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A Comprehensive Study on Exploring Physical Parameters for Optimal Performance of PV Systems

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Abstract
The overall performance of photovoltaic systems is encouraged with the aid of diverse bodily parameters, and expertise their effect is vital for optimizing system performance. This study aims to provide a comprehensive analysis of the physical parameters affecting the performance of PV systems.
The look at begins through examining the impact of solar irradiance on PV machine overall performance. Different levels of solar irradiance are considered, ranging from low to high, and their impact on the system's power output and efficiency is analyzed. It is observed that the system operates at its maximum power output and efficiency under moderate solar irradiance conditions.
The examination of the influence of temperature on the performance of a photovoltaic (PV) system is also explored. The analysis takes into account the temperature coefficient of the PV modules and assesses how it impacts the power output and efficiency of the system It is found that higher temperatures lead to a decrease in power output and efficiency, highlighting the importance of proper thermal management in PV systems.
Furthermore, the study explores the influence of shading on PV system performance. Different shading scenarios are studied, and their impact on the system's power output and efficiency is assessed. It is observed that even partial shading can significantly reduce the system's performance, emphasizing the need for proper site selection and shading mitigation techniques. The role of module orientation and tilt angle in PV system performance is also studied. Various orientations and tilt angles are examined, and their impact on the system's power output and efficiency is compared. It is determined that the optimal orientation and tilt angle depend on the geographic location and the seasonal variations in solar irradiance.

Keywords: *PV Array, Location, Temperature, Irradiance*

1. Introduction

Photovoltaic (PV) array systems have gained significant attention as a sustainable and renewable energy solution. The efficient functioning of PV array systems relies on various factors, including solar irradiance, temperature, and geographical location. Temperature, in particular, plays a crucial role in the performance of PV modules, as it affects their electrical characteristics, such as voltage, current, and output power. When PV modules are exposed to higher temperatures, the efficiency of the system decreases, leading to reduced electricity generation. Moreover, the geographical location of the PV array system introduces another layer of variability. Different locations experience varying levels of solar irradiance, which is the primary energy source for PV systems. Factors such as latitude, altitude, and local weather patterns can influence the amount of solar radiation received, thus affecting the overall system output. Understanding the influence of the location on PV array system performance is essential for optimizing the system design and ensuring optimal energy production.

In this study, we aim to analyze the effect of temperature and location variability on the performance of PV array systems. Through simulation and comprehensive analysis of various temperature and location scenarios, we seek to quantify the effects of these factors on the system's electrical characteristics, such as voltage, current, power, and energy yield. This research will provide valuable insights into the behavior of PV array systems under different operating conditions, enabling engineers and designers to make informed decisions for efficient system design and optimization.

By elucidating the relationship between temperature, location, and PV array system performance, this study will help to contribute to the broader goal of promoting renewable energy sources and ensuring the reliable and efficient operation of PV array systems. The findings will aid in the development of strategies to mitigate the negative impacts of temperature and location variability, ultimately facilitating the widespread adoption of solar energy as a viable alternative to conventional power sources.

Photovoltaic Systems

Light stimulates the production of electricity by photovoltaic cells (Fig.1). In a semiconductor material, charges are created when photons from sunshine are absorbed. This is how electricity is produced. Silicon and other semiconductors can absorb a considerable amount of sunlight, but not at wavelengths that fall below the material's absorption edge (band gap). The voltage is subject to the basic principles of physics and a phenomenon called the temperature coefficient which directly affects the total energy production of a photovoltaic system.

