Analysis of the optimal performance point concerning ambient temperature and irradiance for an off-grid system in comparison to standard conditions in a PV power system

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**Abstract**

Researchers are establishing the challenges associated with power plant of photovoltaic energy systems to enhance their adaptability, durability, and ecological sustainability, aiming to make significant advancements that address current deficiencies in solar energy technology. In this investigation, we developed an off-grid solar photovoltaic system with a power capacity of 4175 kWP. We analyzed the effects of external operating conditions, specifically irradiation and ambient temperature. The study focused on ambient temperatures of 20°C, 30°C, and 35°C, with irradiation levels of 500, 600, 700, and 800 W/m², in comparison to the standard conditions established by the photovoltaic system, which are 1000 W/m² irradiation and an ambient temperature of 25°C. The findings indicated that the output from the off-grid PV system at 1000 W/m² and 25°C yielded the highest performance, with a maximum power point (Pmpp) of 3618.3 kW and a global loss of 13.1%. Following this, the performance at 30°C was 3465.9 kW with a loss of 16.8%, and at 35°C, the Pmpp was 3388.3 kW with an 18.6% loss. Furthermore, the study emphasizes the need to understand the importance of ambient temperature and irradiation as external operating conditions that affect system performance and efficiency. Additionally, it highlights the necessity for further research into external factors influencing system performance, highlighting that understanding optimal conditions is vital before designing any photovoltaic system.

***Keywords*:**

Ambient temperature, Global loss, Irradiation, Off-grid system, Solar Photovoltaic

**Introduction**

Photovoltaic energy encloses earned wide-ranging pivotal in recent years and its prospects are still constantly ascending as sustainable sources that donate significantly to enhancing multifarious aspects of life. Hence, photovoltaic (PV) energy is one of the alternative and renewable energy sources [1].

Solar energy is characterized by abundant, safe, and non-polluting, and poses no harm to the ecosystem [2]. Besides, deliver significant quantities of carbon-free energy [3] Solar PV panels have a long lifespan and low maintenance costs [4],[5]

Which their long lifespan of about 20 years, ability to install and operate in mountainous geographical conditions, suitability for mobile systems, easy maintenance, independence from the grid in remote locations, and connectivity to the grid, these features provide a promising future for these systems [6].

The considerable common solar photovoltaic systems involve the (i) Large-Scale and Small-Scale solar PV systems, (ii) Off-grid and On-grid Solar PV Systems(iii) Hyper Solar PV Systems(iv) Solar Water Pumping Solar PV Systems(v)Solar Street Lighting Solar PV Systems(vi) Solar Heating Solar PV Systems(vii)Self-Charging Solar PV System

Generally, Solar energy is capable harnessed in several ways to produce electrical, thermal, or mechanical energy mainly [7]. Nowadays, solar photovoltaic energy is witnessing massive importance in the energy sector. PV solar systems are being installed on an enormous scale worldwide [8],[9],[10] Further, the crucial of solar photovoltaic energy and the central it plays has made it an important source all over the world and is widely accepted, which has currently prompted the world to focus on photovoltaic energy sources and increase reliance on them continuously year to year, Figure (1) shows modern solar energy generation compared with sources of renewable energy, in 2023 which is measured in terawatt-hours compared with the rates of acceleration of increasing solar photovoltaic energy from 2024 to 2025 as shown in figure(2) particularly in electricity generation.

By 2028, solar photovoltaics will account for 12.6% of all renewable energy utilized [11],[12]. And installations anticipated of solar PV to reach between 5,4575 and 6,1016 GW in 2030 which is 3.86–4.32 times the 2023 level [13],[14],[15]. Plus, the forecast total power output generated by PV, to be 14.5 TW worldwide by 2050[16],[17]. Solar photovoltaic energy and its systems are witnessing significant development in the coming years, as it is envisioned that the energy sectors’ reliance on solar photovoltaic energy in 2100 will reach approximately 85% in energy production due to increased ongoing research and development, such as improving problems such as cell efficiency and external and internal factors inside the solar cell, in addition to emphasizing on finding sustainable solutions to hazardous waste caused by damaged or out-of-service solar photovoltaic panels, etc.

