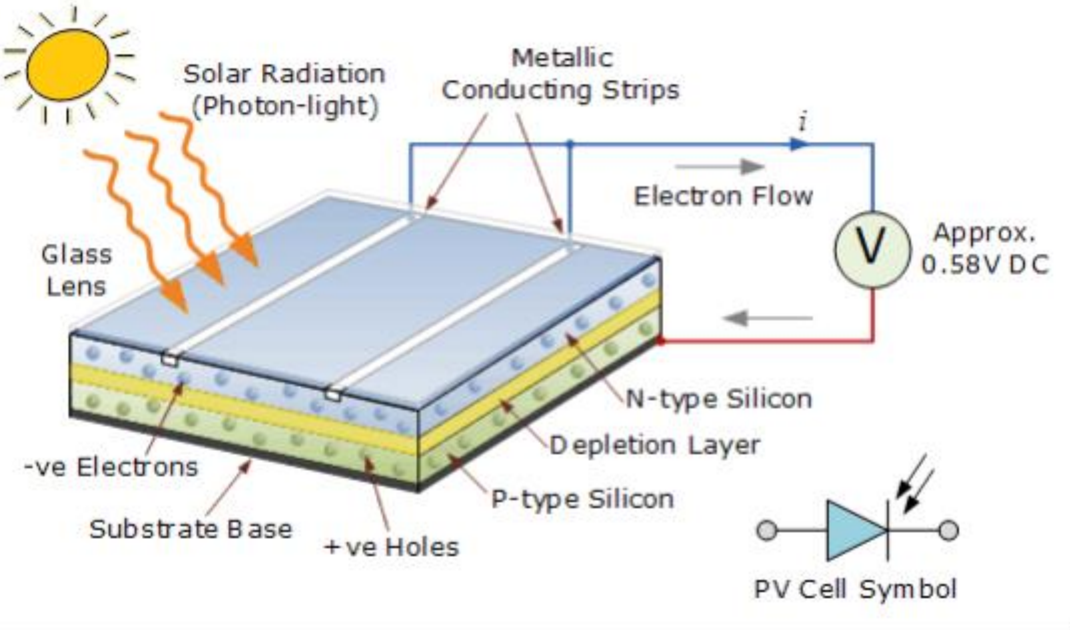


Figure 3 Basic PV cell (Sarah et al., 2020)

3. Mathematical Model Of Solar Photovoltaics

Highlighted by (Rodrigues et al., 2011), the exponential behavior characterizes the voltage and current features of solar cells. Figure 2.4 portrays the ideal equivalent circuit of a solar cell, incorporating a parallel arrangement of a diode and a current source. In practical applications, the equivalent model of solar cells introduces dual internal resistances, one in series and another in shunt.

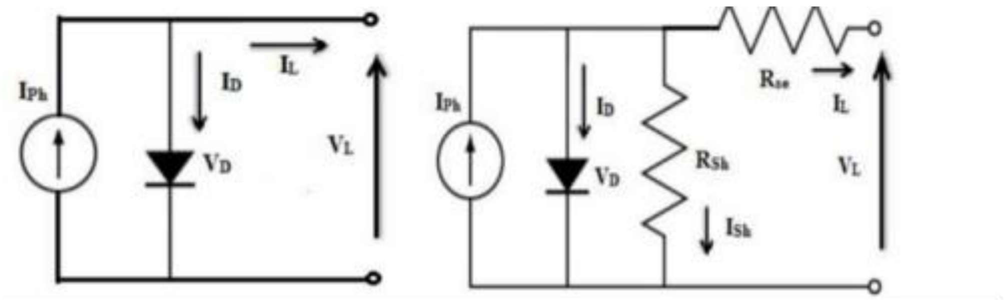


Figure 4 Ideal (left) and Equivalent (right) Circuits of a Solar Cell (Sarah et al., 2020)

The flow of electrons between the composite material and metal contact generates the series resistance, R_{Se}. Just before providing the load, electron and hole pairs recombine, affecting the load current and creating the shunt resistance, or R_{Sh}. I_L is the load current, while V_L stands for the voltage across the external load. The electrons in the "n" side area are activated each time sunlight strikes the solar cell's top. The photocurrent I_{Ph} is created by electrons moving from the "n" area to the "p" region. Kirchhoff's Current Law is used to derive the solar cell's current equation (Sarah et al., 2020) :

$I_L = I_{Ph} - I_D - I_{Sh}$	*II.1 Kirchhoff's Current Law*

Diode current (I_D) and voltage (V_D)is defined by:

$I_D = I_o \left(e^{\frac{qV_D}{nkT}} - 1 \right)$	2.2 Diode current

$V_D = \grave{V}_L + I_L R_{se}{}'$	2.3 Diode current

where q is the charge of the electron, k is the Boltzmann constant and T is the temperature in ^{o}K.

For the open circuit voltage V_{OC}, the load current I_L is zero. Thus it is given as:

$V_{OC} = \frac{nKT}{q} In \left(\frac{I_{Ph}}{I_o} + 1 \right)$	2.4 open circuit voltage

4. Types of PV Technology

a. Monocrystalline silicon

Representing a conventional approach, solar cells utilizing monocrystalline silicon are crafted from pure silicon crystals with an almost flawless continuous lattice structure. This unique characteristic allows for impressive light conversion efficiencies, typically hovering around 15%, though recent advancements from SunPower claim even higher efficiencies, reaching 22–24%. The challenging process of producing silicon crystals is the key contributor to the higher cost associated with this type of photovoltaic technology. To address cost considerations, recent innovations focus on reducing the overall thickness of the silicon material used in monocrystalline cells. Monocrystalline silicon cells typically exhibit a black or iridescent blue hue. Recognized for their durability, these cells are expected to have a lifespan of over 25 years (The Pennsylvania State University, 2013)

b. Polycrystalline (or multi-crystalline) silicon

Creating polycrystalline cells involves arranging multiple grains and plates of silicon crystals onto thin wafers. The production cost of this PV technology is lower than that of monocrystalline silicon cells, attributed to the simplicity and cost-effectiveness of producing smaller silicon components. However, polycrystalline cells exhibit an efficiency around 12% lower. Identified by their mosaic-like appearance, these cells are recognized for their durability and can potentially have a lifespan exceeding 25 years. Nonetheless, drawbacks of this PV technology include mechanical brittleness and a lower conversion efficiency, as highlighted by (The Pennsylvania State University, 2013)

c. Amorphous silicon (Thin-film)

For the creation of thin-film photovoltaic cells, a substrate glass is coated with a layer of silicon film. This technique, in contrast to mono- or polycrystalline cells, demands less silicon for production, albeit at the expense of reduced conversion efficiency. Thin-film PV demonstrates an efficiency of 6%, a significant drop compared to the 15% efficiency of single-crystal Si cells. Enhancing cell efficiency can be achieved through the integration of multiple cells into a layered framework. The key advantage of thin-film photovoltaic technology lies in its ability to deposit amorphous silicon on various substrates, providing flexibility and accommodating diverse shapes. This flexibility renders thin-film cells suitable for a broad spectrum of applications. Amorphous silicon, employed in thin-film technology, also exhibits a lower susceptibility to overheating, a factor that typically diminishes solar cell performance. Illustrated below in Figure 4.9 are the trends in the development and commercial implementation of various silicon PV technologies. Notably, no single type of silicon substrate dominates, as each presents a trade-off between cost and efficiency, as elucidated by (The Pennsylvania State University, 2013)

d. Polymer and Organic PV

Highly desirable for their capability for large-scale manufacturing and adaptability in terms of thicknesses and geometries, organic materials stand out.

These cells, in comparison to silicon cells, are considerably lightweight and boast flexibility, coupled with cost-effective manufacturing. However, their efficiency is roughly one-third of a standard Si cell, and occasional susceptibility to deterioration may result in shorter service life, as indicated by (The Pennsylvania State University, 2013)

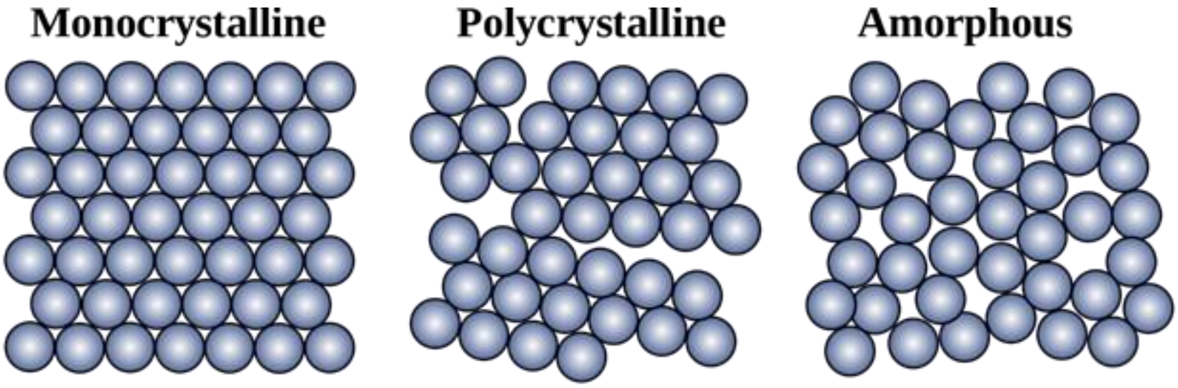


Figure 5 Types of PV Technology (Contributors, 2023)

5. Performance Characterization

a. The Fill Factor (FF) and Conversion Efficiency

These are key factors in solar cell performance (Razykov et al., 2011). FF's value is between 0 and 1. FF is described mathematically as a ratio of the comparing the product of short circuit current and open circuit voltage to the product of the maximum current value (I_m) and voltage (V_m).

$FF = \dfrac{I_m \times V_m}{I_{sc} \times V_{oc}}$	2.5 Fill Factor

$\eta = \dfrac{P_m}{P_{in}}$	2.6 conversion efficiency

b. Effect of the type of PV technology

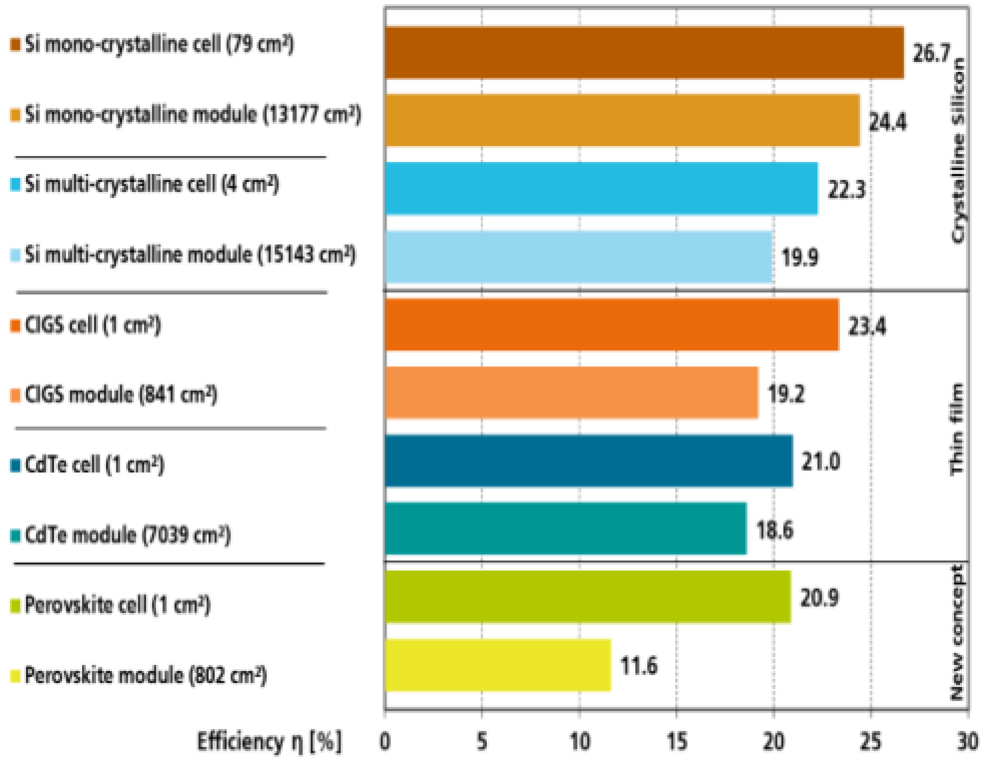


Figure 6 PV cell efficincies

c. Ambient temperature

The module's temperature affects its performance, but the ambient temperature also affects the module's temperature. The reason the module's temperature is greater than the surrounding air is because its glass frame traps heat from the sun's infrared rays. The module temperature rises, which reduces the cell's band gap (S. Kalogirou, 2009).

As a result, the cell's ISC rises while its VOC falls, canceling out the increase and adversely impacting power. Consequently, when the module's operational temperature rises, the module's power falls. The impact on monocrystalline PV cells is more than that on other technologies. Research indicates that 15% of a performance reduction may be observed in monocrystalline modules, however this percentage is just 5% in amorphous photovoltaic cells (Kumar & Rosen, 2011).

Raising the temperature can lead to physical issues like hot spots, deterioration in the wires or encapsulant, as well as a minimum efficiency and power at stagnation temperature(Ali et al., 2010).

d. Solar Irradiation

There is a linear link between solar irradiance and module power. Increased solar radiation produces more power by supplying more incident photons to activate the electrons in the solar cell's structure. Studies also reveal that various PV systems react differently to rising radiation(Ali et al., 2010).

e. Tilt Angle

The efficiency of the photovoltaic module relies upon on the quantity of sun radiation it receives, that's managed with the aid of the lean perspective and orientation of the solar module (El-Sebaii et al., 2010) . The solar module points north inside the southern hemisphere and south inside the northern hemisphere. But, the lean angle ought to be adjusted depending at the module installation vicinity. Several techniques may be used to optimize the rotation perspective, such as pc modeling, mechanical monitoring, or determining the most beneficial route all through daylight(Yadav & Chandel, 2013) .

6. Advantages of a Solar Cell

- Positioned as a renewable power source, a solar plant aligns with environmentally friendly practices.
- Operating silently without any moving components, it guarantees a noise-free operation.
- Exempt from emissions and radiation, the system upholds a pristine energy profile.
- Electricity generation is achieved without the need for fuels or water.
- Solar cells exhibit enduring durability with a lifespan of around 30 years

7. Disadvantages of Solar Cell

- Functionality is restricted without light from any source.
- The installation comes with a high initial cost.
- Power generation diminishes in cloudy weather.
- Implementing solar panels or cells demands a substantial geographical area, particularly for off-grid applications with energy storage requirements.

- Photo-Voltaic solar cells generate direct current (DC), necessitating the use of DC appliances or inverters (to convert DC to AC) for solar cell-based plants.

8. PV from cell to an array

Referred to as a cell, a semiconductor device transforms sunlight into electricity. A PV module, consisting of cells connected in series, is further integrated into a PV array through series and parallel connections. The output power required cannot be generated by a solitary solar cell, necessitating the connection of multiple photovoltaic cells to enhance the power output of a photovoltaic system. Typically, a solar module involves linking an adequate number of solar cells in series to establish the required standard voltage and output. Solar modules, or photovoltaic modules, available on the market for solar power generation facilities, can be designed to produce outputs ranging from 3 to 300 watts. Despite a single photovoltaic solar cell generating a minimal quantity, typically ranging from 1 to 2 watts, practicality constraints arise when integrating such low-power devices into a system.

The creation of a commercial solar system, alternatively known as a solar module or photovoltaic module, involves combining the necessary number of cells. Solar cells within a solar module are connected to a battery system, such as battery cell units. Consequently, the voltage across the positive terminals of a cell, linked to the negative terminal voltage of the solar module, equals the simple sum of the voltages across each of the module's series-connected cells (alternative energy tutorials, 2023)Referred to as a cell, a semiconductor device transforms sunlight into electricity. A PV module, consisting of cells connected in series, is further integrated into a PV array through series and parallel connections. The output power required cannot be generated by a solitary solar cell, necessitating the connection of multiple photovoltaic cells to enhance the power output of a photovoltaic system. Typically, a solar module involves linking an adequate number of solar cells in series to establish the required standard voltage and output. Solar modules, or photovoltaic modules, available on the market for solar power generation facilities, can be designed to produce outputs ranging from 3 to 300 watts. Despite a single photovoltaic solar cell generating a minimal quantity, typically ranging from 1 to 2 watts, practicality constraints arise when integrating such low-power devices into a system. The creation of a commercial solar system, alternatively known as a solar module or photovoltaic module, involves combining the necessary number of cells. Solar cells

within a solar module are connected to a battery system, such as battery cell units. Consequently, the voltage across the positive terminals of a cell, linked to the negative terminal voltage of the solar module, equals the simple sum of the voltages across each of the module's series-connected cells (alternative energy tutorials, 2023).