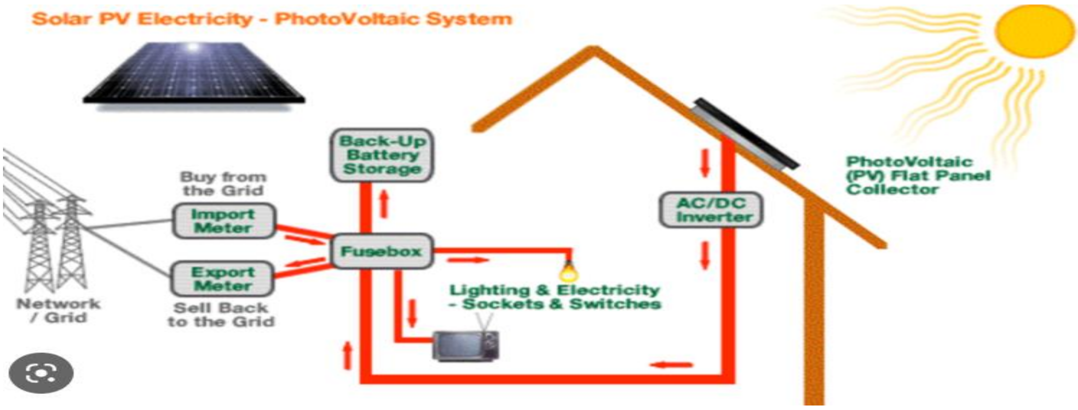

Figure 1 Solar Photovoltaic System Schematic

Photovoltaic science has advanced to a professional level. When new photovoltaic materials become available, researchers eventually adjust their language to include descriptions of the resulting phenomena. Based on their thermodynamic analysis, Shockley & Queisser (S-Q) (1961) determined that a single-junction device might have a maximum efficiency of a little over 33%. These barriers are due to hot collisions of high-energy photons above the single band gap and collisions of photons below the band gap.

The equilibrium photonic flux from the sun into the photovoltaic device & out into the universe is another foundation of this theory. This set of imaging modes includes both established materials such as crystalline and polycrystalline silicon-based photovoltaics, as well as more modern organic materials, either dry or wet, as well as state-of-the-art hybrid organic-inorganic materials. The science is well-developed, but the implications of that science are not generally recognized. Photonic technology was used to adjust the ratio of incoming to emitted photon flux in high-efficiency gallium arsenide (GaAs) single-junction solar cells, resulting in a 28.8% increase in power conversion efficiency (PCE) (Miller et al. 2012).

Tandem solar cells also referred to as multi-junction solar cells, are more efficient at converting solar energy into usable form because they combine multiple materials with varying band gaps & connect them in series to reduce heat & transmission losses. These solar cells work exceptionally well under full sunlight, with a power conversion efficiency of up to 44.7% at high doses. Most applications for these solar cells are in highly focused solar radiation on Earth's surface. These structures have a greater material & processing cost because of the skillful assembly of several compound semiconductors on top of one another. Because of the need for high-performance, low-cost concentrators that function best in direct sunlight, these solar cells are most applicable when combined with concentrating optical elements. Applications have been shown to work in the multi-MW range & today such concentrator systems are becoming more generally available.

Photovoltaic energy conversion attempts that make use of the infrared & far infrared region of the solar spectrum, which contains 50% of the solar energy, are relevant, especially when used in tandems. Although the most efficient band gap for single-band gap devices is between 1.4 & 1.1 eV, the lower energy portion of the solar spectrum is lost.

Solar photovoltaic (PV) technology has become widely adopted recently. There are two key meteorological parameters—temperature & sun irradiation—that affect the performance of all solar panels. The solar array's I-V and P-V characteristics are illustrated in Fig. 1 at a constant temperature of 250 C and solar irradiations of 1kW/m2, 1.2kW/m2, and 0.8kW/m2. More power is produced when the current across the panel increases since the voltage across it changes relatively little as the irradiance increases. This means that as solar irradiation increases, so does the amount of energy harvested.

Temperatures of 650 C, 450 C, & 250 C, as well as a continuous irradiation of 1000 W/m2, are depicted in the I-V and P-V characteristics of a solar array. Array power is diminished because voltage decreases with rising temperature while current changes only slightly. As a result, the array loses efficiency & generates less power in extreme heat.