However, this may contribute to creating a sustainable space that contributes to cracking the challenges encountering solar photovoltaic energy and promoting it towards an outlook future that extends to thousands of years. As it might serve as a renewable alternative to traditional primary energy sources [20],[21]. therefore, the focus on the challenges of this energy is imminent, as, despite its characteristics, there are challenges facing these systems such as losses as a result of external conditions on photovoltaic, internal conditions in solar cells, etc.

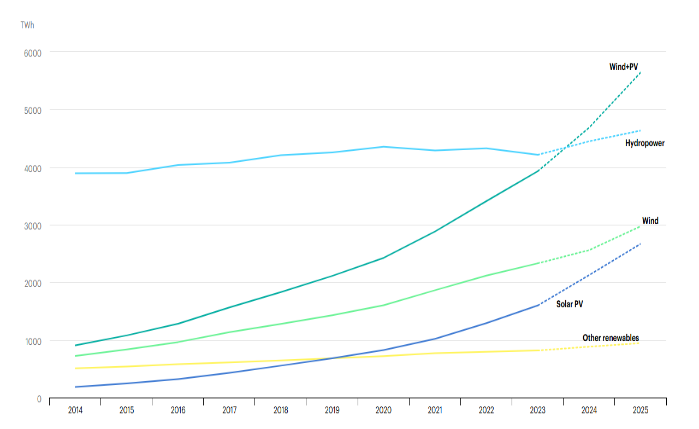
In this work, we will investigate the role of the performance of the effect of changing Irradiation and ambient temperature on the PMPP array. Consequently, we will experiment with the change in the PMPP array rates of the solar photovoltaic system compared to the standard conditions of the system's photovoltaic module, we will see how the variables affect the performance of the solar photovoltaic system.

Fig.1. Illustrates Sources of modern renewable energy production worldwide [18].

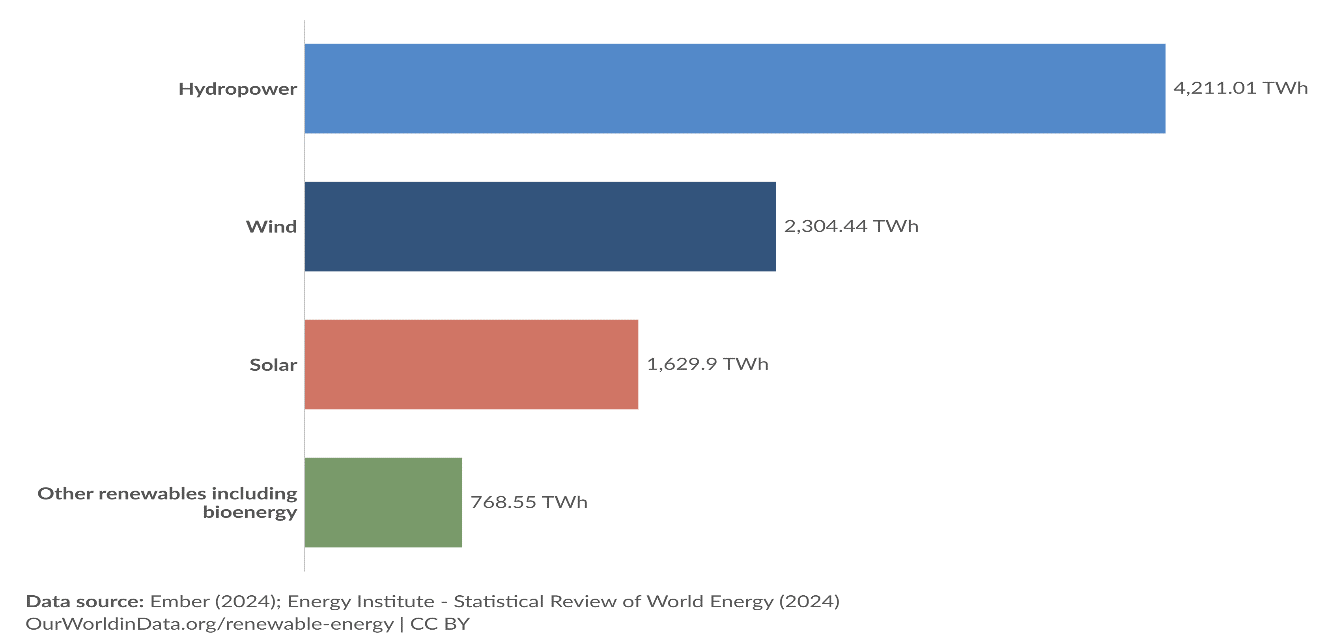


Fig.2. Illustrates sources of renewable energy for producing electricity between 2014 and 2025[19].