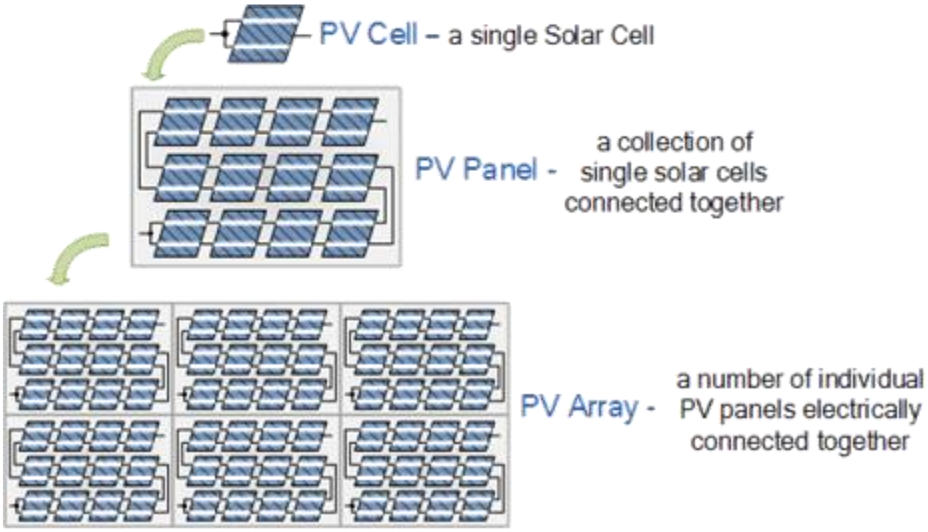


Figure .7 A Photovoltaic Solar Array (alternative energy tutorials, 2023)

9. Electrical Features of a PV Cell

Among the defining characteristics of power (P), current (I), and voltage (V), one finds the open-circuit voltage (Voc), short-circuit current (Isc), and maximum power point (MPPT) voltage and current. The output features of photovoltaic cells, drawing energy from their surroundings, closely correlate with environmental factors like sun irradiance, temperature, flight altitude, atmospheric mass, and even atmospheric density (Ouédraogo et al., 2021). For an accurate estimation of output, it is crucial to thoroughly account for the fluctuations in various environmental parameters at different times and altitudes, with a particular focus on the primary influencing elements. Illustrated in Figure 2.8 are the Characteristics of a Photovoltaic Cell.

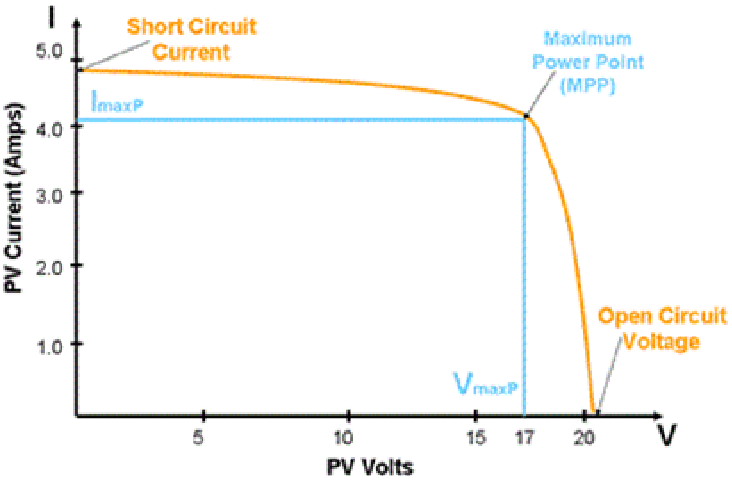


Figure 8 Characteristics of a Photovoltaic Cell

10. Conversion of Solar Energy into Electrical Energy

The conversion of solar energy into electrical energy is achieved by the use of photovoltaic panels. Photovoltaic is the direct conversion of sunlight to electricity. The solar panel is in direct sunlight. With this one, sunlight is captured and converted into an electrical current. The accumulator batteries receive this electric current after going via the charge controller. DC current is what is sent to the batteries. The inverter converts the DC current kept in the batteries into an AC current from the batteries. The inverter also converts the battery voltage to the standard domestic voltage. After that, electrical energy may be used. According to Figure 2.9, the solar panel, charge controller, battery, inverter, and AC load make up the majority of a photovoltaic system. (Singh Brar et al., 2017)

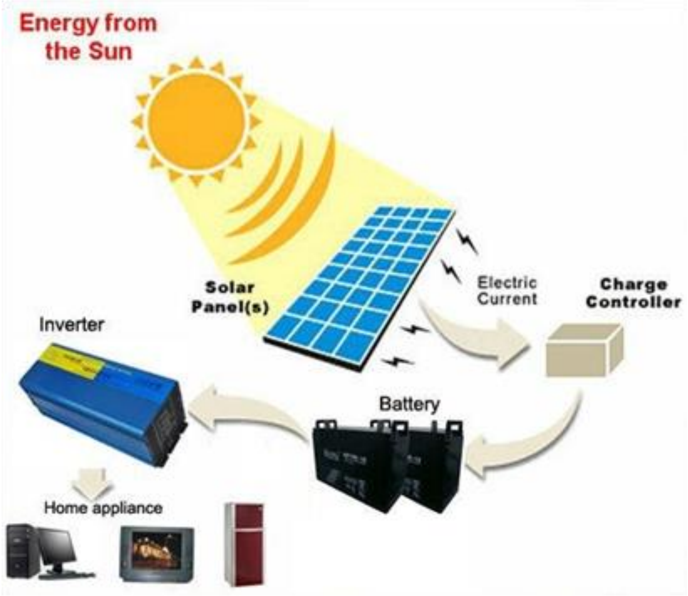


Figure 9 Basic diagram of a photovoltaic system (Singh Brar et al., 2017)

11. Influence of Atmospheric Conditions on the Performance of PV Solar Modules

a. Temperature Effect on a PV Solar cell Performance

The PV solar module temperature coefficient is a crucial characteristic that shows how the output of the module is influenced by its temperature. PV solar modules are rated at, which refers to typical testing circumstances. STC consists of a 25 °C temperature, 1000 W/m2 of radiation, and 1.5 air masses. Due to variations in ambient temperature, solar irradiance, and ambient mass, PV solar module actual production (under real circumstances) differs from PV solar module production at STC (rated), where the PV solar module power value at STC is referred to as rated or nominal power. The temperature coefficient, which varies with different temperatures, determines how much productivity is reduced as a result of rising temperatures.

The semiconductor band gap narrows as the temperature rises, which lowers the voltage at the solar cell's P-N junction as shown in Figure 2.10. The rise in solar cell temperature causes a decrease in a semiconductor's band gap, which results in an increase in the material's electron energy and an increase in the number of electrons in the conduction band (Dash & Gupta, 2015) .

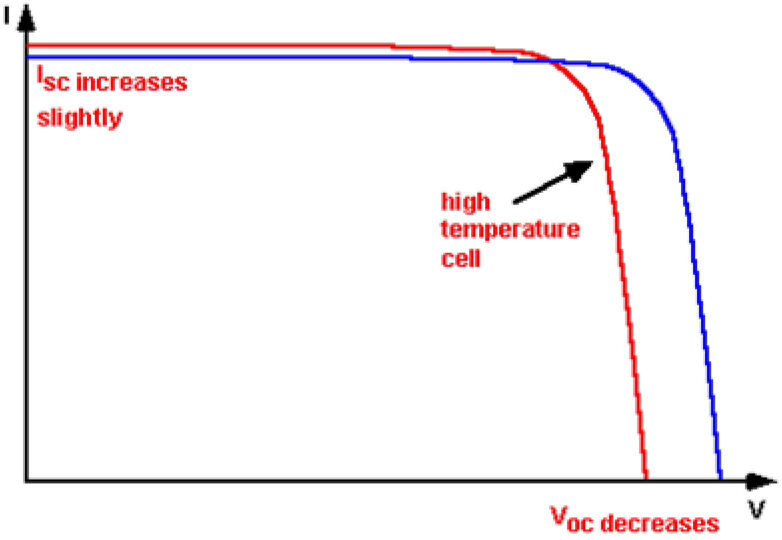


Figure 10 The relationship between temp. and voltage

b. Cloud Effect

The components of the local atmosphere are what have the other atmospheric effect on solar radiation received. The amount of solar radiation received is influenced by the cloud cover class. Figure 2.11 shows the impact of cloud cover on the output of a PV solar cell. The output power of PV solar modules is inversely proportional to the incoming light intensity. The PV solar cell can generate the most electricity during the hours of sunshine since it gets higher intensity solar radiation under clear skies than it does under overcast skies. Solar radiation will be at its lowest intensity when there is an overcast sky. The quantity of PV solar cell output is determined by cloud cover thickness and sky distribution, with heavier clouds further reducing production (Bird & Riordan, 1986).

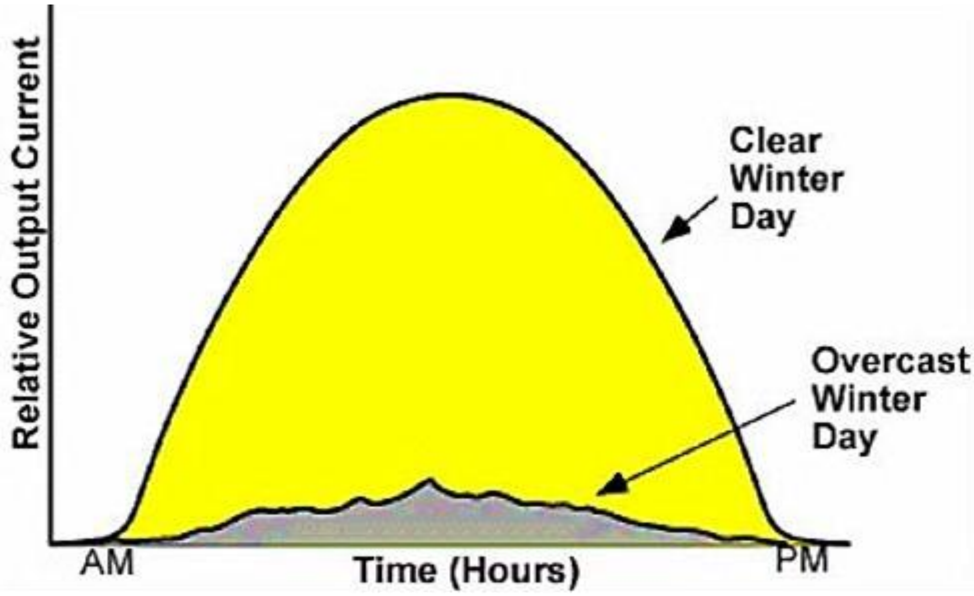


Figure 11 Cloudness effect on the solar radiation

c. Wind Effect

The manufacturing of solar cells faces minimal impact from wind speed, particularly in regions like Jordan-Amman where the wind is not as forceful. The influence of wind speed on the surface temperature of PV solar modules is negligible. Acting as an advection current, wind speed transfers heat from the surface of PV solar modules into the atmosphere, resulting in a reduction in the heat generated by the modules. This, in turn, contributes to a modest increase in the efficiency and performance of the PV solar modules (Koutroulis et al., 2001).

d. Solar Radiation Effect on the PV Solar cell Performance

The amount of sunshine influences the amount of electricity that a PV solar system creates using solar cell technology. More sunshine means the system produces more electricity. When there's less than 100 W/m2 of sunshine, the open circuit voltage increases from 0.0 to 0.5 volts because the solar system temperature drops. At the start of sunrise, the open circuit voltage of the solar cell goes up to just about its maximum level. When sunshine levels increase from 100-1000 W/m2, the voltage increases logarithmically to about 0.6 volts.The size of the solar cell affects the short circuit current, which rises linearly with solar radiation intensity. Because high-intensity solar radiation raises solar module temperature and increases current, the voltage of the PV solar module or cell is indirectly impacted by the intensity of the sun's radiation while the voltage is directly impacted by the PV solar module's type and its temperature coefficient. The voltage is increased or decreased in value depending on the PV solar cell type (Antonio Luque & Steven Hegedus, 2003). In figure 2.12 we see the solar radiation intensity effect on the PV solar cell operating curves.

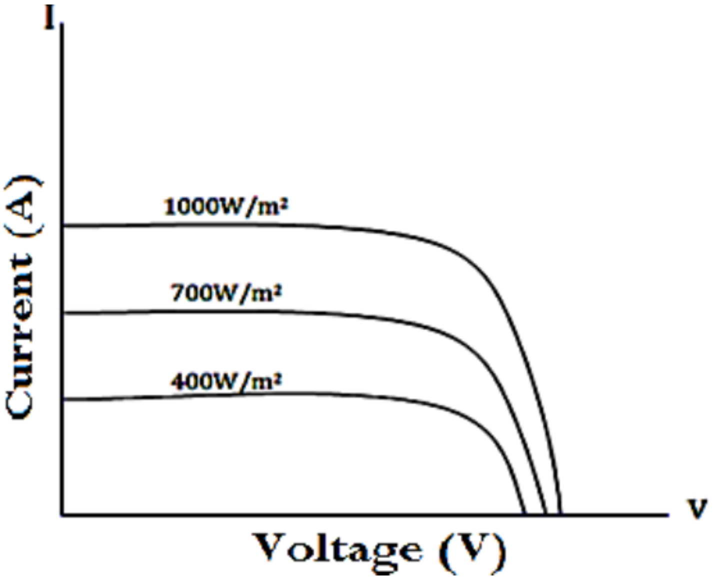


Figure 12 solar radiation intensity

e. Dust Effect

The ability of a solar panel to convert sunlight into electricity is inhibited when dust accumulates on the panel. The panel needs sunlight to generate energy through a process called photoelectric conversion; However, when there is dust on the screen, less sunlight is absorbed. The operational efficiency and power output of the panel suffers as a result. According to studies, dust can cause power production to drop anywhere between 4.5% and 8.1%. To preserve the panel's sensitivity to electrical factors and remove dust particles from its surface, an auto-cleaning system must be in place in order to increase performance. (Kaldellis & Kapsali, 2011).

C. Photovoltaic Systems

1. Introduction

Comprising solar panels, an inverter, and various electrical and mechanical components, a photovoltaic (PV) system utilizes solar energy to produce electricity. The scale of PV systems spans from small rooftop or portable units to large utility-scale power facilities (University of Calgary, 2020).

a. Working principle

The occurrence of the photovoltaic effect takes place when sunlight, composed of energy packets known as photons, strikes a solar panel. This process results in the generation of an electric current. While each panel produces a moderate amount of electricity, they can be aggregated into a solar array to yield larger quantities of energy. It's essential to recognize that the power generated by a solar panel (or array) is in direct current (DC). However, the majority of electronic devices, such as phones and laptops, are designed to operate on the electrical utility grid, which delivers and requires alternating current (AC). Consequently, solar power must undergo conversion from DC to AC using an inverter before it can be utilized (University of Calgary, 2020).

2. Advantages of PV Systems (Balfour et al., 2013)

- **Fewer blackouts**: PV systems are less subject to power outages compared to other electricity sources. This characteristic has led to their widespread popularity in healthcare settings.
- **Low operations and maintenance cost:** PV systems that are designed and installed correctly exhibit minimal operations and maintenance (O&M) expenses. As a result, these systems offer enhanced cost-effectiveness and a higher return on investment (ROI).
- **Increased efficiency at high altitudes**: PV systems demonstrate improved efficiency when deployed at higher altitudes due to their exposure to a greater amount of solar radiation.

3. Disadvantages of PV Systems (Balfour et al., 2013)

- **Initial expense**: The cost of a PV systems is high. However, most PV users find that the cost is recuperated in energy savings in five to 10 years.
- **Energy conservation:** practices A conservative attitude regarding energy use must be adopted to realize greater financial savings. Lower levels of energy waste result in the need for a smaller and less-expensive PV system.

4. Components of a PV system (Yang, 2020)

The Solar resource: The sun serves as the energy source for all photovoltaic (PV) systems within our solar system.

Array: An array is made up of several panels that are connected in series and parallel to give certain voltages and currents. Typically, the array is attached to a mounting frame.

Battery: A battery is an electrical energy storage device that operates on direct current (DC). Where outages are a risk, even grid-connected PV systems might benefit from a battery backup system.

Inverter: Transforming direct current (DC) electricity into alternating current (AC) power, the DC-AC inverter enables the utilization of this power in appliances, electronics, and various devices.

Charge controller: Regulating, charging, and maintaining battery voltage, the charge controller fulfills these functions..

Electrical load: includes the electronics and other appliances that utilize the power produced by the PV system. DC or AC electrical loads are both possible. Both types of electrical loads can be present on a single PV system.

Wiring: The wiring encompasses the wires that form complete circuits by connecting the system components.

Surge protector: A tool safeguarding against destructive power fluctuations and electrical shock due to short circuits is a surge protector.

5. Photovoltaic System Types.

There are various types of a PV system as follows:

a. Off-grid/Stand-alone System

Designed to supplement or replace the conventional grid power source, an off-grid/stand-alone solar electric system is typically utilized in rural or remote areas where access to the main power grid is limited due to the high cost of grid electricity. This system incorporates batteries as a storage solution and includes various components. Solar energy charges the batteries in off-grid systems, storing the energy until needed. The stored battery power is then used to operate various devices, either directly from the batteries as low-voltage equipment (such as 12V DC lights) or through a power inverter. The inverter, connected to the batteries, converts the battery voltage into mains equivalent for powering regular AC equipment (e.g., computer, television, radio, etc.).

Off-grid systems can vary in scale, ranging from a simple setup comprising a single PV module, battery, and controller to more sophisticated and costly systems featuring advanced control technology and substantial backup generators (Stapleton et al., 2012) Figure 2.12 provides a visual representation of the fundamental components of an off-grid system.

Designed to supplement or replace the conventional grid power source, an off-grid/stand-alone solar electric system is typically utilized in rural or remote areas where access to the main power grid is limited due to the high cost of grid electricity. This system incorporates batteries as a storage solution and includes various components. Solar energy charges the batteries in off-grid systems, storing the energy until needed. The stored battery power is then used to operate various devices, either directly from the batteries as low-voltage equipment (such as 12V DC lights) or through a power inverter. The inverter, connected to the batteries, converts the battery voltage into mains equivalent for powering regular AC equipment (e.g., computer, television, radio, etc.). Off-grid systems can vary in scale, ranging from a simple setup comprising a single PV module, battery, and controller to more sophisticated and costly systems featuring advanced control technology and substantial backup generators (Stapleton et al., 2012) Figure 2.13 provides a visual representation of the fundamental components of an off-grid system.