The type of Photo-voltaic installed has a significant effect on the electrical output of the system. Depending on the environmental conditions & solar cell type, a typical Photo-voltaic module may convert between 5% & 21% the conversion of the incoming solar radiation into electricity. The remaining solar energy is converted to heat, which causes a rise in the Photo-voltaic module's temperature & greatly affects the module's PV efficiency. Photovoltaic thermal (PVT) collectors can be used to harvest this heat by channeling water or air movement beneath the Photo-voltaic module. In the existing literature on PVT, Only crystalline Si and a-Si have been seen. The PVT's electrical-to-thermal ratio & electrical efficiency will both improve due to the use of crystalline Si, which is more efficient than amorphous silicon. Both a-Si & c-Si PVT-liquid & PVT-air collector measurements are presented in Tripanagnostopoulos et al. He discovers that his PVT liquid collector's c-Si prototype has an efficiency of 55% & his a-Si prototype has an efficiency of 60% at zero decreased temperature, whereas his PVT air collector's c-Si prototype has an efficiency of 38% & the a-Si prototype has an efficiency of 45%. The electrical performance of a-Si modules is only 6%, while that of c-Si modules is 12%. (Ji J, Chow TT, He W (2003).) also discovered that a-Si had a greater thermal yield. Although c-Si has been shown to have a higher thermal efficiency in some trials, a-Si has been shown to have a lower efficiency in others (Affolter P, Haller A, Ruoss D, Toggweiler P(2001)). Traditional PV modules, unglazed PVT modules, & glazed PVT modules were evaluated & contrasted by Zondag et al. We calculated annual electrical efficiency to be 7.2%, 7.6%, & 6.8%. The electrical performance of a thermosyphon PVT collector was determined (Chow T.T (2003)) by positioning the Photo-voltaic either at the top or bottom of the absorber. He discovered a 3% improvement in electrical efficiency at the lower, cooler end. Using a PV-connected unglazed transpired collector (Naveed AT, Kang EC, Lee EJ (2006)) analyzed a PVT air system. It was established that lowering the temperature by 3-9 o C improved the electrical performance, which allowed for a reduction in the light area from 25 m2 to 23 m2. A photovoltaic laminate is combined with a triangular water tank in an unglazed integrated solar home system [Krauter & Ochs & Krauter] The tank reduces the PV's temperature by absorbing more heat. Depending on the stratification, a 9-12% increase in electrical yield is typically observed for high radiance Photo-voltaic systems compared to traditional solar home systems.

System Description

Boost converters & inverters are the two preliminary power electronic parts of a solar Photo-voltaic system. The boost converter converts the variable DC generated from the Photo-voltaic panel into a constant dc value & the inverter converts this constant DC value into an AC value that is compatible with the associated AC loads, as shown in the diagram of the solar Photo-voltaic system (close loop) in Fig. 3.

As the input parameters (temperature & solar radiation) & output parameters (loads) fluctuate, the system parameters, such as inverter output voltage & DC link voltage, will change, which is neither necessary nor acceptable. Employing PI controllers to achieve the controlled system to alter the switching of power electrical components. Figure 2 depicts the diagram of the whole system for the system closed loop used in conjunction with a standalone controller.

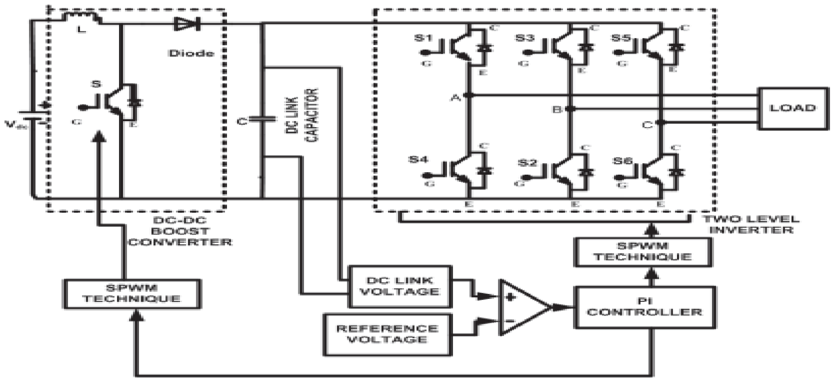

Figure 2 The complete schematic of a closed-loop solar photovoltaic system

A. Boost Converter

The following are some of the primary uses of dc-dc converters.