**2.Literature reviews**

*1.A comprehensive overview of PV system*

Previous studies have addressed various aspects of photovoltaic energy systems, including verifying the effectiveness of the systems and installing them for different purposes to diminish dependence on fossil fuel sources and achieve environmental sustainability via photovoltaic energy systems, such as stand-alone, Grid-connected, and hybrid, to establish a safe route in the field of future energy, We will review the studies from various aspects, as follows:

This study assesses the potential of off-grid solar photovoltaic systems in Punjab, finding them economically viable and capable of mitigating substantial CO2 emissions [22]. The study models solar grass-cutting equipment using PVSYST, demonstrating its environmental benefits and effective performance compared to diesel alternatives [23]. This study analyzes load requirements and designs a solar PV system for the mechanical department in Bikaner, noting performance ratios and losses [24]. A study in M'sila, Algeria, assesses a PV system's feasibility, revealing energy outputs, performance, and temperature-related losses [25]. On one hand, the study demonstrates in contemporary times photovoltaic systems are increasingly popular due to their sustainability and autonomy, and on the other hand. Assesses the performance of a grid-connected silicon-poly PV system with a peak power of 20.0 kW and a voltage of 17v, supplying electricity to an academic institution for enhanced operational understanding [24] The study assesses a stand-alone photovoltaic (SAPV) system using PVSYST software to predict yearly energy production. It simulates the SAPV configuration, determining electrical energy generation from the PV array, various power losses, and optimal system size. Additionally, it calculates total energy flow, enabling predictions of energy supplied to the load throughout the year [27].