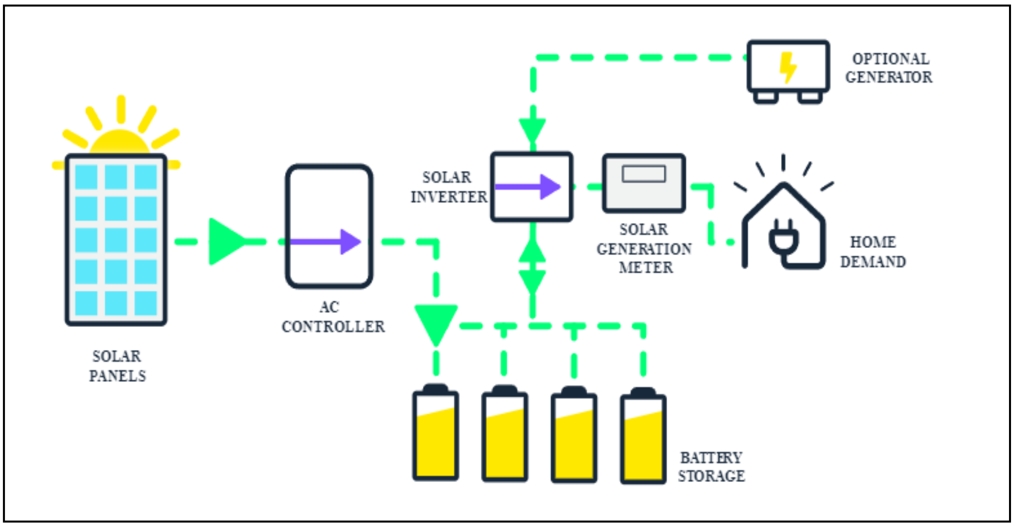


Figure 13 Off-grid System Scheme (Deege Solar, 2021)

b. On-grid/grid-connected system.

Unlike off-grid systems, an on-grid photovoltaic system is consistently linked to the utility grid and comprises six main components, as illustrated in Figure 2.13. These systems vary in size, encompassing small rooftop installations for homes and businesses to large solar power plants designed for utility applications. The fundamental concept of this system is to supply surplus power to the utility grid. Consequently, the grid serves as a storage system, enabling the building's power requirements to be met by importing electricity from the grid. An advantage of this configuration is that the system doesn't need to generate sufficient electricity to cover the property’s power demand, as is necessary in an off-grid system (Contributors, 2023b). This system type has several branches, including Central Grid-Connected PV Systems, which function similarly. These systems involve a direct connection of a large PV array to transmission lines. The scale of grid-connected central PV systems can range from as small as 50 kWp, with recent installations in Europe showcasing systems as large as 60 MWp. Significantly, there are companies planning grid-connected PV power plants exceeding 1 GWp, and numerous such plants are expected to be completed in the near future.

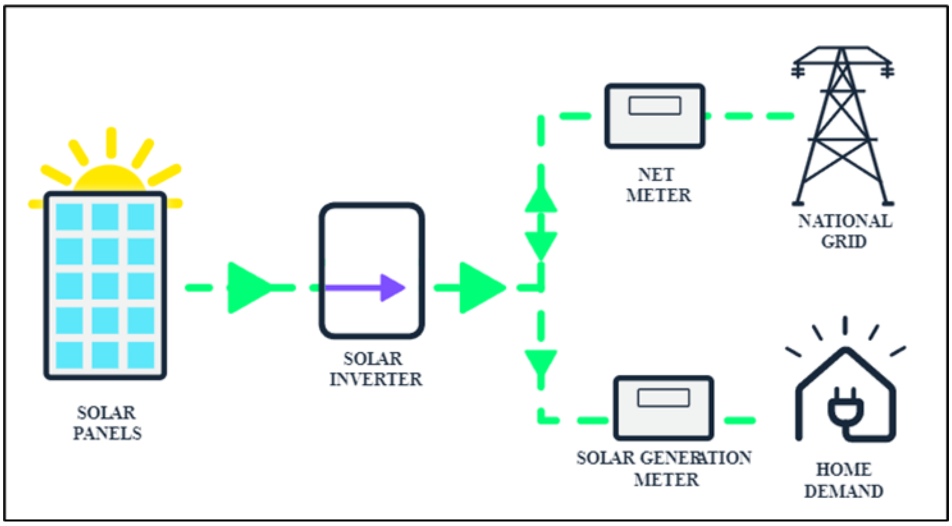


Figure 14 on-grid system Scheme (Deege Solar, 2021)

D. PV Performance Parameters.

PV performance optimization involves a multidimensional analysis of various aspects of PV technology, from solar module design and installation to overall system monitoring and maintenance The goal is to maximize energy efficiency, reduce losses, and expand the Performance life of PV systems This approach combines advanced techniques, data analytics, and new technologies to address the key challenges faced by solar systems (Marion et al., n.d.).

The below parameters are provided by IEC standard 61724:

1. Final yield (YF)

The ratio of the total energy produced by the system during a specified time interval to the rated power generation defines the final yield. Rated power generation refers to the energy that the system could potentially produce under standard test conditions (STC), characterized by a cell temperature of 25°C, an irradiance of 1000 W/m2 (Decker & Jahn, 1997).

$Y_F = \left(\frac{E_{AC}}{P_O}\right) (\text{kWh.kWp} - 1)$	Equation 2.7 Final yield (YF)

E stands for the amount of energy that is produced by the system in a specified time interval (E_{out} after the inverter) and P_O stands for rated power.

2. Reference yield

Describing the relationship between the total solar radiation (kWh/m2) reaching the panel and the reference solar irradiance (1 kW/m2) under standard test conditions (STC), the term "reference yield" (YR) is used. This is calculated by dividing the in-plane solar irradiation by 1 kW/m2. Equation 2.8 demonstrates that the reference yield represents the in-plane solar irradiation or an equivalent to the hours at the reference irradiance (Decker & Jahn, 1997).

$Y_r = \left(\frac{H_t}{G_{STC}}\right) (\mathrm{kWh.kWp} - 1)$	Equation 2.8 Reference yield (YR)

where H_t is the total in-plane solar radiation and G_{STC} is the reference irradiance at Standard Test Conditions, typically 1000 Wh/m^2.

3. Performance Ratio

Crucial for calculating system efficiency from solar conversion to the ultimate electricity supplied into the grid, the term "performance ratio" signifies the relationship between the energy fed into the grid (final yield) and the maximum energy the system could generate at its rated DC power during a specific peak sun-hour period (Reference Yield). This parameter is essential for determining various specifics about the PV system, including inverter losses, shading-related losses, DC and AC cable losses, and dust collection losses on the solar PV system's rated output. The performance index, as outlined in Equation [2.9] following IEC standards, is impacted by system efficiency and various environmental conditions (Decker & Jahn, 1997).

$Performance\ Ratio = \frac{Y_f}{Y_r} * 100\%$	Equation 2.9 Performance Ratio (PR)

E. Surplus Energy and Net Metering

1. Surplus energy

In photovoltaic (PV) systems, surplus energy is the additional power generated above and beyond the demands of immediate consumption. When net metering is used in grid-tied systems, surplus electricity is easily routed back into the grid, giving owners credits for future usage. On the other hand, excess energy is stored in batteries in off-grid systems with energy storage, guaranteeing a steady supply of electricity even during times of low solar activity. In order to maximise energy excess, load shifting techniques schedule energy-intensive jobs during periods of strong solar production, which promotes effective energy use. Innovative strategies include exporting excess energy to assist other energy systems or making contributions to community and virtual power plants, which increase the energy grid's overall sustainability and resilience. The significance of incorporating renewable sources into our energy mix is highlighted by efficient management of surplus energy. (Pacis et al., 2016)

2. Net metering

Customers that own renewable energy facilities, such solar power, can employ net metering, an electrical policy that enables them to contribute their output to the outside world while using electricity as needed. The flow of electricity from power generation to the end user, who can now install a renewable energy facility and return excess electricity to the distribution grid to receive credit for this export. (Ashna & George, 2013). In figure 2.15, An electronic energy metre that can detect energy flow in both directions is called a bidirectional meter. This makes them perfect for applications using renewable energy sources like solar and wind power, which, when linked to the grid, may provide electricity.

Figure 15 Bidirectional meter

F. Key Factors Affect the PR Value

There are several factors that affect the final PR value, but in the methodology section of this research, we explore two essential elements in the realms of environmental management and renewable energy: Soil Mitigation and Tracking Solar Systems. Our approach and the significance of focusing on these two areas are detailed below.

1. Soil Mitigation and Yearly Loss Factor

Maintaining high efficiency in photovoltaic (PV) systems necessitates addressing soil and dust accumulation, a key factor influencing the Performance Ratio (PR) of these systems. PR, indicative of system efficiency, is negatively impacted when solar panels are obscured by soil or dust, as this hinders sunlight absorption by the photovoltaic cells. Implementing a consistent cleaning regimen, preferably monthly, is a vital strategy for soil mitigation. This regular maintenance significantly reduces the annual loss factor, which is a measure of the efficiency decrease due to panel soiling. In areas with considerable dust, like Amman-Jordan, the absence of such cleaning measures can result in notable declines in energy production, affecting both the financial and environmental efficacy of the solar setup. Therefore, to ensure optimal energy output and extend the system's operational life, integrating a structured cleaning schedule is imperative for any PV installation (Einhorn et al., 2019).

2. Tracking Solar Systems

Photovoltaic (PV) solar monitoring systems play an important role in increasing the performance ratio (PR) of solar installations. PR, an important metric when evaluating the performance of a PV system, has a significant impact on the efficiency of these tracking systems. As the sun is actively directed by solar panels, tracking systems maximize the incident sunlight, resulting in significant increases in energy output compared to conventional systems Single-axis trackers, which move devices east-west following the sun's daily path, greatly improve energy capture. But dual axis probes that adjust both vertically and horizontally to better match the direction of the sun during the day and seasons. This dual axis alignment can capture maximum solar radiation, thus increasing the public relations of the system and provide increased ultimate strength. The choice between single-axis and double-axis systems depends on factors such as location, specific installation needs, and cost considerations. A single-axis system is a more cost-effective option in many situations(K, 2016) .

G. key factors affect System output (E_{out}).

The primary output of a photovoltaic (PV) device, i.E., electrical power, is commonly measured in kilowatt-hours (kWh). This measurement is essential in representing the full electricity produced by means of the PV gadget over a fixed period of time, which could vary from each day to month-to-month or maybe annually. The factors below mainly impact the system output of a PV system (Vidyanandan, 2017)

1. Solar Irradiance

The amount of solar radiation that reaches the PV panels is perhaps the maximum substantial issue. Higher irradiance stages lead to higher electricity output. Geographic vicinity, time of yr, and every day weather situations play crucial roles in figuring out sun irradiance.

2. Panel Efficiency

The efficiency of the solar panels themselves determines how correctly they could convert daylight into electricity. Technological improvements and the exceptional of the photovoltaic materials effect this performance.

3. System Size and Capacity

The total size of the PV system, often measured in kilowatts (kW) or megawatts (MW), without delay affects its ability output. Larger systems with greater panels can glaringly generate greater power.

4. Orientation and Tilt of Panels

The path that the panels face (orientation) and the perspective at which they're tilted relative to the ground can significantly affect their potential to capture daylight. Optimal orientation and tilt depend upon the geographic region and the neighborhood weather.

5. Temperature

Solar panels operate much less successfully at higher temperatures. Excessive warmth can reduce the output of the panels, that is why cooler climates or cooler instances of the day can on occasion see greater green production.

6. Shading

Shading from timber, homes, or other boundaries can substantially reduce the strength output of PV panels by using blockading sunlight.

7. System Losses

Failures in inverters, cabling, and other electrical components lead to missing systems. These losses can reduce the total amount of usable electricity generated by the system.

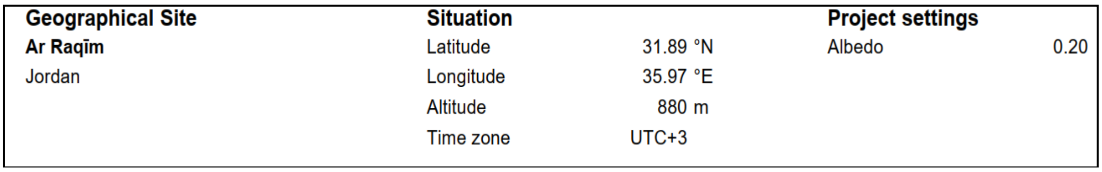
8. Tracking system

Systems with solar trackers that change the position of the panels to monitor the movement of the sun are able to capture more sunlight than standard systems, thus increasing overall energy consumption.

III. CURRENT PV SYSTEM SİTE DESCRİPTİON AND SİTUATİON

A. Site Description

The solar system we are optimizing is installed on the rooftop of a Structural Metals Manufacturing factory with a System Size of 80 Kw, called ABU HANTASH & AMR CO located in Amman, Jordan. The aim is to enhance its performance ratio (PR). Amman, characterized by its semi-arid climate, presents unique challenges and opportunities for solar energy utilization. The goal is to maximize the efficiency of the solar installation, ensuring sustainable and cost-effective energy production.



Geographical Site	**Situation**		**Project settings**	
Ar Raqīm	Latitude	31.89 °N	Albedo	0.20
Jordan	Longitude	35.97 °E		
	Altitude	880 m		
	Time zone	UTC+3		

Figure 16 Location data (PVsyst 7.4 Software, 2023)

1. Climatology of the test region

Amman experiences a unique climate that is typically warm and agreeable, marked by dusty conditions. On average, the city's highest annual temperature hovers around 25.3°C. The peak of warmth occurs in August, where the average temperature is 35°C and the highest is 38°C. In stark contrast, the chilliest month is January, exhibiting average temperatures that range from a minimum of 6°C to a maximum of 14°C. The efficiency of photovoltaic (PV) modules in Amman is intrinsically linked to solar radiation; an increase in the number of sunlight hours each day leads to a corresponding rise in the modules' electrical output. As per data from (*Www.Weather-and-Climate.Com*, 2023), Amman boasts around 3290 annual hours of sunshine, presenting an advantageous condition for the operation of PV systems.

2. Relative humidity.

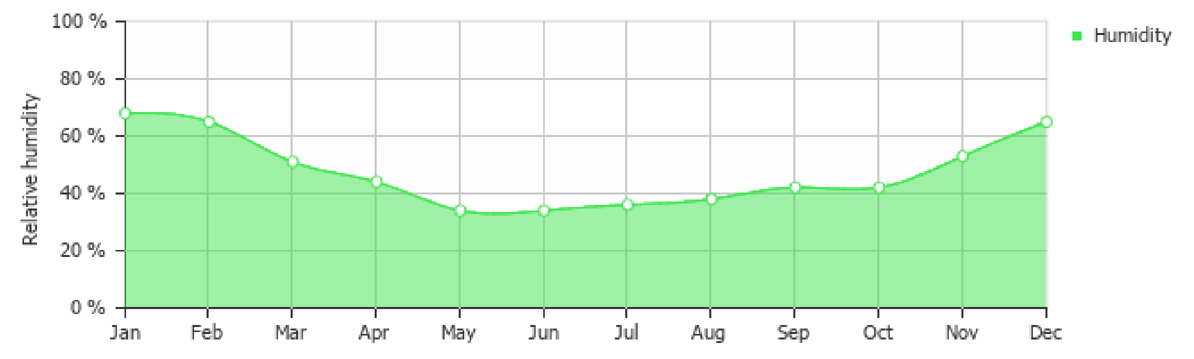


Figure 17 Relative humidity in Amman (Www.Weather-and-Climate.Com, 2023)

3. Temperature

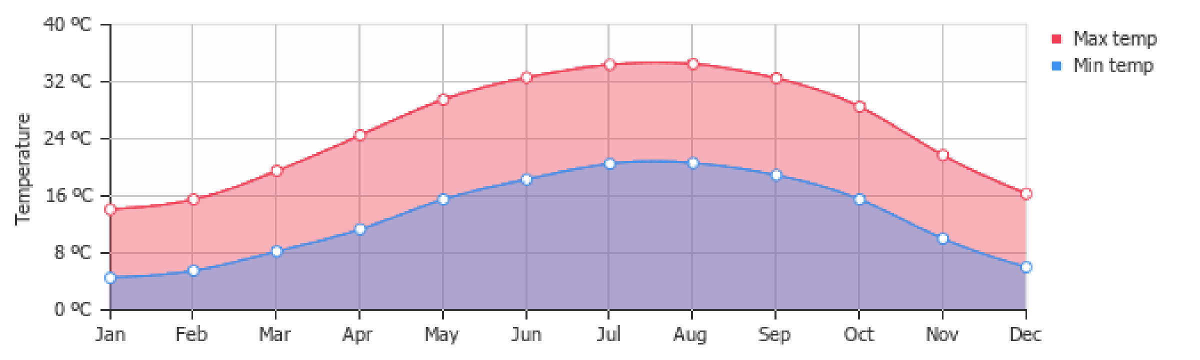


Figure .18 Average temperature in Amman (Www.Weather-and-Climate.Com, 2023)