1. The goal is to stabilize the dc voltage at the output by converting it from a variable input. x The output voltage's ripple must be minimized.
2. To stabilize the DC output voltage & prevent voltage drop or rise due to changes in load or line.
3. To Separate the input from the load. When the input voltage is insufficient, the output voltage is raised to meet the minimum necessary value. Boost converters that utilize a 569 converter consist of several components, including an inductor, a switch (usually an IGBT or MOSFET), a diode, and a capacitor,

B. Inverter

A voltage source inverter's primary purpose is to transform a constant direct current (dc) amount into three-phase alternating current (ac) voltage with variable amplitude & fixed frequency, making it suitable for use with ac loads. In Fig.3, we see the fundamental layout of a voltage inverter with three-phase inputs. Switches are what the IGBTs are used for. In this work, the SPWM switching technique is used to create the gate pulses used by the inverter switch.

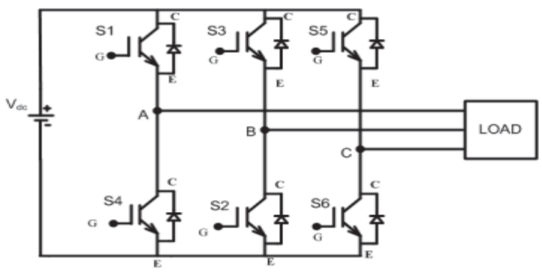

Figure 3 Three-phase inverter

The system's output voltage can be regulated & its THD can be lowered thanks to PWM approaches. The magnitude & frequency of the output voltage can be adjusted with the use of the SPWM switching method. The SPWM system makes use of a high-frequency triangular carrier wave & a sinusoidal modulating signal for comparison. The modulating signal's peak magnitude is smaller than the carrier signal's peak magnitude. Unipolar & Bipolar modes of operation are available under the SPWM methodologies. Since the unipolar operation results in less input ripple current, it is favored. After the comparator's output pulses are applied to the gate of the IGBTs, the switches can be driven (Raja Ram Kumar, Sunil Kumar & Alok Yadav (2013) & Pranay S. Shete, Rohit G Kanojiya & Nirajkumar S. Maurya (2012)). Figure 7 depicts the SPWM approach for pulse production. For SPWM pulse production, the following values were considered: reference sine wave amplitude = 0.8, carrier wave amplitude =1, & switching frequency = 50 Hz, 1 kHz. Hence, the index of amplitude modulation is 0.8. When the modulation index is less than 1, the rms voltage of the output can be more precisely regulated.

A. **Boost Converter Control Scheme**

If you want a well-regulated system & reliable output, you should keep the voltage across the dc connection stable. The dc link is held constant throughout the operation thanks to a PI controller in the input loop whose value is tuned to control the system's input side. So, the input loop can be controlled with a PI controller instead of the MPPT method.

The DC link's real voltage is measured & compared to a standard. The PI controller receives the error signal. The boost converter switch receives a pulse generated by comparing the PI controller's output with that of a triangle generator.

B. **Inverter Control Scheme**

Changes in the system parameters also impact the inverter's output voltage. As a result, the inverter output is also held steady. An inverter regulates the system's output side, and Figure 4 shows the inverter's control scheme. The DC link voltage is measured and compared to a reference value. The generated error is transmitted to the PI controller. The result of the PI calculation will be a dc value. This dc quantity is multiplied by the sinusoidal value to create an ac value, which is used to provide pulses for inverter switches.