This study demonstrates modeling and simulating a 1 MW photovoltaic plant in northern Morocco using PVsyst software. It evaluates performance ratios and power losses due to temperature and electric power, assessing the feasibility of solar installation by comparing energy production at various northern sites [28]. This paper illustrates some of the key features of the operating performance of the 81.9 kWp PV system installed on the roof of academic buildings. Real-time data was monitored over 12 months to evaluate the performance ratio, energy yield, efficiency, and losses associated with the system. The performance evaluation was done by PVsyst and was validated using the experimental data generated from the PV grid-connected system. The experimental result shows that the maximum final yield of 4.5 kWh/kW/day was obtained during April and the minimum of 2.4 kWh/kW/day was obtained during November. The annual average array and system efficiency was 13.1 % and 12.8 %, with July reported maximum efficiency of 13.4 % and 13.1 % respectively. The effect of high temperature and solar irradiance was observed in May, resulting in the lowest array efficiency of 12.6 %. System performance is seen to have seasonal implications, this was verified through simulation studies, and it was found that to overcome energy shortages, especially during winter seasons, PVsyst analysis predicts such shortcomings more accurately [29]. This study proposes a hybrid strategy for optimal sizing of stand-alone photovoltaic systems, focusing on worst-case PV generation [30]. This study presents a simulation of a 1kWp photovoltaic system for Hamirpur, India, using PVsyst software. The system, with an annual solar radiation of 4.4 kWh/m², shows a performance ratio of 0.724, indicating its viability [31]. This study develops a design for a grid-connected solar power system in Bahteem, Egypt, which is projected to generate 400 KWp, improving electricity prices and reducing environmental impact [32]. This study evaluates the performance of a grid-connected 1 MW solar photovoltaic system in Shapur, Gujarat, India.[33]. The study focuses on optimizing solar energy utilization for a "photovoltaic + energy storage" system, considering factors like power generation, storage demand, location, and environmental impact to improve economic efficiency and reliability [34]. This study evaluates a 100 kWp grid-connected Si-poly photovoltaic system for an educational institute, analyzing energy output, grid injection, performance ratio, and annual losses using PVsyst software and Metronome data [35]. The study highlights PVSyst as a reliable tool for modeling and predicting solar PV system performance [36]. This study presents a comprehensive approach for sizing and optimizing a floating photovoltaic (FPV) water pumping system in Mafraq, Jordan, integrating technical, environmental, and economic factors, yielding a proposed 165 kW system that enhances efficiency and reduces emissions [37]. The study shows numerous On-Grid PV systems are being established worldwide to diversify energy sources. In Kathmandu, Nepal, a 115.2 kWp solar plant at Tribhuvan University Teaching Hospital aims to meet its energy demands and cut electricity costs, Although it doesn’t currently feed energy to the grid, simulations predict a potential generation of 199 MWh annually, with actual production recorded at 35 MWh in its first year, Performance parameters using PVSYST show an 83.5% performance ratio and 1728 kWh/kWp specific yield[38]. This study details the design of a standalone PV system for Dina Farm Rest, Egypt, encompassing location data, energy demand, and component selection, it involves sizing based on watt-hour calculations and utilizes PVSyst software for performance analysis, yielding insights on energy generation and efficiency, useful for other similar projects [39]. Study elucidates the design and simulates a 60kWp solar power plant—an on-grid photovoltaic system using PV-syst software version 7.2.2—in rural Uttar Pradesh, India, the analysis covers seasonal tilt angles of 10° for summer and 47° for winter, followed by performance and loss studies [40]. This study designs and evaluates a grid-connected solar photovoltaic rooftop system for an academic campus. Using PVsyst software and NASA meteorology data, it estimates annual energy production of 590MWh, addressing 11% of total energy consumption and reducing 42 tons of CO2 emission [41]. In this study, photovoltaic panel modeling was conducted in Karbala and Erbil Provinces, Iraq, using PV-Syst software. The optimal tilt angle for Karbala was found to be 31 degrees, yielding a production of 1815 kWh/year, while Erbil’s optimal angle was 33 degrees, resulting in 1743 kWh/year, enhancing system efficiency and performance Study in Iraq [6]. This study examines the load requirements of Mandali City houses in Iraq and designs a stand-alone photovoltaic system, using PVsyst software to analyze performance ratio and losses [42]. The study presents a stand-alone photovoltaic system to supply power to three laboratories in the electronic and communications engineering department at Al-Nahrain University, Baghdad for enhancing power continuity through PVSyst simulations [43].

*2.Review Studies of previous PV-System simulations*

We will elaborate on previous studies of the systems that were simulated via the PVsys software as shown in Table (1) where the studies dealt with different aspects and purposes that were simulated for various locations around the world, we conclude that the design of photovoltaic energy systems, or rather through connected systems, has a great trend, while independent energy systems have been adopted in fewer applications due to the high cost they require despite the positive aspect they provide, as they provide electrical energy without relying on the national grid, as they appear as the best autonomous systems that can be adopted in remote or rural areas, in addition to hybrid energy systems, which are the most widely utilized sort at present. In this, we will emphasize reviewing the previous literature on Grid-connected and stand-alone systems.