4. Monthly hours of sunshine

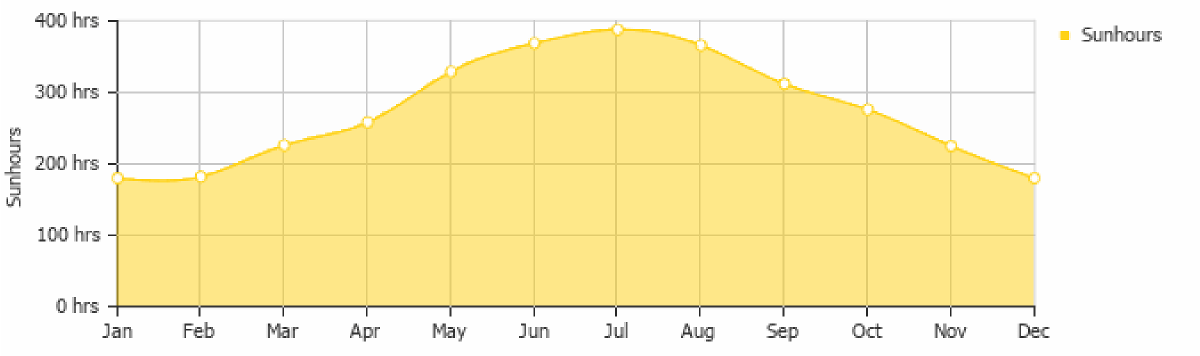


Figure 19 Monthly hours of sunshine (Www.Weather-and-Climate.Com, 2023)

5. Wind speed

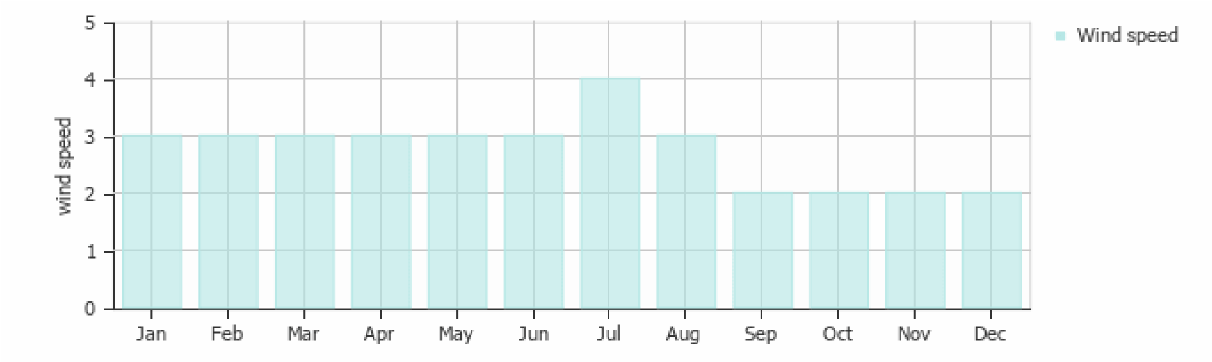
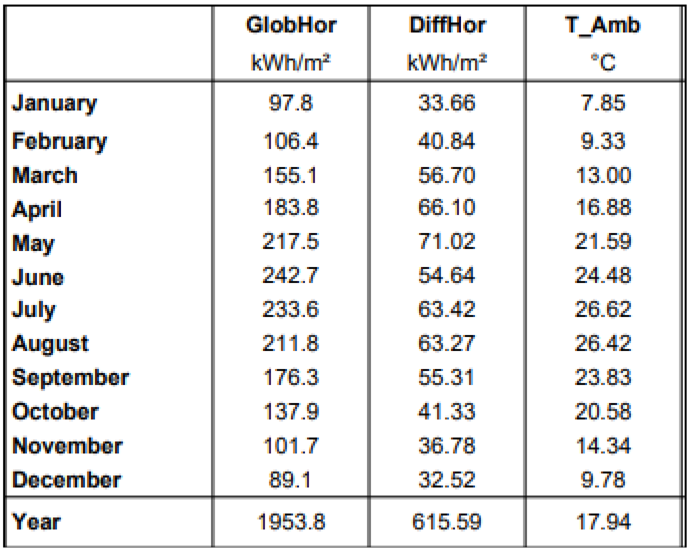


Figure 20 Average wind speed (Www.Weather-and-Climate.Com, 2023)

6. Irradiation of the site

The below data is fixed based on the location, and it does not have any relation to the PV panel.



	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C
January	97.8	33.66	7.85
February	106.4	40.84	9.33
March	155.1	56.70	13.00
April	183.8	66.10	16.88
May	217.5	71.02	21.59
June	242.7	54.64	24.48
July	233.6	63.42	26.62
August	211.8	63.27	26.42
September	176.3	55.31	23.83
October	137.9	41.33	20.58
November	101.7	36.78	14.34
December	89.1	32.52	9.78
Year	1953.8	615.59	17.94

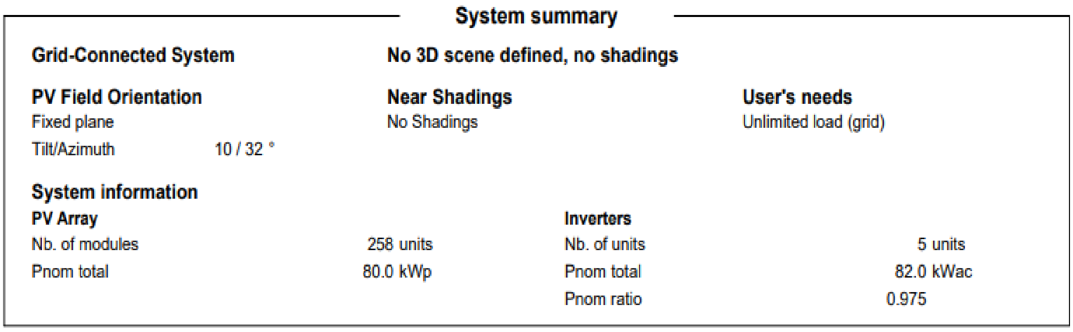
Figure 21 Irradiation of the site values through the year(PVsyst 7.4 Software, 2023)

Legends

GlobHor: Global horizontal irradiation **DiffHor: Horizontal diffuse irradiation** **T_Amb: Ambient Temperature**

B. System Situation

The currently installed system is a roof-mounted PV system installed on the factory’s steel structure hanger, The system summary and the characteristics of the system are mentioned in Figure 2.21 and Figure 2.22.



System summary

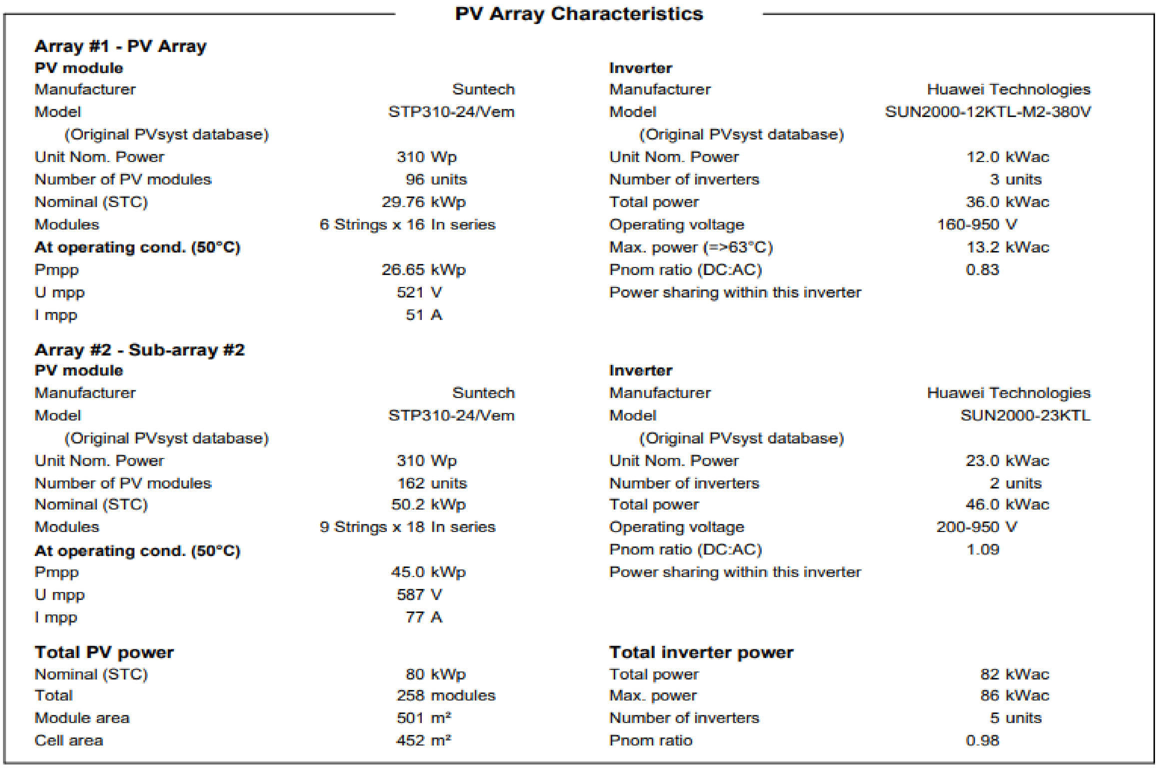
Grid-Connected System | **No 3D scene defined, no shadings**

PV Field Orientation		**Near Shadings**	**User's needs**
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	10 / 32 °		

System information

PV Array		**Inverters**	
Nb. of modules	258 units	Nb. of units	5 units
Pnom total	80.0 kWp	Pnom total	82.0 kWac
		Pnom ratio	0.975

Figure 22 Current System summary (PVsyst 7.4 Software, 2023)



PV Array Characteristics

Array #1 - PV Array			
PV module		**Inverter**	
Manufacturer	Suntech	Manufacturer	Huawei Technologies
Model	STP310-24/Vem	Model	SUN2000-12KTL-M2-380V
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	310 Wp	Unit Nom. Power	12.0 kWac
Number of PV modules	96 units	Number of inverters	3 units
Nominal (STC)	29.76 kWp	Total power	36.0 kWac
Modules	6 Strings x 16 In series	Operating voltage	160-950 V
At operating cond. (50°C)		Max. power (=>63°C)	13.2 kWac
Pmpp	26.65 kWp	Pnom ratio (DC:AC)	0.83
U mpp	521 V	Power sharing within this inverter	
I mpp	51 A		
Array #2 - Sub-array #2			
PV module		**Inverter**	
Manufacturer	Suntech	Manufacturer	Huawei Technologies
Model	STP310-24/Vem	Model	SUN2000-23KTL
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	310 Wp	Unit Nom. Power	23.0 kWac
Number of PV modules	162 units	Number of inverters	2 units
Nominal (STC)	50.2 kWp	Total power	46.0 kWac
Modules	9 Strings x 18 In series	Operating voltage	200-950 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.09
Pmpp	45.0 kWp	Power sharing within this inverter	
U mpp	587 V		
I mpp	77 A		
Total PV power		**Total inverter power**	
Nominal (STC)	80 kWp	Total power	82 kWac
Total	258 modules	Max. power	86 kWac
Module area	501 m²	Number of inverters	5 units
Cell area	452 m²	Pnom ratio	0.98

Figure .23 PV System Characteristics (PVsyst 7.4 Software, 2023)

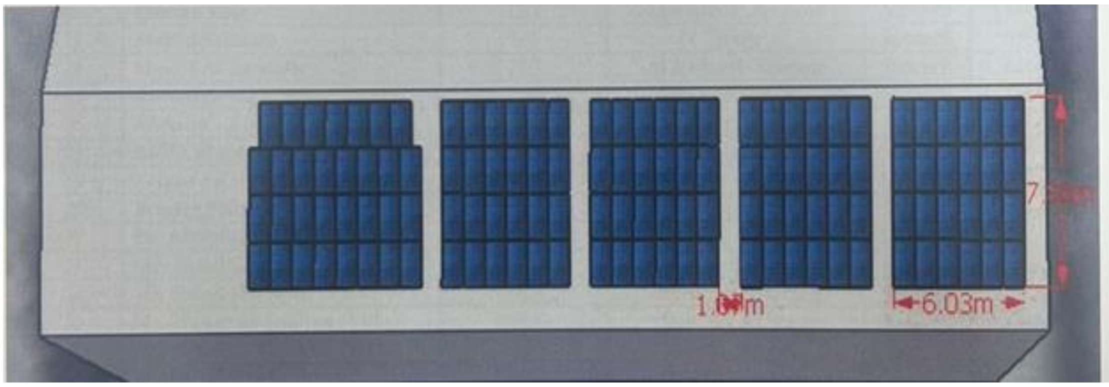


Figure 24 Scheme of the roof-mounted system

IV. METHODOLOGY

A. Problem Statement

In this optimization study our main goal is to enhance the PR value and increase the yearly energy production with a trade-off between the mentioned factors and the profit we get. The PR is essential for determining various specifics about the PV system, including inverter losses, shading-related losses, DC and AC cable losses, and dust collection losses on the solar PV system's rated output. The enhancement that is going to be added to the system is a single-axis tracking system to increase the sun radiation collected by the PV. Also, soil mitigation is a significant factor that impacts the final energy produced by the system. Thus we suggested a schedule to have a frequent cleaning process by a specialized Jordanian company to clean the PV panels once a month which means 12 times a year. In the next sections, we will describe the model used and the algorithm to get optimal values to gain profit as mentioned before.

B. Introduction

To achieve the objectives outlined above, a mixed-method approach will be employed. Initially, a comprehensive literature review will be conducted to establish a foundational understanding of the topic. The primary data collection will be carried out by developing a non-linear model to find the optimal profit as z. collected data will then be analyzed PSO algorithm to derive meaningful conclusions and interpretations. Through this methodological approach, this study endeavors to provide a comprehensive and nuanced understanding of the optimization we are implementing and offer actionable recommendations for addressing contemporary challenges and fostering positive change within the field.

C. Physical optimization of the current system

1. Soil mitigation

A frequent schedule is developed to have a frequent cleaning process by a specialized Jordanian company to clean the PV panels once a month which means 12 times a year since it is randomly cleaned in the current situation. The price offer I got is 0.7 USD for each panel. In this case, the yearly soil mitigation loss is going to be decreased from around 30% to 3 – 5%.

Using a basic formula we get:

The total cost of cleaning/month = 258 panels * 0.7 USD/each = 180.6 USD/month

Yearly total cost = 180.6 * 12 month = 2167 USD/year

Yearly t

2. Tilt angle

As I visited the site in Jordan and I found that it is possible to install a tracking system that will be completely made locally out there in Jordan with a design suggested by us using cheap raw materials available in the market.

The tilt angle of the current system is 10^o, but according to a study made by (Altarawneh et al., 2016), the results showed an annual optimal fixed tilt angle in Jordan is around 30^o. It means we will change the angle between the solar panel and the horizontal plane β from 10^o to 30^o to have the optimal angle throughout the year of an on-grid system as shown in Figure 4.1 below.

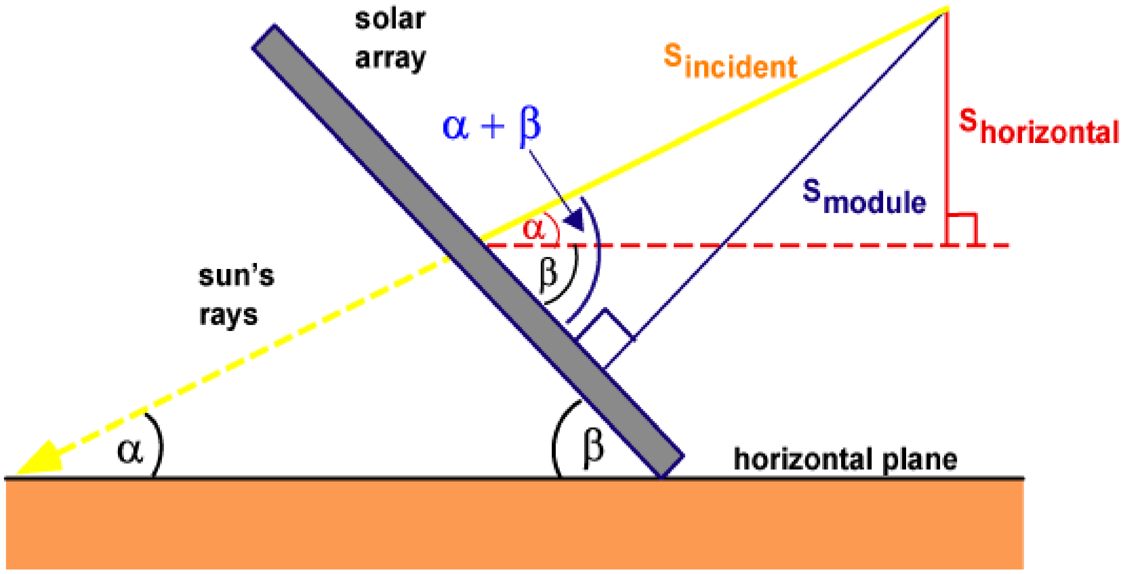


Figure 25 Tilt angle β

3. Solar tracking system

The most important enhancement is going to be done is the single solar tracking system. A single tracking system tracks the sun's path daily from east to west, this means we always want to keep the sun perpendicular to the surface of the solar panel to capture the maximum amount of radiation that basically increases the output voltage of the panel throughout the day. In the fixed system (no tracking system installed) the sun radiation will be perpendicular to the surface of the panel for a short time during the day, for instance from 12:00 – 14:00 in Amman-Jordan.

As (Rooij, 2020) stated the effectiveness of a single-axis solar tracker over a fixed solar tracking mount panel is 32.17%. The efficiency increase is a game-changer, so it is worth it to customize the system and install a single-axis tracking system. Figure 4.2 shows the tracking system that is going to be used.