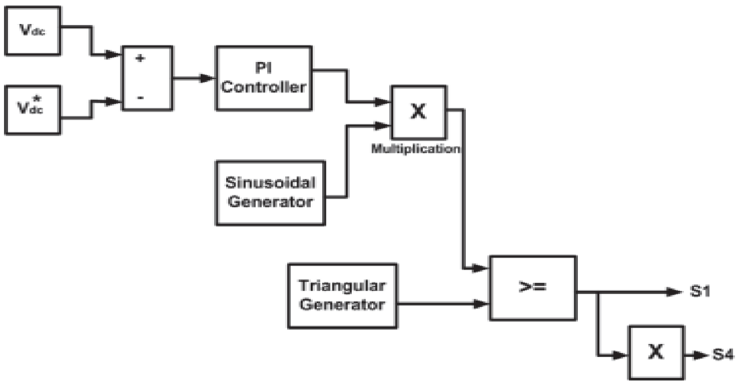

Figure 4 Inverter Control System

Likewise, we can apply this method to the other two branches of the inverter. The mean temperature of the air at the Earth's surface fluctuates worldwide, depending on factors such as prevailing winds, ocean currents, continentally, & latitude.

In each winter hemisphere, middle & high latitudes in average temperature have considerable north-south gradients, demonstrating the influence of latitude. At high latitudes, higher surface reflectivity due to snow & ice along with low solar altitudes contributes to these gradients, but the quick decline in available solar radiation is also a major factor. In comparison, there is surprisingly little temperature change throughout a large swath of the tropical ocean.

The greater temperature variation over land compared to water is the primary cause of continentally, which is a metric used to differentiate between continental & marine climates. This disparity arises from the fact that land surfaces have substantially lower effective heat capacities and, in general, lower evaporation rates. The potential of the earth of conducting heat determines the thickness of the layer that heats or cools a land area. Since they are weak conductors, have no moisture to evaporate, &, have low effective heat capacity, dry, sandy soils experience the most extreme temperature swings. The effective heat capacity of water surfaces is the highest by a wide margin, thanks to the penetrating ability of solar radiations which tend to distribute heating effect to depths of several meters & the mix water at the surface. Furthermore, evaporation accounts for roughly 90% of the ocean's radiation budget. As a result, shifts in ocean temperatures are gradual.

Depending on the prevailing wind strength & direction, proximity to the ocean may mitigate the impact of continentality. North or south-flowing ocean currents may further modify the temperature contrast between the ocean & the continents' borders. Nonetheless, continentality does account for a significant portion of the fluctuation in usual temperature at particular latitudes & in the variance in temperature amid January & July for most latitudes.

Time of day, season, & extremes

Where solar radiation is highest, such as on high mountain plateaus & in dry tropical climates, the diurnal temperature range tends to grow. Parts of the British Isles closest to the Atlantic have an average daily temperature range of 9 °F (5 °C) in July & 5 °F (3 °C) in January. Malta, a small island in the Mediterranean Sea, experiences a temperature range of 12 °F (6.5 °C) in July & 8 °F (4.5 °C) in January. The average monthly high in Tashkent, Uzbekistan, is 16 degrees Fahrenheit (9 °C), while the average monthly high in Khartoum, Sudan, is 17 degrees Celsius (63 °F). Located around 1,000 meters above sea level, Kandahar, Afghanistan has January highs of 14 °C & July lows of 20 °C. In September & October, the average daily changes between the highest & lowest temperatures reach 23 °C when there is less cloudiness as compared with July. The average January temperature in Colombo, Sri Lanka is 8 degrees Celsius, while the average July temperature is 4.5 degrees Celsius.

At high latitudes & away from the ocean, the magnitudes of the seasonal temperature variation & The differences between the same month in different years and epochs tend to increase.

Height-dependent variation

Both the surface of the Earth & the stratosphere (about 50 km, or 30 miles) above it contribute to the overall temperature of the atmosphere. At these concentrations, the radiation balance indicates a net gain. As one moves away from these sources of heat, the ambient temperature drops (Aside from the ionosphere and outer atmospheric layers, where various processes are active). In the lower atmosphere, the typical global lapse rate of temperature is 0.6 to 0.7 °C per 100 meters (approximately 1.3 to 1.1 °F per 300 ft). Because the balance in radiation in free air is less favourable at higher altitudes, & air rising experiences and as the pressure of the surrounding atmosphere lowers, the expansion's temperature decreases, cooler conditions prevail at higher altitudes. Condensation (with the release of latent heat) is caused by adiabatic cooling, & the lapse rate of temperature is around 1 °C per 100 meters (about 2 °F per 300 feet) for dry air & 0.5 °C per 100 meters for saturated air. Rising air currents are either accelerated or retarded depending on the disparity between their Rates of temperature change (and consequently density), as well as the condition of the surrounding air, which affects whether or not vertical convection, which is associated with the creation of tall cumulus clouds and showers, is favored.