Table.1. PVsyst simulation based on prior study.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Ref | Year | Software | Type | Site | Nominal PV power | Tilt/Azimuth | SI.NO |
| [44] | 2023 | PVSyst | Grid-connected | Karunya Institute of technology | 14.8 KWp | 25 ͦ /20 ͦ | 1 |
| [45] | 2022 | PVSyst | Grid-connected | Tetulia, Panchagrah, Bangladesh | 3.3 KWP | 27 ͦ /0 ͦ | 2 |
| [46] | 2024 | PVSyst | Stand-alone | Mandali City | 4 KWP | 32 ͦ /0 ͦ | 3 |
| [47] | 2024 | PVSyst | Grid-connected | Salah al-Din | 999999 KWP | 30 ͦ/0 ͦ | 4 |
| [48] | 2023 | PVSyst | Grid-connected | Darab and Meybod-in Fars and Yazd | 9.9 KWP | 33 ͦ /0 ͦ | 5 |
| [49] | 2021 | PVSyst | Grid-connected | Cairo International Airpor | 19916 KWP | 30 ͦ /-20 ͦ | 6 |
| [50] | 2022 | PVSyst | Grid-connected | AI Juaima'h, Dammam | 960 KWP | 30 ͦ /0 ͦ | 7 |
| [51] | 2022 | PVSyst | Grid-connected | Ghor | 6399 KWP | 34 ͦ /0 ͦ | 8 |
| [52] | 2018 | PVSyst | Stand-alone | Karnataka | 2.5 KWP | 15 ͦ /180 ͦ | 9 |
| [53] | 2020 | PVSyst | No sizing | Daily Household consumption | 0.3 KWP | 13 ͦ /0 ͦ | 10 |
| [54] | 2025 | PVSyst | Grid-connected | Kţbīyah | 641KWP | 30 ͦ /0 ͦ | 11 |

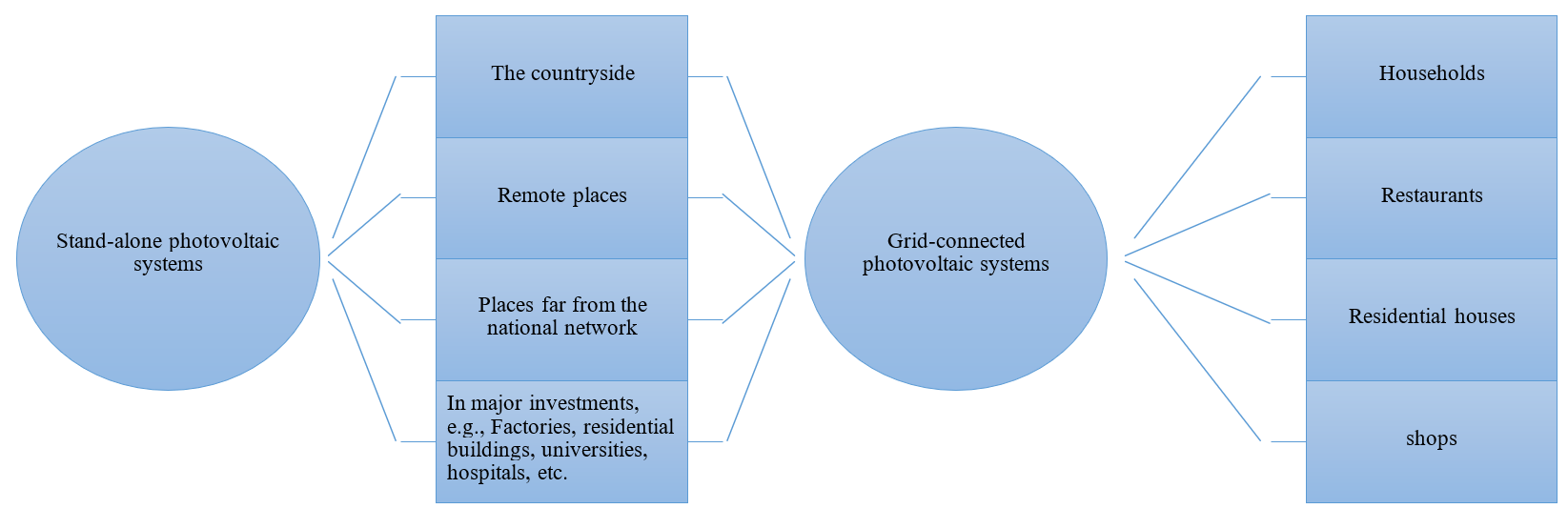


Fig.3. Optimal applications of PV systems

Fig.3. Shows the most prominent applications in which connected and independent photovoltaic energy systems can be used. This is based on the applications that have been implemented in recent years and are still ongoing. On the other hand, stand-alone systems effectively deliver reliable electricity in remote areas and areas far from the grid from the grid [55].

**MATERIAL AND METHODS**

In this work, the photovoltaic modules of (JKM585M-7RL4-V) and the battery type DCB102Z

were relied upon. Hence, **the tables (2,3)** shows the PV Array Characteristics of the off-grid

photovoltaic system.