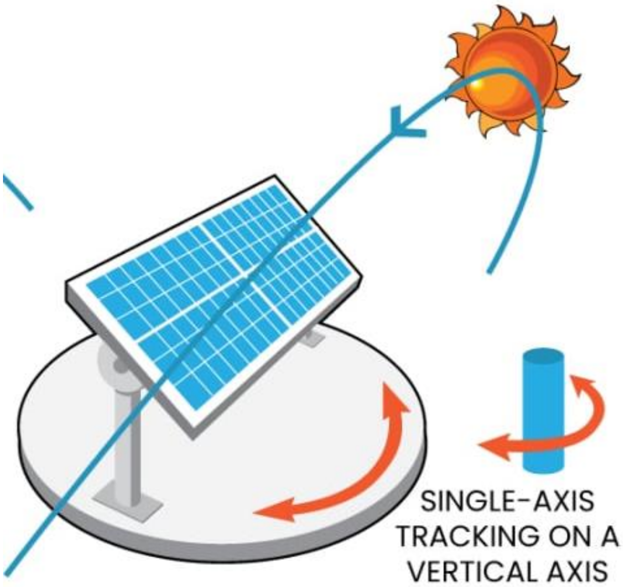


Figure 26 Single-axis tracking system

Here a question may come to our mind, if the tracking system is effective, then why it is not widely used? There are many reasons like the limited area or the difficulty of getting solar trackers, especially in the growing nations such as Jordan, Syria or Palestine, etc. The main issue in the tracking systems is the initial cost of installing them, they are avoided since when the engineer computes the payback period he finds that it is not profitable. It is right because when those trackers are purchased from China for example the cost could be sometimes double the installation cost of the PV system itself.

a. Rotating motor and moving mechanism design

To have a good trade-off between the enhancements of the system and the cost, we developed our own design, this design is profitable, effective, and applicable in Jordan using cheap and locally available raw materials. Basically, this design includes a linear actuator to be used as a motor so the solar panels will be able to move from east to west during the day.

The figures below will illustrate our design, all the figures were sketched in SketchUp software by me to show exactly how this design could be translated into reality. The design, as mentioned, uses cheap and available raw materials.

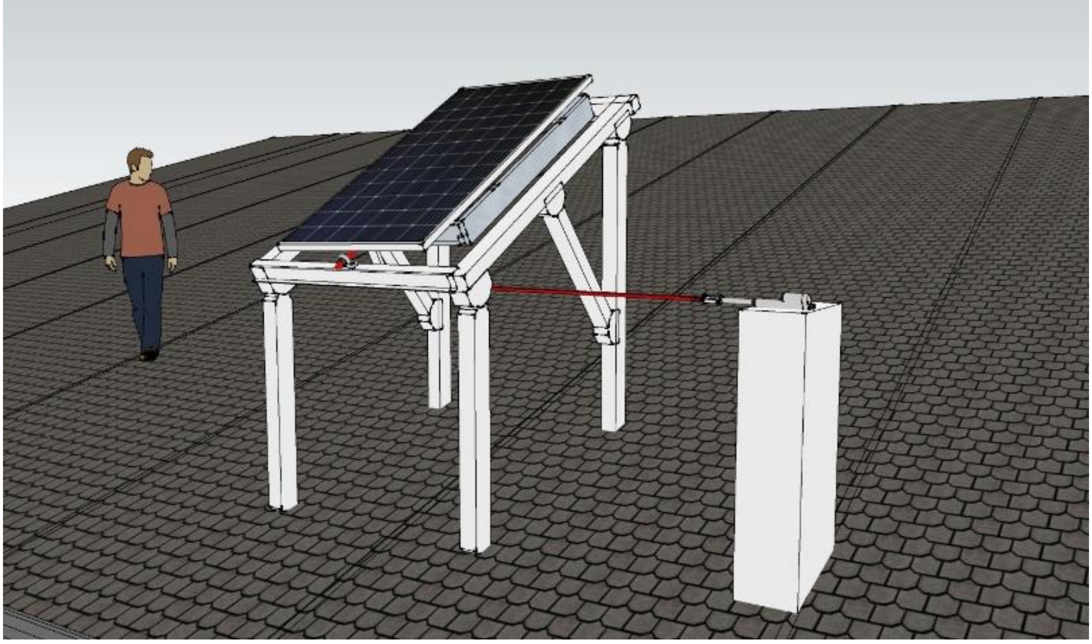


Figure 27 The main layout of the design (Sketchup software)

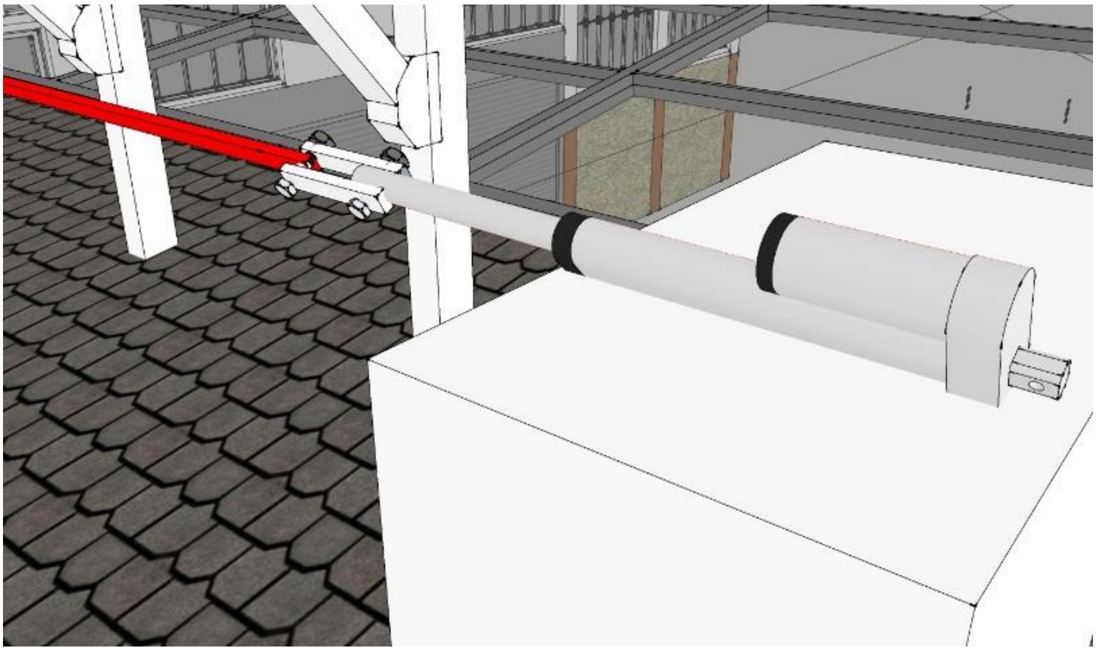


Figure 28 Linear actuator and the moving arm (Sketchup software)

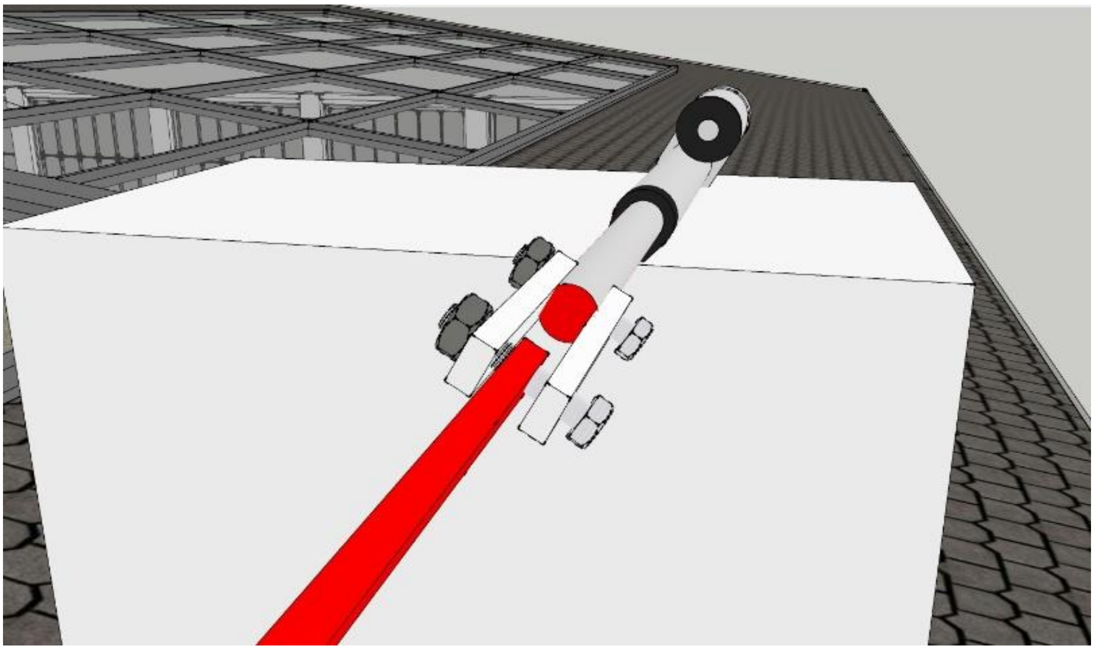


Figure 29 Flexible coupling between the actuator and the moving arm

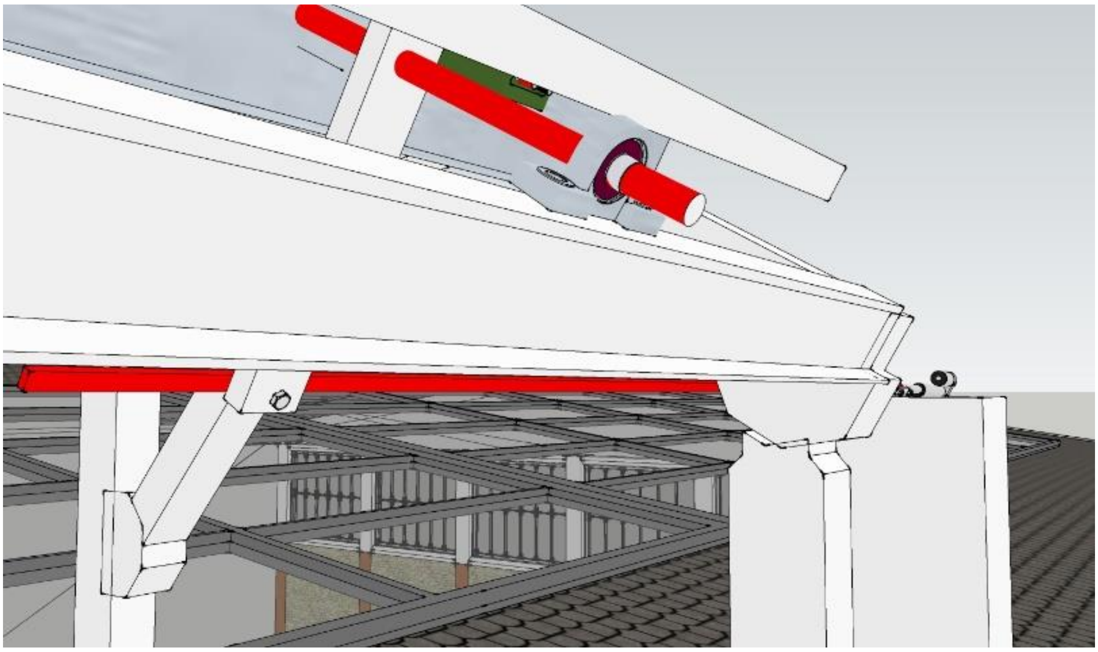


Figure 30 The rotation axis and the fixed panel on the mounting structure

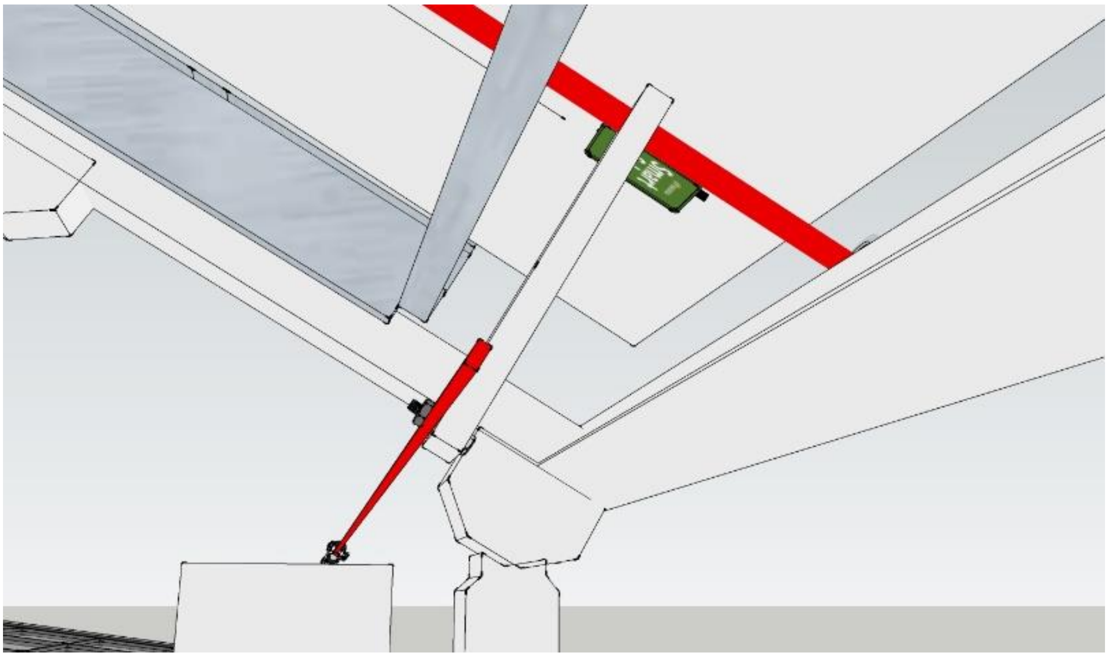


Figure 31 The joint between the moving arm and the solar panel

To clarify the design shown, it consists of 4 main components in this design are as follows:

- Linear actuator
- Moving Arm
- Pillow bearing
- Light-dependent resistors (LDR)
- Arduino UNO microcontroller

i. Linear actuator

A linear actuator is a type of actuator that generates motion in a single straight line based on system input. They extract energy from the system in the most appropriate form available, whether electrical, mechanical, hydraulic, or pneumatic, and transform it into linear motion to raise or move the weight provided. The linear actuator can move in one or two directions: push, pull, or both (Firgelli, 2015).

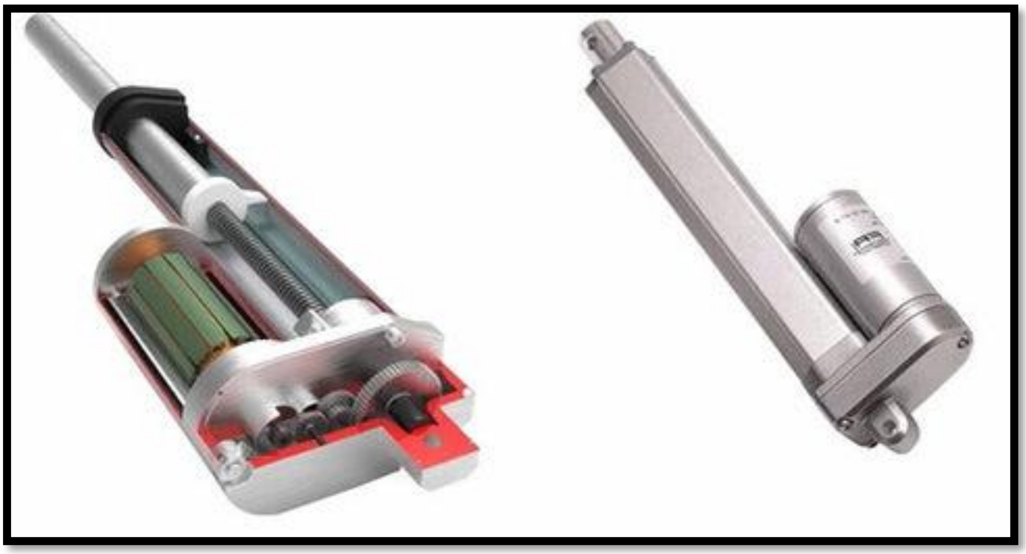


Figure 32 Linear actuator (Firgelli, 2015)

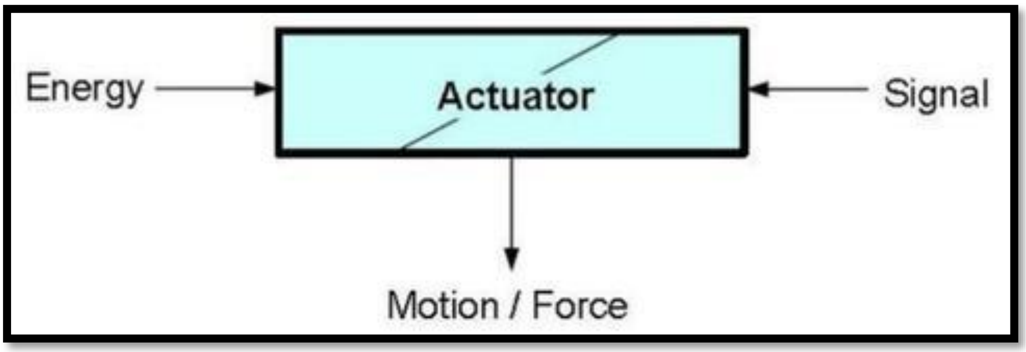


Figure 33 Working principle of the actuator (Firgelli, 2015)

The solar panel is subject to an axle, and the panel is driven by the linear actuator. We also took into consideration the required output force extracted from the actuator to overcome the friction force between the panel and the axle. Since, as shown before, the panel is subjected to an oblique axis, and this axis is mounted on a pillow bearing, then we can easily find the force needed by the actuator to overcome friction forces.