This is why, except for large plateaus, where the elevated surface provides additional heat, the air temperature is often lower at higher elevations than it is at lower ones (additionally, on calm, sunny days, even a mountain peak can significantly warm the air that comes in touch with it).

Deep inside the Sun, nuclear fusion produces enormous amounts of energy, which is progressively transferred to the solar surface before being radiated into space. Depending on their mass & distance from the Sun, the planets can absorb a negligible portion of this energy. For instance, in the upper atmosphere of Earth, a square meter of space aligned perpendicularly (90 degrees) to the Sun's beams receives around 1,365 watts of solar power. The quantity of solar energy collected by Earth varies throughout the year by around 3.4%, with a peak on January 3 (when Earth is closest to the Sun), similar to how much energy an ordinary electric heater uses. The slight ellipticity of Earth's orbit around the Sun is what causes this variance. While approximately 31% of this energy is lost to space, the remainder is more than enough to drive atmospheric winds & ocean currents & maintain practically all biospheric activity.

A surface's energy reception is proportional to its solar elevation angle when it is not parallel to the Sun. Above, the Sun is at an angle of 90 degrees, which varies predictably with latitude, season, & time of day. On June 22nd, for all latitudes that are higher than the Tropic of Cancer (23.5° N), the noontime elevation angle is at its greatest & on December 22nd, at its least. The opposite is true south of the Tropic of Capricorn (23.5° S), & The maximum elevation angle (90°) between the two tropics happens twice a year. When the Sun's rays are dispersed over a broader region, their intensity decreases when the Sun is at a lower elevation angle. Hence, one of the primary reasons for the reliance of climatic regimes on latitude is the variation in solar elevation. The duration of daylight is also an important consideration. In contrast to the continuous 12-hour day at the Equator, the duration of the day varies from 0 (winter solstice) to 24 (summer solstice) for latitudes poleward of 66.5° N & S. From high latitudes to the tropics, the seasonal temperature range declines until it is smaller than the diurnal temperature range.

Effect on energy production

Electricity generation was analyzed to see how latitude affected output from East & West power facilities. In terms of latitude, the power plant is closer to the equator, so its solar radiation value is higher than that of other provinces, & this fact was analyzed (Demirkiran, Muhammet & Karakaya, Abdulhakim. (2022)) to see how the difference in latitude affects electricity production in the north & south. As a result, both electricity output & revenue will rise. Because of the high elevation at which the power plant is situated, the average yearly temperature there is lower. The panels will function better at lower temperatures. Since solar radiation declines from summer to winter, it stands to reason that less electricity is generated during the colder months. Fig. 5 "(Kawajiri K, Oozeki T, Genchi, Y (2011)) displays the worldwide distribution of yearly total irradiance (Hy) on equator-pointing tilted surfaces calculated by adding the monthly total solar irradiation values in the NASA database, which are averages of 22 years of data from 1983 to 2005. Figure 6 displays a global distribution of the annual energy generation potential of c-Si Photo-voltaic systems". Large Photo-voltaic potentials can be found in places with high irradiation. Energy potentials of over 1800 kWh/kW Photo-voltaic can be found in the Himalayas & Southern Andes, thanks to their enormous irradiation values & low temperatures. The Himalayas are highly desirable because of their proximity to major energy consumers in the future, such as China & India. Installation of Photo-voltaic systems in high-altitude regions presents several challenges, including those related to transportation of the Photo-voltaic system & increased maintenance requirements as a result of the harsh environmental conditions. There are currently several Photo-voltaic plants operating at high altitudes.