*1****.*** *Photovoltaic (PV) technology*

Photovoltaic (PV) technology is a very significant technology that can convert solar radiation directly into electrical energy through a photovoltaic panel [56],[57],[58]. Photovoltaic conversion is the direct conversion of sunlight into electricity without any heat engine to interfere. Photovoltaic devices are rugged and simple in design requiring very little maintenance and their biggest advantage is their construction as stand-alone systems to give outputs from microwatts to megawatts. Hence, they are used for power sources, water pumping, remote buildings, solar home systems, communications, satellites and space vehicles, reverse osmosis plants, and even megawatt-scale power plants. A photovoltaic power generation system consists of multiple components like cells, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. These systems are rated in peak kilowatts (kWp) which is an amount of electrical power that a system is expected to deliver when the sun is directly overhead on a clear day [59]**.**

2.Analysis PV-Off-grid System

PVsys software was used to control an off-grid photovoltaic system. The work was based on many questions from engineers and researchers in the field of photovoltaic energy about why the standard conditions of 1000 w/m2 and a temperature of 25° C were chosen, we designed a system and conducted investigations on the effect of (Irradiation) and (Ambient temperature) as they are among the most prominent external conditions that affect the performance of photovoltaic modules This work was done in(All Al Mu‘tadilah, Iraq at altitude (32.89N°) , Longitude(41.52E°) and Altitude(454m) at Time zone(UTC+3 ) according to PVSyst. However, this evaluation was conducted to address the many questions about the impact of external conditions and their volatility in Iraq, which negatively affects the performance of photovoltaic units in the collector field. Therefore, the study effect of each loss on the PV array reveals the numerous modern aspect capable enhance towards to solve PV systems.

Table 3. The main characteristics of module

|  |  |
| --- | --- |
|  | PV module |
| Jinkosolar | Manufacture |
| JKM585M-7RL4-V | Model |
| 585 Wp | Unit Nom. Power |
| 7136 units | Number of PV modules |
| 892 Strings x 8 In series | Modules |
|  | At operating cond. (50°C |
| 3809kWp | Pmpp |
| 322 V | U mpp |
| 11820 A | I mpp |

Table 4. The main characteristics of Battery

|  |  |
| --- | --- |
|  | **Battery** |
| Panasonic | Manufacturer |
| DCB102Z | Mode |
| Lithium-ion, LCO | Technology |
| 5000 in parallel x 5 in series | Nb. of units |
| 10.00% | Discharging min. SOC |
| 58441.5 KWh | Stored energy |
|  | Battery Pack Characteristics |
| 241 V | Voltage |
| 270000 Ah (C10 | Nominal Capacity |
| Given monthly values | Temperature |

**Results and Discussion**

Through the simulation software PVsyst, we will elucidate the design of a stand-alone photovoltaic system to investigate external operating conditions specifically, irradiation, and Ambient Temper, changes on the array, and we will compare them with the normal conditions of the solar panel. Consequently, the primary purpose of this work is to show the most important external conditions and their impact on the performance of the photovoltaic system to study the different aspects of the system and other factors that may affect the production rate of the independent photovoltaic station. In addition, this system can be adopted in numerous countries not only in Iraq. The figure (4). illustrates the criteria

of the solar photovoltaic system designed to verify the best conditions that can be adopted by choosing the best conditions attainable in this work

|  |
| --- |
|  |
| Fig.4. Board for PV-Off-grid system |

Table.5. Synopsis of system results

|  |  |
| --- | --- |
| 7354188 kWh/year | Available Energy |
| 10 kWh/year | Used Energy |
| 1762 kWh/kWp/year | Specific production |
| 0.00% | Perf. Ratio PR |
| 100.00% | Solar Fraction SF |
|  | Orientation |
| 50 / 0 ° | Tilt/Azimuth |
| 7136 units | Nb. of modules |
| 4175KWP | Pnom total |

The table (5) shows the basic factors obtained from the PVsyst software criteria, which indicate the average values ​​of the basics of the designed system to find a validated methodology in this work ,which the emphasis was on simulating the stand-alone system where the user's needs are fixed constant load with a capacity of 1W and the global 10.0kwh/Year.