Each linear actuator has a different output force that has to overcome the force of the rotating PV panel. But regarding physics laws, the force of a hanged body, PV panel in our case, could be negligible since it is rotating on a pillow bearing as mentioned before. However, this force can be calculated then we get a suitable actuator to overcome this force.

Force = $\mu \times$ Weight of the panel

Friction coefficient μ of the bearing = 0.05

Weight of each panel = 19 Kg

Force = 0.05 * 19 Kg

Total force = 0.95 * 258 panels = 245 N

Thus, we need an actuator that can overcome this force. The Disecq motor, shown in Figure Appendix, is a perfect choice since it has an output force of 1500N that can easily move the whole solar system, but it is not possible since we can just install this number of panels in a straight line. We have to use 10 motors to cover all the panels. The needed motors are available as scrap in the factory's storage so we have no additional cost to buy the actuators.

The arrangement of the panels is going to be changed since we need them to be in a straight line, thus:

Total panels = 258 panel

Number of panels in each line = 258/10 ≅ 26 panels/line

ii. Light-dependent resistors (LDR)

The LDRs function as sensors, sensing the quantity of light entering the solar panels. Following that, the LDR sends data to the Arduino microcontroller. They operate based on photoconductivity, which provides less resistance in high light intensity and more resistance in low light intensity. (Ahmad and Yousuf, 2016). A solar tracker is designed utilizing linear actuators, a light sensor made up of four LDRs, and an Arduino UNO board. LDRs detect the quantity of sunlight falling on them. A single-axis solar tracker will include a single motor and two LDRs on the left and right. As the sun steadily advances westward, the voltage across the east-facing LDR increases, while the voltage across the west-facing LDR decreases. This will prompt the Arduino UNO to rotate the motor, tilting the solar panel to the west.

iii. Arduino UNO

Arduino UNO is a microcontroller board built on the ATmega328P. It contains 14 digital input/output pins (6 of which may be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB port, a power connector, an ICSP header, and a reset button. It includes everything necessary to support the microcontroller; simply connect it to a computer via a USB connection or power it with an AC-to-DC converter or battery to get started. You can tamper with your

UNO without worrying about making a mistake; worst case scenario, you can replace the chip for a few bucks and start over (Contributors, 2024).

iv. Pillow bearing

A pillow block bearing is a bearing used in low-torque, light-loading applications. It consists of a mounting bracket, or pillow block, that houses a bearing. Typically, the block is secured to a foundation or workpiece while the shaft and the inner ring of the bearing rotate freely (bearings direct, 2024) .

D. Proposed Model

1. Introduction to the Model

A nonlinear model describes nonlinear interactions in experimental data. Nonlinear regression models are commonly considered to be parametric, with the model stated as a nonlinear equation. Machine learning algorithms are commonly employed for non-parametric nonlinear regression (Perkins, 2001).

2. The mathematical model

We developed the non-linear model below to maximize the **z value** representing the profit. The final z value we will get after running this model will be how much money we gained or saved as profit in USD.

$$\boldsymbol{Maximize\ z = \left((EP - ER) * PE\right) - TC}$$

TC = Total Cost

EP =Energy produced = Pinitial * soil mitigation loss * PR

ER = Energy required (Constant)

PE = Revenue for unit Energy Sold ($/kwh)

TC = Total cost = TSC (Tracking System Cost) + SC (Soil Mitigation Cleaning Cost

3. Constraints

Table 1 Constraints

EP = Pinitial * soil mitigation loss * PR	TC = SC + TSC	SC = Cleaning_cost * Xi
SMR = (0.97-(12- Xi)*((0.97-0.7)/11))	PR = SMR*BPR	
TC = TSC + SC	BPR = BPR_0*Y0 + BPR_1*Y1	

4. Needed Data to run the model

Table 2 . Needed Data to run the model

EP = Energy Produced	ER = Energy Required	PE = Revenue for unit Energy Sold	TSC = Tracking System Cost
SC = Soil Mitigation Cleaning Cost	TC = Total Cost	PR = Performance Ratio	$OSP0_{optimal}$= Optimal System Performance under Current Conditions (Constant Value)
$OSP1_{optimal}$ = Optimal System Performance when Single Axis Tracking System is Installed (Constant Value)	CC = Fixed Cleaning Cost (Constant Value)	Xi = Cleaning Frequency (Decision Variable) (i = 1…n)	
SMR = Soil Mitigation Rate	TS1 =Single Axis Tracking System Cost (Constant Value)	Y0 = Binary Integer Decision Variable when current system conditions remain the same (0,1)	
BPR_0 = Base PR value under current system settings. (Constant Value)	BPR_1 = Base PR value after Single Axis Tracking System Installation (Constant Value)	Y1 = Binary Integer Decision Variable for Single Axis Tracking System Installation (0,1)	

E. Data collection

The data used in this thesis were collected from two main sources: factory databases and market prices obtained from various vendors operating within Jordan.

Factory Database Usage:

Information on the current system size, the energy produced, the layout of the system, and the new system size was obtained from internal factory databases. The factory database provided detailed information on daily production, raw materials, and the number of machines used.

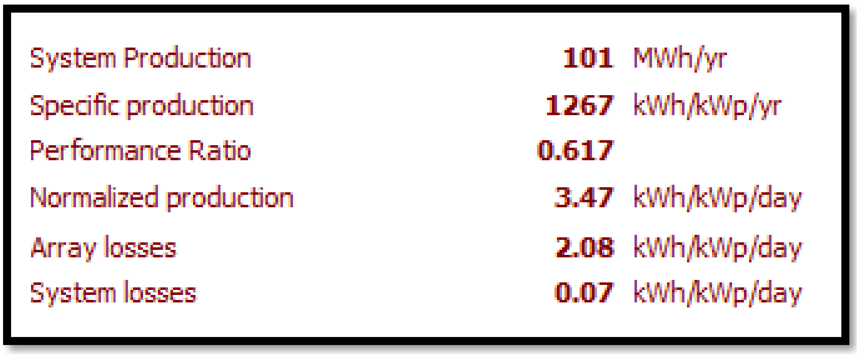
Market value in Jordan:

Prices related to the equipment needed and the cost of cleaning the panels were collected from various vendors operating in the Jordanian market. Prices were collected through direct interviews and analysis of publicly available pricing data. Particular attention was paid to ensure that the price data were representative and accurate considering variations across regions and periods.

Combining data from factory databases and market prices obtained from Jordanian traders, this study aims to gain comprehensive insights into the operational and economic aspects of factory operations in the region's market conditions. The enhancement includes installing a single-axis tracking system and developing a frequent cleaning schedule to avoid soil and dust accumulating.

1. Yearly energy production and PR value.

The data is taken directly from the factory since they have a monitoring and data logging system that logs the real-time data throughout the year. Figure shows the current data of the system



System Production	**101**	MWh/yr
Specific production	**1267**	kWh/kWp/yr
Performance Ratio	**0.617**	
Normalized production	**3.47**	kWh/kWp/day
Array losses	**2.08**	kWh/kWp/day
System losses	**0.07**	kWh/kWp/day

Figure 34 Current system data

2. Soil mitigation

The frequency of cleaning is taken from the database of the yearly report, but it was done by the workers in the factory themselves which is not a good idea since they do not have enough experience that is why, as mentioned before, we asked a professional company to clean the panels 12 times a year.

F. Particle Swarm Optimization (PSO)

1. Overview

Particle Swarm Optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution about a given measure of quality. It mimics the social behavior of birds flocking or fish schooling. In this chapter, we introduce PSO as the primary methodology for solving the problem at hand. We've chosen this optimization technique for its straightforward nature, its ability to work quickly and effectively, and its knack for skillfully handling the complex, many-layered problems we're tackling in our research. Its user-friendliness and practicality make it a perfect fit for the challenges we're facing.

2. PSO Algorithm

The basic steps of the PSO algorithm are as follows:

1. **Initialization:** Randomly initialize the position and velocity of each particle.

2. **Evaluation:** Calculate the fitness value of each particle using the objective function.

3. **Update Personal and Global Bests:** Update pBest and gBest based on the evaluations.

4. **Update Velocity and Position:** Adjust the velocity and position of each particle based on the pBest, gBest, and current velocity.

5. **Termination:** Repeat steps 2-4 until a stopping criterion is met (like a maximum number of iterations or a satisfactory error threshold).

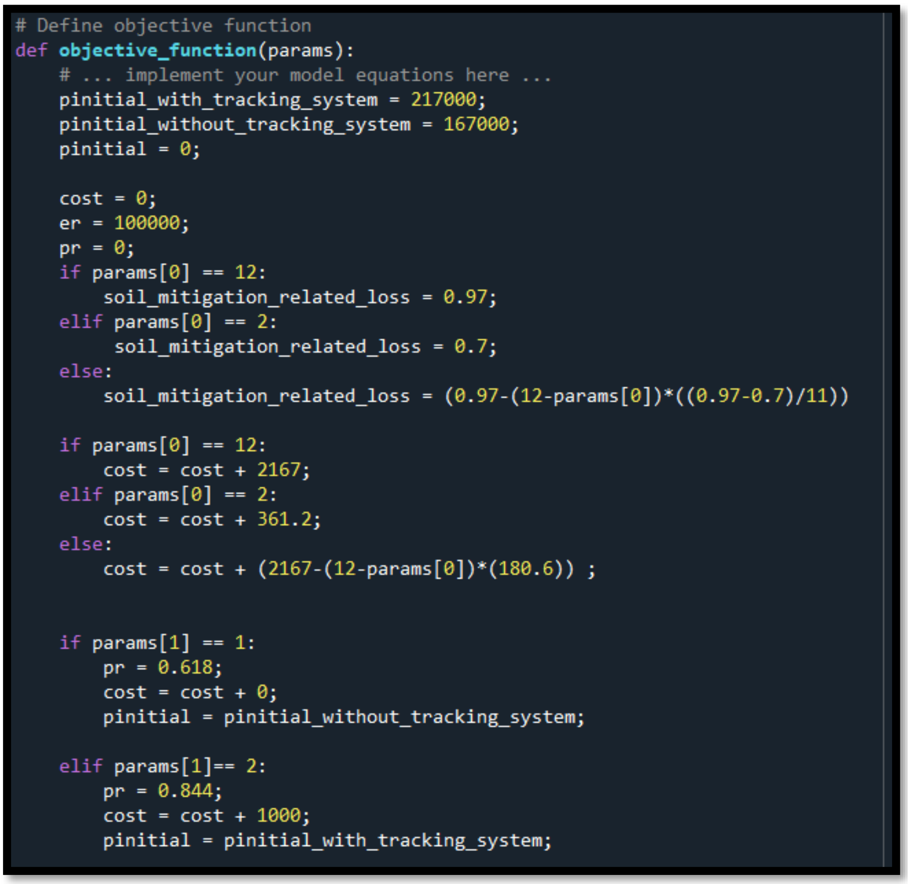
3. Application in the Current Study

In this research, PSO is applied to the mentioned model to find the optimal values. The choice of PSO is justified by its suitability to the problem's nature, comparative advantages over other methods, and its capability of iterations. In general, PSO locates each swarm by first producing a random population. In each iteration, the best answer is kept in its memory while it continues to converge on the optimal solution to change each person’s velocity. In the following figures, the PSO will be illustrated, and how the model is translated into Python code using Spyder software will be also shown.

```python
# Initialize swarm
particles = [[random.uniform(*bounds[i]) for i in range(len(bounds))]
             for _ in range(n_particles)]
velocities = [[0 for _ in range(len(bounds))] for _ in range(n_particles)]
pbest = particles.copy()
pbest_revenue = [func(particle) for particle in pbest]
gbest = particles[0]
gbest_revenue = func(gbest)

for iter in range(max_iter):

    # Update particle fitness
    revenue = [func(particle) for particle in particles]

    # Update personal best
    for i in range(n_particles):
        if float(revenue[i]) > float(pbest_revenue[i]):
            pbest_revenue[i] = revenue[i]
            pbest[i] = particles[i].copy()

    # Update global best
    if max(revenue) > gbest_revenue:
        gbest_revenue = max(revenue)
        gbest = particles[revenue.index(gbest_revenue)].copy()

    # Update velocities
    for i in range(n_particles):
        for j in range(len(bounds)):
            velocities[i][j] = w * velocities[i][j] + \
            c1 * random.random() * (pbest[i][j] - particles[i][j]) + \
            c2 * random.random() * (gbest[j] - particles[i][j])

    # Update positions
    for i in range(n_particles):
        for j in range(len(bounds)):
            particles[i][j] += velocities[i][j]

        # Apply boundary constraints
        for j in range(len(bounds)):
            particles[i][j] = min(max(particles[i][j], bounds[j][0]), bounds[j][1])

    # Display progress
    if iter % 10 == 0:
        print(f'Iteration {iter}: GBest PR = {gbest_revenue:.4f}')

return gbest, gbest_revenue
```

Figure 35 Initialization of the PSO

First, we started with the objective function to make the Python code understand our equations. The $P_{initial}$ is the theoretical yearly energy production (Kwh/year) in the best case scenario that cannot be approached in real life, first with a tracking system and a frequent cleaning schedule 12 times a year, second without a tracking system, and 2 times a year cleaning which means the current system. The soil mitigation parameter (params[0]) is presented in an IF condition that lets the PSO choose between two options, The First condition says cleaning 12 times a year, and the second says 2 times a year since we have a bond [2,12] for the cleaning frequency. Then in each condition, we have a different loss in efficiency, 3% if we implement 12 times it means we have a 97% efficient system. In the second condition, there is a loss of 30% and only a 70% efficient system. In the context of the cost, there are also two IF conditions, the first one says if the 12 times a year is chosen it means there is a cost of 2167$ added to the initial cost if the 2 times a year is chosen it means there is a cost of 361.2$ added to the initial cost. The PR conditions related to the tracking system are presented as params [1], the bond here is [1,2] The first one equals 1 means no tracking system is applied and the cost will be zero since no money is paid. The second equals 2 means a tracking system is applied with a cost of 1000$ and this is the initial cost of our own-designed tracking system.

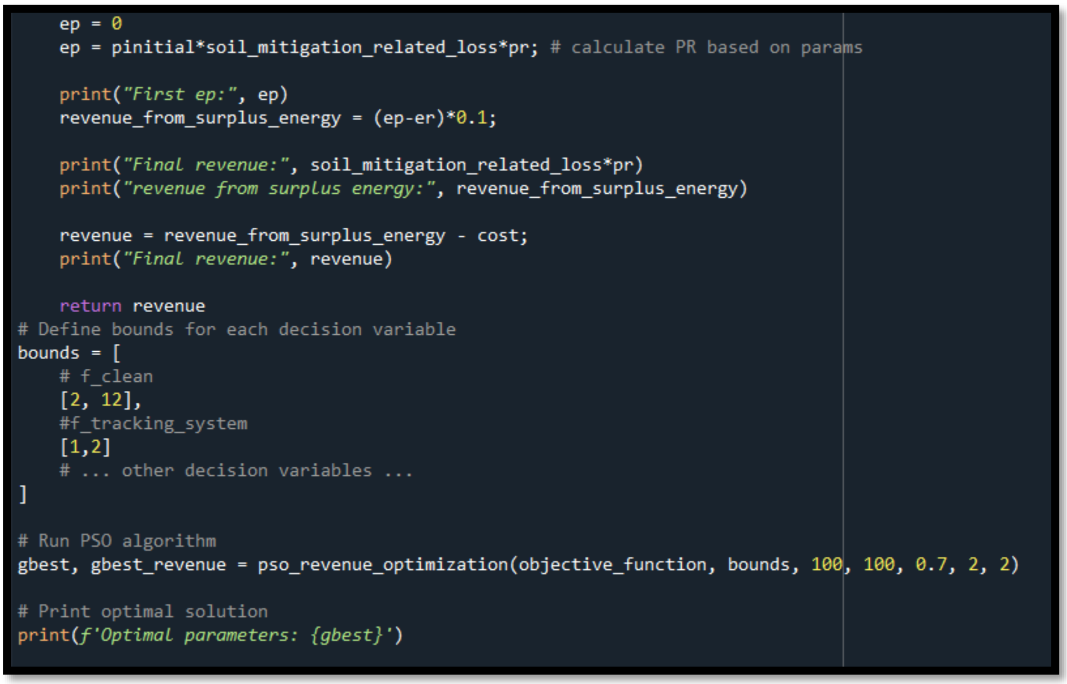


```
# Define objective function
def objective_function(params):
    # ... implement your model equations here ...
    pinitial_with_tracking_system = 217000;
    pinitial_without_tracking_system = 167000;
    pinitial = 0;

    cost = 0;
    er = 100000;
    pr = 0;
    if params[0] == 12:
        soil_mitigation_related_loss = 0.97;
    elif params[0] == 2:
         soil_mitigation_related_loss = 0.7;
    else:
        soil_mitigation_related_loss = (0.97-(12-params[0])*((0.97-0.7)/11))

    if params[0] == 12:
        cost = cost + 2167;
    elif params[0] == 2:
        cost = cost + 361.2;
    else:
        cost = cost + (2167-(12-params[0])*(180.6)) ;


    if params[1] == 1:
        pr = 0.618;
        cost = cost + 0;
        pinitial = pinitial_without_tracking_system;

    elif params[1]== 2:
        pr = 0.844;
        cost = cost + 1000;
        pinitial = pinitial_with_tracking_system;
```

Figure 36 The IF conditions of the code

The energy produced (ep) is calculated by the equation written in the code.