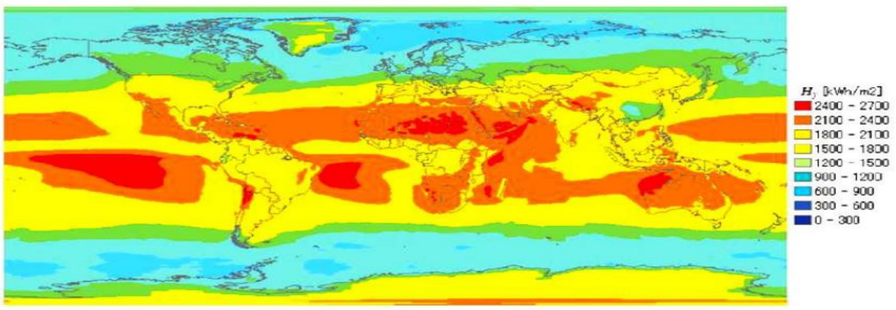

Figure 5 Global map of annual total irradiation (Hy) on equator-pointed surfaces tilted at the latitude angle

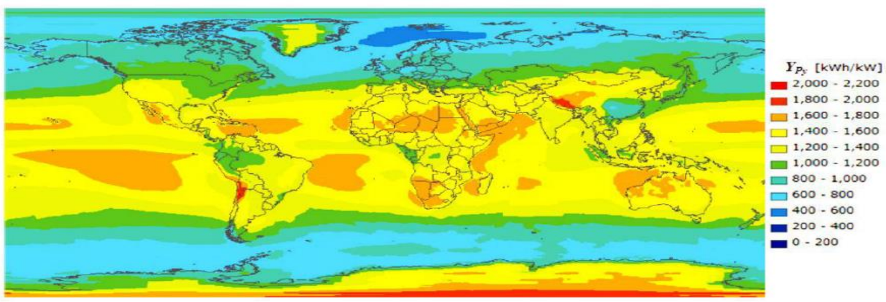

Figure 6 Global potential map of Photo-voltaic energy generation (Ypy) by C-Si Photo-voltaic module.

2. Conclusion

This study has investigated the impact of temperature and location variability on the stimulation of photovoltaic (PV) array systems. The findings highlight the significance of these factors in influencing the performance and efficiency of PV modules.

Temperature variations have been identified as a critical factor affecting PV array system performance. Higher temperatures lead to reduced efficiency and output, which can directly impact the overall energy yield of the system. Understanding the temperature coefficient and its implications is crucial for accurately estimating the energy production of PV array systems and optimizing their design.

Furthermore, the geographical location of the PV array system plays a crucial role in its performance. Variations in solar irradiance levels, influenced by factors such as latitude, altitude, and local weather patterns, directly impact the energy production of the system. Accounting for these location-based variables is vital for designing PV array systems that can harness the maximum solar potential available

The efficiency of the photovoltaic conversion process depends critically on the operating temperature & location. A Photo-voltaic module's electrical efficiency and, by extension, its power output, decrease linearly with increasing Tc. Freely mounted Photo-voltaic arrays, PV/thermal collectors, & building integrated Photo-voltaic (BIPV) systems are all covered by the many correlations for Tc that have been published in the previous research. The material & system dependencies of the numerical parameters are in addition to those of the primary environmental variables they include. Applying a specific formula for the operating temperature of a photovoltaic module requires caution due to the building integration level in mind or a specific mounting geometry established formulae. Hence, if you're looking for a correlation that will work for your needs, it's best to check the primary sources.

To further advance the field, future research should explore advanced modeling techniques and experimental validation to refine the understanding of temperature and location effects on PV array systems. Additionally, incorporating real-world data and considering other factors such as shading, soiling, and system degradation would provide a more comprehensive understanding of the challenges and opportunities in optimizing PV array system performance.

Ultimately, by addressing the variability in temperature and location, this research contributes to the ongoing efforts to promote renewable energy sources and pave the way for a more sustainable and greener future.

Conflict of Interest Nil

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