**Analysis of Simulation of System Test**

Table (6) The table shows the test results at (20°C) Ambient temperature, (25°C), at irradiation 500, 600, 700, 800, 1000w/m2. The results show that the lower the Ambient temperature, the higher of rate for Pmpp and the global loss will high and Ambient temperature at (30°C) Ambient temperature, (35°C), at irradiation 500, 600, 700, 800, 1000W/m2. The results show that the lower the Ambient temperature, the higher of rate for Pmpp and the global loss will high.

Table.6. The case of investigation at ambient temperature

|  |  |  |
| --- | --- | --- |
| Irradiation | **20 °C** | **25 °C** |
| **500w/m2** |  |  |
| **600w/m2** |  |  |
| **700w/m2** |  |  |
| **800w/m2** |  |  |
| **1000w/m2** |  |  |
| **Irradiation** | **30 °C** | **35 °C** |
| **500w/m2** |  |  |
| **600w/m2** |  |  |
| **700w/m2** |  |  |
| **800w/m2** |  |  |
| **1000w/m2** |  |  |

**Table.7. Summary of test criteria values**

|  |  |  |  |
| --- | --- | --- | --- |
| Global loss | Pmpp array | Ambient Temper (°C) | Irradiation(w/) |
|  |  |  | 500 |
| 8.1% | 1907.3 | 20 |  |
| 9.9% | 1871.2 | 25 |  |
| 11.6% | 1834.7 | 30 |  |
| 13.4% | 1798.5 | 35 |  |
|  |  |  | 600 |
| 9.30% | 2265.2 | 20 |  |
| 11.0% | 2222.4 | 25 |  |
| 12.8% | 2179.3 | 30 |  |
| 14,5% | 2135.5 | 35 |  |
| 10.5% | 2613.1 | 20 | 700 |
| 12.2% | 2562.6 | 25 |  |
| 14.0% | 2511.4 | 30 |  |
| 15.7% | 2459.5 | 35 |  |
|  |  |  | 800 |
| 8.3% | 3060.3 | 20 |  |
| 10.0% | 3003.6 | 25 |  |
| 11.8% | 2946.2 | 30 |  |
| 13.5% | 2887.9 | 35 |  |
| 13.1% | 3618.3 | 20 | 1000 |
| 14.9% | 3542.6 | 25 |  |
| 16.8% | 3465.9 | 30 |  |
| 18.6% | 3388.3 | 35 |  |

**Conclusion**

Photovoltaic energy systems (PVES) have gained prominence due to volatile fossil fuel prices and their environmental impact, prompting a shift towards alternative energy like solar power.  Despite this trend, challenges persist for solar systems in various countries, particularly where radiation levels do not meet standard conditions, such as 1000 W/m² and 25°C.  Additionally, there are concerns regarding waste produced during the renewal or manufacturing of these systems, etc. This work emphasis on the influence of external factors, namely ambient temperature and irradiation, on the performance of Maximum Power Point (Pmpp)and global loss. It emphasizes the significance of determining the optimal ratios of these factors and their effects. Furthermore, the study employs the PVsys software to analyze and verify standard conditions, aiming to establish the most suitable operating conditions for future solar photovoltaic systems.

**The Observations of this work**

1. It is preferable to choose a balance between Global Loss and PMPP rates, for example, when choosing good height rates in (Maximum Power Point Power), you should take good (Global Loss) rates that are compatible with efficiency. provided by the system.
2. When designing any system, it is preferable to determine the external conditions and climatic fluctuations of the site, who will be exposed to these losses, and determine a higher rate of losses than the expected losses.
3. In some locations, when designing the photovoltaic system, the annual external conditions are not calculated, and it is sufficient to determine according to the maximum weather conditions.
4. Determining the rates of Wind Velocity, which is an important factor that affects the performance of PV units.
5. Identify the best Incidence Angle before designing any photoelectric system.
6. 6.Investigating (Beam/Global ratios) and choosing the best conditions enables to enhance the system efficiency

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