The revenue is calculated by deducting the energy required from the energy produced and then multiplying by 0.1$ the cost of each Kw injected into the grid. The final revenue is the revenue from surplus energy injected into the grid minus the total cost of the tracking system and the cleaning process.



```
    ep = 0
    ep = pinitial*soil_mitigation_related_loss*pr; # calculate PR based on params

    print("First ep:", ep)
    revenue_from_surplus_energy = (ep-er)*0.1;

    print("Final revenue:", soil_mitigation_related_loss*pr)
    print("revenue from surplus energy:", revenue_from_surplus_energy)

    revenue = revenue_from_surplus_energy - cost;
    print("Final revenue:", revenue)

    return revenue
# Define bounds for each decision variable
bounds = [
    # f_clean
    [2, 12],
    #f_tracking_system
    [1,2]
    # ... other decision variables ...
]

# Run PSO algorithm
gbest, gbest_revenue = pso_revenue_optimization(objective_function, bounds, 100, 100, 0.7, 2, 2)

# Print optimal solution
print(f'Optimal parameters: {gbest}')
```

Figure 37 The model as a python code

V. RESULTS AND ANALYSİS

A. Introduction

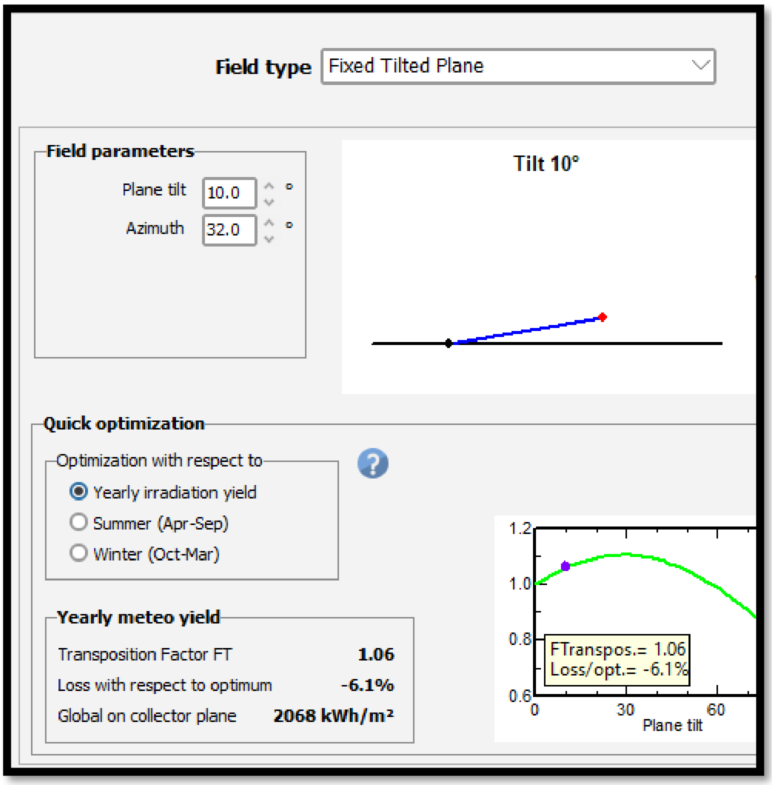
In this section, we present the observations and analysis from the integration of PVsyst software to optimize the performance of solar photovoltaic (PV) systems. The results presented here are a general overview of the use of PVsyst to model different PV system configurations under different environmental conditions is based on, followed by optimization using PSO algorithms to adjust the system parameters and improve the performance parameters

The main objective of this study is to demonstrate the usefulness of computational tools and optimization algorithms to improve the performance and results of solar PV installations By combining the accurate simulation capabilities of PVsyst with the optimization capabilities of PSO is aimed at achieving an optimal planning system

B. PVsyst Simulation Results

1. Current System Data

The data of the current system in Figure 5.1 is shown in PVsyst 7.4. The current yearly loss factor is also shown in Figure 5.2. The tilt angle and the azimuth are provided directly from the site. The exact current installed system data is input into PVsyst then the simulation is run to get the results in Figure 5.3.



Field type Fixed Tilted Plane

Field parameters

Plane tilt 10.0 °

Azimuth 32.0 °

Quick optimization

Optimization with respect to

● Yearly irradiation yield

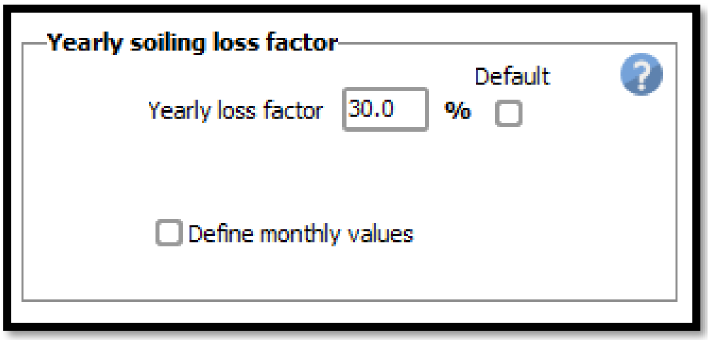
○ Summer (Apr-Sep)

○ Winter (Oct-Mar)

Yearly meteo yield

Transposition Factor FT	**1.06**
Loss with respect to optimum	**-6.1%**
Global on collector plane	**2068 kWh/m²**

Figure 38 Current system tilt angle with no tracking system installed (PVsyst 7.4 Software, 2023)



Yearly soiling loss factor

Yearly loss factor 30.0 %

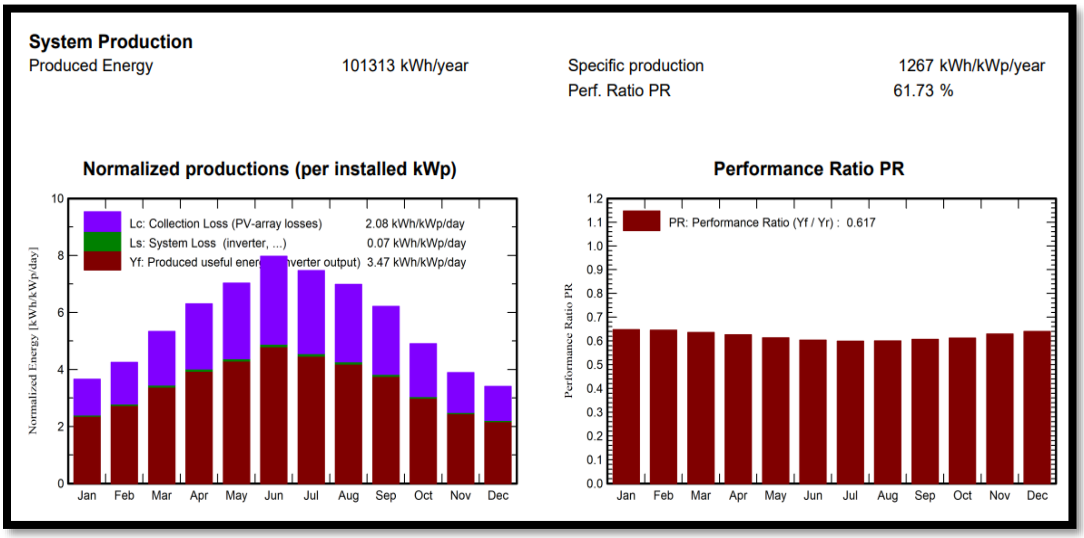
Default ☐

☐ Define monthly values

Figure 39 Yearly soiling loss factor (PVsyst 7.4 Software, 2023)

2. Current System Results

The results in Figure 5.3 are obtained after running the simulation using the values illustrated in Figure 5.1 and Figure 5.2.



System Production

Produced Energy 101313 kWh/year

Specific production 1267 kWh/kWp/year

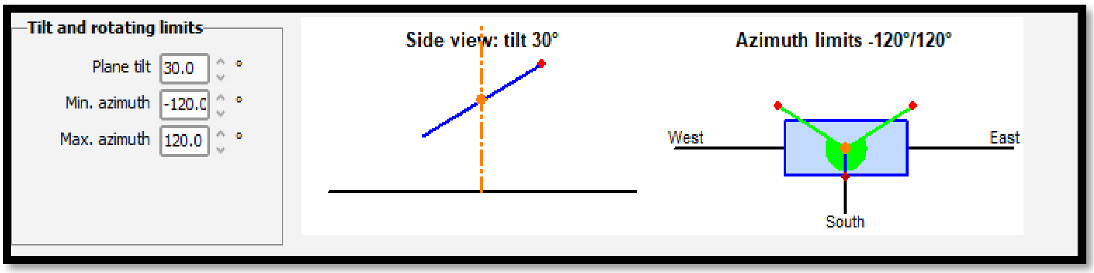
Perf. Ratio PR 61.73 %

Figure 40 Current system results (PVsyst 7.4 Software, 2023)

As we delve into the results above, it becomes evident that the current simulation based on the available data yields a yearly energy production of 101313 kWh/year and a performance ratio (PR) value of 0.61, equivalent to 61%. However, these figures fall below the anticipated performance potential of the system, indicating room for improvement through the optimization strategies discussed previously.

3. Optimized System Data

We optimized the system by raising the tilt angle to 30 degrees and widening the azimuth limits to -120 degrees to 120 degrees. Our daily tracking system, ensures the solar panels capture the most sunlight possible. By precisely aligning with the sun's path throughout the day, we maximize energy production and system efficiency.



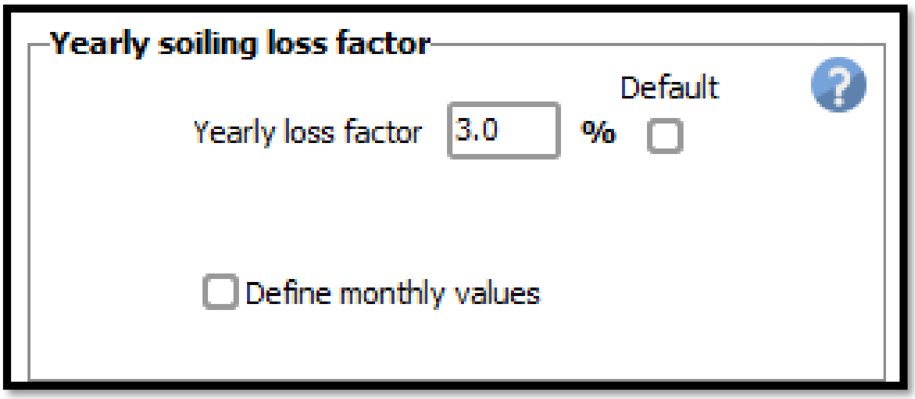
Tilt and rotating limits

Plane tilt 30.0 °

Min. azimuth -120. °

Max. azimuth 120.0 °

Figure 41 Optimized system tilt angle and tracking system data (PVsyst 7.4 Software, 2023)



Yearly soiling loss factor

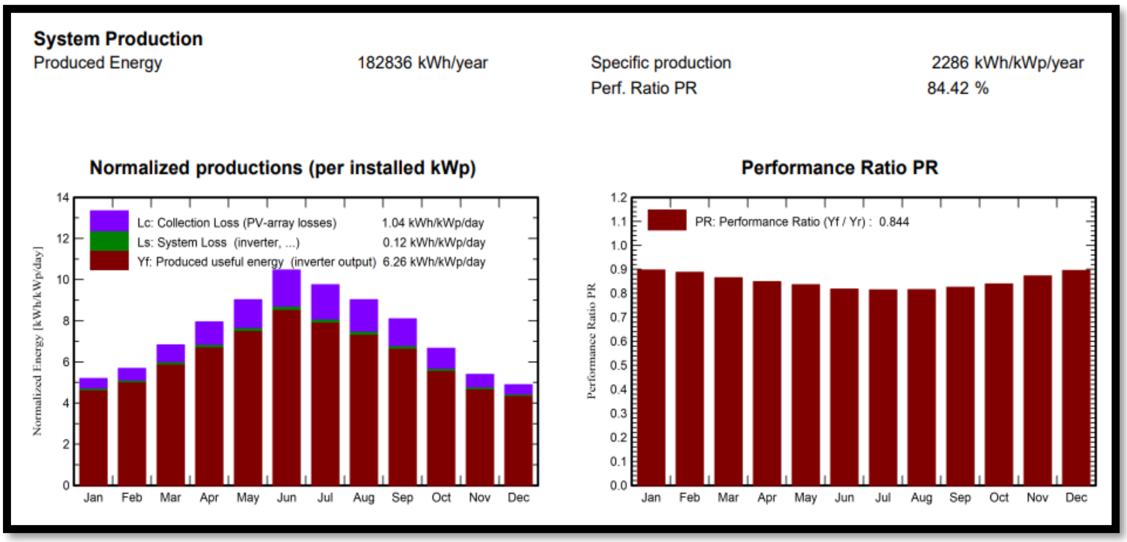
Yearly loss factor 3.0 %

Default ☐

☐ Define monthly values

Figure 42 Yearly loss factor after frequent cleaning applied (PVsyst 7.4 Software, 2023)

4. Optimized System Results



System Production

Produced Energy 182836 kWh/year

Specific production 2286 kWh/kWp/year

Perf. Ratio PR 84.42 %

Figure 43 Optimized system results (PVsyst 7.4 Software, 2023)

C. PSO algorithm results

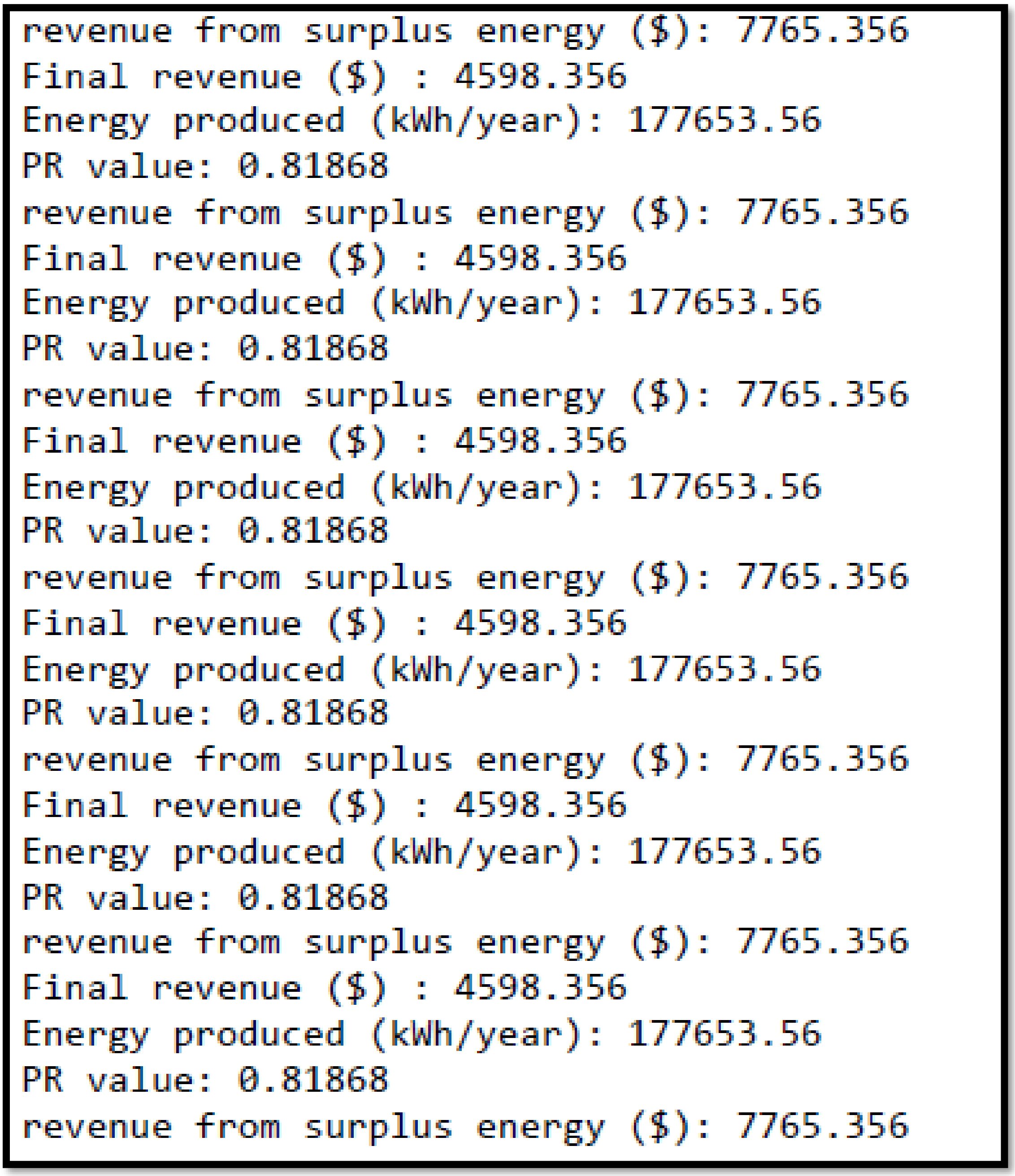
1. Formulas And Cost Analysis

By performing 100 iterations of the PSO algorithm using the Spyder software, we obtained results very similar to those produced by the PVsyst software. This design confirms the robustness and reliability of our optimization method, as it provides results consistent with established industry-standard simulation tools. The high level of results between the PSO and PVsyst highlights the effectiveness of the PSO algorithm in efficiently exploring the parameter space and finding the optimal solutions to maximize the efficiency of solar PV systems.

For instance, as seen in Figure 5.7, the yearly energy produced is 177653 kWh/year which is close to the number we obtained from PVsyst which was 182836 kWh/year as illustrated in Figure 5.6.

The cost analysis is determined using PSO and it also matches the calculations done by hand before running the code. In addition, the PR value is close to the value in Figure 5.6 which was 0.84%.

This session gives us confidence in the accuracy of our optimization procedure and the integrity of the results obtained. Furthermore, the highly consistent results of software systems highlight the versatility and interoperability of optimization methods in solar research Regardless of the software used to perform the analysis, the underlying principles in the PSO framework remain exactly It will be simpler. By using Spyder software for PSO-based optimization, we not only validate the reliability findings but also demonstrate the applicability of computational tools in solving challenging technical challenges These results this combination strengthens the reliability of our optimization method.



```
revenue from surplus energy ($): 7765.356
Final revenue ($) : 4598.356
Energy produced (kWh/year): 177653.56
PR value: 0.81868
revenue from surplus energy ($): 7765.356
Final revenue ($) : 4598.356
Energy produced (kWh/year): 177653.56
PR value: 0.81868
revenue from surplus energy ($): 7765.356
Final revenue ($) : 4598.356
Energy produced (kWh/year): 177653.56
PR value: 0.81868
revenue from surplus energy ($): 7765.356
Final revenue ($) : 4598.356
Energy produced (kWh/year): 177653.56
PR value: 0.81868
revenue from surplus energy ($): 7765.356
Final revenue ($) : 4598.356
Energy produced (kWh/year): 177653.56
PR value: 0.81868
revenue from surplus energy ($): 7765.356
Final revenue ($) : 4598.356
Energy produced (kWh/year): 177653.56
PR value: 0.81868
revenue from surplus energy ($): 7765.356
```

Figure 44 PSO results

2. Optimal Parameters

After multiple rounds of testing, the crucial result of the PSO algorithm is in finding the best settings for our solar PV system. As shown in Figure 5.8, the ideal settings are found to be [2, 12], meaning that the most effective setup includes choosing system number 2, using a tracking system, and scheduling cleaning activities 12 times a year. This discovery emphasizes the importance of tracking systems and regular cleaning schedules in optimizing system efficiency and energy production. Even when taking costs into account, the PSO algorithm consistently chooses these best settings, showcasing their vital role in improving overall system performance. The durability of these parameters underscores their relevance in ensuring a successful solar PV system.

```
Optimal parameters: [12, 2]
```

Figure 45 PSO optimal solution

VI. CONCLUSION

In conclusion, our study has shown that PVsyst software may be integrated with the Particle Swarm Optimization (PSO) method to maximize solar photovoltaic (PV) system performance. A thorough examination of the simulation results and optimization results has led to the identification of numerous important conclusions.

First, we used the PVsyst program to precisely predict how solar PV systems would operate in different scenarios. This allowed us to get important knowledge on energy output, performance ratios, and shading losses. Our optimization efforts were guided by these simulations, which also indicated areas that needed work.

Second, by using the PSO technique, we were able to find the best system configurations by methodically exploring the parameter space. Through tweaking variables like the tilt angle, installing the tracking system, and cleaning interval, we were able to significantly improve the energy yield and performance ratios. The best settings for optimizing system performance and energy output, according to our data, were choosing system number 2, adding a tracking system, and planning cleaning tasks twelve times a year. Notably, the PSO algorithm continuously prioritized these ideal configurations, highlighting their significance in reaching optimal performance, even when taking cost factors into account. Furthermore, our optimization methodology's stability and dependability were confirmed by the convergence of findings between the PVsyst and Spyder software platforms. This consistency gives us hope that our findings may be applied to actual solar PV system design and deployment situations. It means that our enchantment has proven its efficiency whether our design of the solar tracker or the cleaning schedule developed. In summary, our study advances our understanding of optimization techniques and renewable energy technologies. We offer practical insights for enhancing solar PV system performance and quickening the shift to a sustainable energy future by showcasing the effectiveness of combining PVsyst software with the PSO algorithm.

VII. REFERENCES

JOURNAL

ALI, A. H. H., MATSUSHITA, Y., & OOKAWARA, S. (2010). Photovoltaic Module Thermal Regulation: Effect of the Cells Arrangement Configurations on the Performance. **International Journal of Thermal and Environmental Engineering**, *2*(1), 41–47. https://doi.org/10.5383/ijtee.02.01.006

ALTARAWNEH, I. S., RAWADIEH, S. I., TARAWNEH, M. S., ALROWWAD, S. M., & RIMAWI, F. (2016). Optimal tilt angle trajectory for maximizing solar energy potential in Ma'an area in Jordan. **Journal of Renewable and Sustainable Energy,** *8*(3). https://doi.org/10.1063/1.4948389

ANTONIO LUQUE, & STEVEN HEGEDUS. (2003). **Handbook of Photovoltaic Science and Engineering** (A. Luque & S. Hegedus, Eds.). John Wiley & Sons, Ltd. https://doi.org/10.1002/0470014008

BIRD, R. E., & RIORDAN, C. (1986). Simple Solar Spectral Model for Direct and Diffuse Irradiance on Horizontal and Tilted Planes at the Earth's Surface for Cloudless Atmospheres. **Journal of Climate and Applied Meteorology,** *25*(1), 87–97. https://doi.org/10.1175/1520-0450(1986)025<0087:SSSMFD>2.0.CO;2

DASH, P., & GUPTA, N. C. (2015). Effect of Temperature on Power Output from Different Commercially available Photovoltaic Modules. *Int.* **Journal of Engineering Research and Applications.**

DECKER, B., & JAHN, U. (1997). **Performance Of 170 Grid Connected Pv Plants In Northern Germany-Analysis Of Yields And Optimization Potentials** (Vol. 59).

DEEGE SOLAR. (2021). *Different Types of Solar PV Systems | On Grid, Hybrid & Off* **Grid Solar.**

https://www.deegesolar.co.uk/different_types_of_solar_pv_systems/

EINHORN, A., MICHELI, L., MILLER, D. C., SIMPSON, L. J., MOUTINHO, H. R., TO, B., LANAGHAN, C. L., MULLER, M. T., TOTH, S., JOHN, J. J., WARADE, S., KOTTANTHARAYIL, A., & ENGTRAKUL, C. (2019). Evaluation of Soiling and Potential Mitigation Approaches on Photovoltaic Glass. **IEEE Journal of Photovoltaics,** *9*(1), 233–239. https://doi.org/10.1109/JPHOTOV.2018.2878286

EL-SEBAII, A. A., AL-HAZMI, F. S., AL-GHAMDI, A. A., & YAGHMOUR, S. J. (2010). Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, **Saudi Arabia. Applied Energy**, *87*(2), 568–576. https://doi.org/10.1016/j.apenergy.2009.06.032

FRAUNHOFER ISE. (2019). *fraunhofer-ise-annual-report-2019-2020*.

K, R. (2016). SOLAR TRACKING SYSTEM- A REVIEW. **International Journal of Sustainable Engineering,** *10*. https://doi.org/10.1080/19397038.2016.1267816

KALDELLIS, J. K., & KAPSALI, M. (2011). Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements. **Energy,** *36*(8), 5154–5161. https://doi.org/https://doi.org/10.1016/j.energy.2011.06.018

KORSUN, I. V. (2020). Contribution of Ukrainian Scientists to the Development of Electrodynamics. **Ukrainian Journal of Physics**, *65*(1), 82. https://doi.org/10.15407/ujpe65.1.82

KUMAR, R., & ROSEN, M. A. (2011). A critical review of photovoltaic–thermal solar collectors for air heating. **Applied Energy,** *88*(11), 3603–3614. https://doi.org/10.1016/j.apenergy.2011.04.044

MARION, B., ADELSTEIN, J., BOYLE, K., HAYDEN, H., HAMMOND, B., FLETCHER, T., CANADA, B., NARANG, D., KIMBER, A., MITCHELL, L., RICH, G., & TOWNSEND, T. (n.d.). Performance parameters for grid-connected PV systems. **Conference Record of the Thirty-First IEEE Photovoltaic Specialists Conference, 2005.,** 1601–1606. https://doi.org/10.1109/PVSC.2005.1488451

Ministry of Environment. (2021). **Executive summary.**

PACIS, M. C., SESE, J. T., BLASTIQUE, H. A., CASIBANG, M. D. C., LADISLA, G. G., & VILLANO, R. G. D. (2016). Metering of surplus energy on PV systems using ZigBee Wireless Technology. **2016 6th IEEE International Conference on Control System,** *Computing and Engineering (ICCSCE),* 348–353. https://doi.org/10.1109/ICCSCE.2016.7893597

PERKINS, N. C. (2001). NONLINEAR SYSTEMS, OVERVIEW. In S. Braun (Ed.), **Encyclopedia of Vibration** (pp. 944–951). Elsevier. https://doi.org/https://doi.org/10.1006/rwvb.2001.0036

PVSYST 7.4 **software**. (2023).

RAZYKOV, T. M., FEREKIDES, C. S., MOREL, D., STEFANAKOS, E., ULLAL, H. S., & UPADHYAYA, H. M. (2011). Solar photovoltaic electricity: Current status and future prospects. **Solar Energy,** *85*(8), 1580–1608. https://doi.org/https://doi.org/10.1016/j.solener.2010.12.002

RODRIGUES, E., MELICIO, R., MENDES, V. M. F., & CATALÃO, J. (2011, June). **Simulation of a Solar Cell considering Single-Diode Equivalent Circuit Model.**

S. KALOGIROU. (2009). Solar energy engineering: processes and systems. **Academic Press.**

SARAH, K. E., ROLAND, U., & OKAFOR, E. N. C. (2020). **A Review of Solar Photovoltaic Technologies.** www.ijert.org

SINGH BRAR, M., KUMAR, R., & KUMAR, S. (2017). Conversion of Solar Energy into Electrical Energy Using Photovoltaic Technology: A Review. **Photovoltaic Technology: A Review. Int. Arch. App. Sci. Technol,** *8,* 14–18. https://doi.org/10.15515/iaast.0976-4828.8.4.1418

THE MINISTRY OF ENERGY AND MINERAL RESOURCES. (2020). **Summary of Jordan Energy Strategy.**

VIDYANANDAN, K. V. (2017). An Overview of Factors Affecting the Performance of Solar PV Systems. *Energy Scan (A House Journal of Corporate Planning, NTPC Ltd.), 27,* 2–8.

YADAV, A. K., & CHANDEL, S. S. (2013). Tilt angle optimization to maximize incident solar radiation: A review. **Renewable and Sustainable Energy Reviews**, *23*, 503–513. https://doi.org/10.1016/j.rser.2013.02.027

YANG, J. , Y. X. & J. L. (2020). Chapter 7 Components of a PV system. In **Solar Photovoltaic Power Generation** (pp. 245–284). De Gruyter. https://doi.org/10.1515/9783110524833-007

INTERNET SOURCE

CONTRIBUTORS, W. (2023). *Amorphous silicon*. Wikimedia Foundation. https://en.wikipedia.org/wiki/Amorphous_silicon

CONTRIBUTORS, W. (2024). *Arduino Uno*. Wikimedia Foundation. https://en.wikipedia.org/wiki/Arduino_Uno

FIRGELLI. (2015). *What is a Linear Actuator? | FIRGELLI*. https://www.firgelliauto.com/pages/what-is-a-linear-actuator

GLOBAL SOLAR ATLAS. (2019). *Global Solar Atlas*. https://globalsolaratlas.info/download/jordan

NATIONL ELECTRIC POWER COMPANY. (2020). *Nationl Electric Power Company - NEPCO*. Http://Www.Nepco.Com.Jo/En/Jordan_electric_system_en.Aspx.

ROOIJ, D. DE. (2020). *Single Axis Trackers*. Sinovoltaics (Hong Kong Office). https://sinovoltaics.com/learning-center/csp/single-axis-trackers/

THE INTERNATIONAL TRADE ADMINISTRATION. (2019). *Jordan - Renewable Energy*. https://www.trade.gov/country-commercial-guides/jordan-renewable-energy

THE PENNSYLVANIA STATE UNIVERSITY. (2013). *Types of PV technology and recent innovations | EME 812: Utility Solar Power and Concentration*. https://www.e-education.psu.edu/eme812/node/608

ZAFAR, S. (2021). *Solar Energy in Jordan | EcoMENA*. https://www.ecomena.org/solar-energy-jordan/

www.weather-and-climate.com. (2023). https://weather-and-climate.com/average-monthly-Humidity-perc,Amman,Jordan

STAPLETON, GEOFF, NEILL, & SUSAN. (2012). *Grid-connected Solar Electric Systems*. www.TechnicalBooksPdf.com

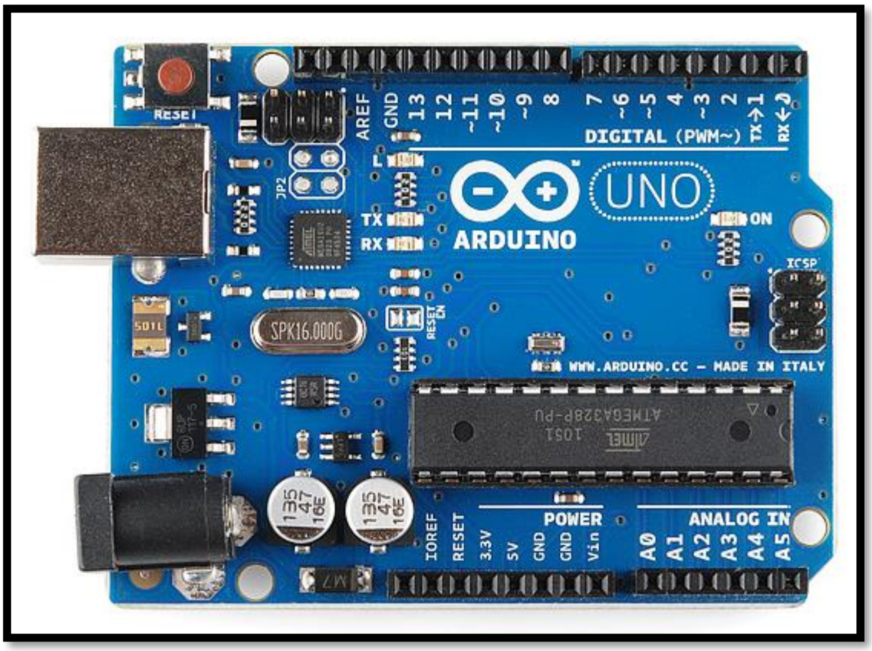
ALTERNATIVE ENERGY TUTORIALS. (2023). *Photovoltaic Array or Solar Array uses PV Solar Panels*. https://www.alternative-energy-tutorials.com/photovoltaics/photovoltaic-array.html

BEARINGS DIRECT. (2024). 12mm bore KP001 Mini Zinc Pillow Block Bearing Set Screw KP01UU. In *2024*. https://bearingsdirect.com/12mm-bore-kp001-mini-zinc-pillow-block-bearing-set-screw-kp01uu/

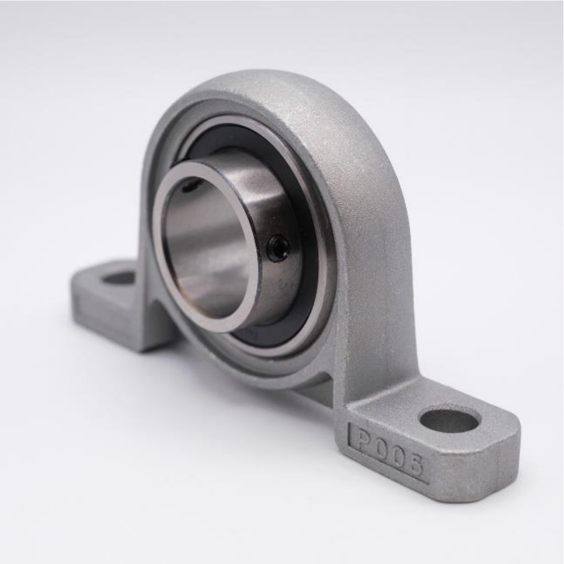
BALFOUR, J. R., SHAW, M., & NASH, N. B. (2013). *Introduction to Photovoltaic System Design*. Jones & Bartlett Learning. https://books.google.com.tr/books?id=kN1x4Rnv64kC

APPENDIX

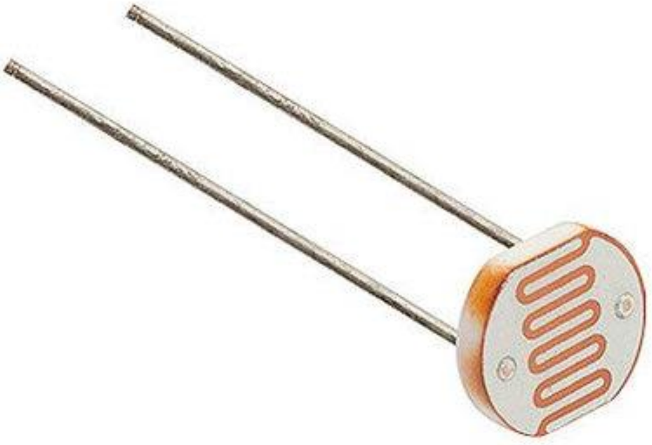
Arduino Uno R3



Pillow bearing

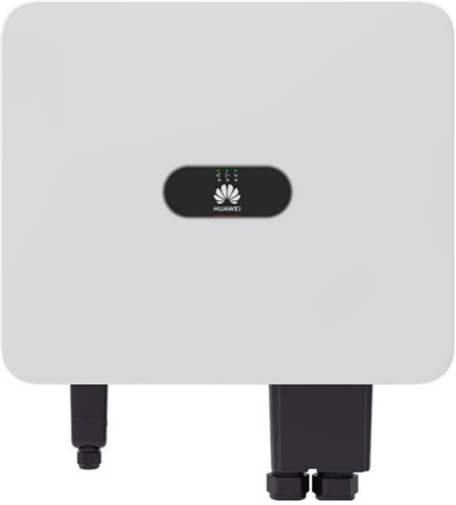


Light dependent resestor LDR



Disecq motor

Huawei SUN2000-12KTL



Huawei SUN2000-23KTL

Suntech STP310 - 24

RESUME