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Overview of the Factors Influencing the Efficiency of PV Solar Cells

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Abstract **Review Article**

PV technology works through the direct conversion of sunlight into electricity, a process based on the photoelectric effect. This phenomenon happens when specific materials absorb light particles, leading to the release of electrons. Capturing these electrons produces an electric current. Which can be harnessed as usable electricity. The development of more efficient PV system designs and enhancements in their operation and maintenance are key areas of current innovation. These advances are crucial for improving the overall performance and sustainability of solar energy systems, making them a more viable and dependable option for future energy needs. In the literature there are plenty of papers on solar energy, in order to advance the research on this subject we needs up to date information on the current situation. As such is lacking at present, A current literature review of this phenomenon is reffered for more detail.

Keywords: Photovoltaic (PV) Technology, Solar Energy, Renewable Energy, Photoelectric Effect, Sustainable Energy.

1. INTRODUCTION

Renewable energy, particularly photovoltaic (PV) energy, is playing an increasingly crucial role in electricity generation. Fossil fuels, which have traditionally dominated the energy landscape, are non-renewable and contribute significantly to environmental degradation. As the world shifts towards more sustainable alternatives, PV energy stands out due to its widespread availability—solar energy is abundant across the globe [1].

Solar energy is currently the most widely available and clean energy source for many countries. In recent years, photovoltaic (PV) technology has become a major player in terms of installed capacity. Among the various renewable energy technologies, solar PV has experienced the most significant growth, increasing by approximately 15 times since 2010. Projections indicate that by 2030, PV systems could account for around 69.6% of the electricity generated from solar energy [2].

2. Characterization of Solar Cells

Characterization of solar cells involves evaluating their performance and properties to understand how effectively they convert sunlight into electrical energy. Several key parameters and techniques are used in this process. Photovoltaic devices, generate an electric voltage between two electrodes when light shines on them. This phenomenon occurs due to the interaction between light and the material, typically a semiconductor, which incorporates a p-n junction where the photovoltage develops.

For efficient energy conversion, the semiconductor material must absorb a significant portion of the solar spectrum. The light absorption occurs in a region close to or beneath the surface, depending on the material's properties. When light photons are absorbed, they create electron-hole pairs. If recombination (where electrons and holes neutralize each other) is minimized, these charge carriers reach the junction and are separated by an electric field, allowing for the generation of electricity.

This process is the fundamental principle behind the operation of solar cells and how they convert sunlight into electrical energy [3].

Understanding the electrical I-V (current-voltage) characteristics of a solar cell as shown in Figure 1 is essential for assessing its output performance and overall efficiency. The key electrical parameters of a photovoltaic (PV) cell or module are captured in the I-V characteristics curve, which illustrates the relationship between the current and voltage generated by the solar cell [4].

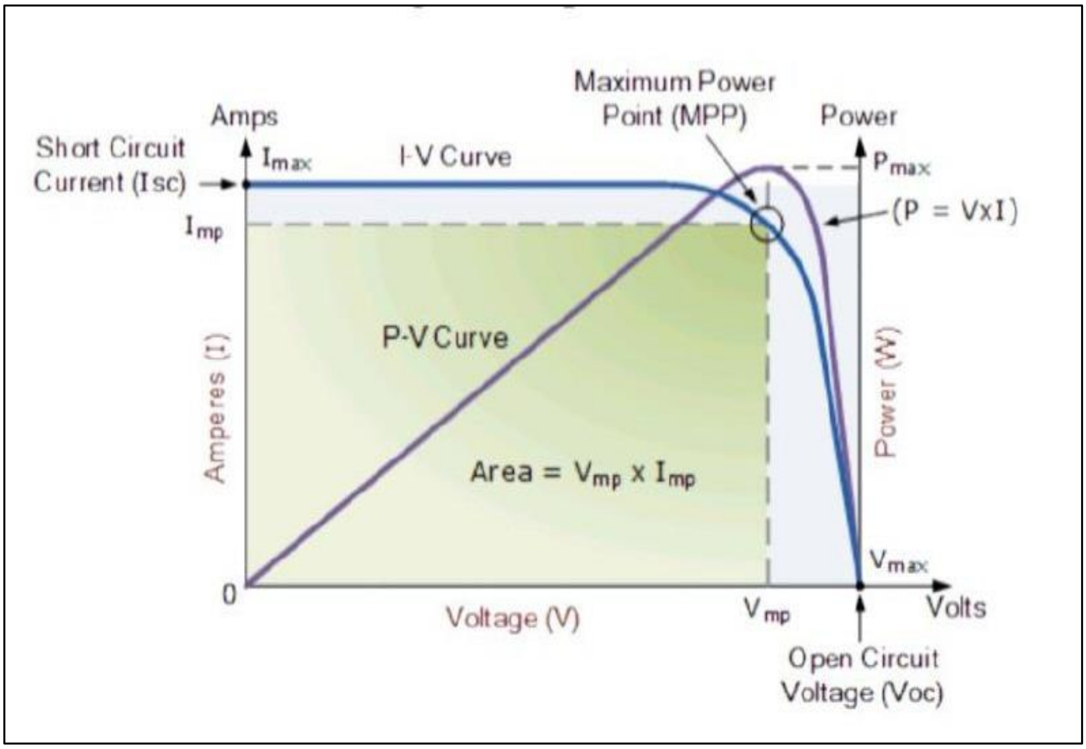

Figure 1: Solar cell I-V characteristic curves

The amount of solar radiation, or insolation, that strikes the cell primarily determines the current produced, while increases in the solar cell's temperature tend to decrease its voltage. Since solar cells generate direct current electricity, the power output is calculated as the product of current and voltage. This allows for the creation of I-V curves, which graphically represent the current versus voltage behavior of a PV device under different operating conditions.

By analyzing these curves, key performance metrics such as the **maximum power point (Pmax), fill factor (FF)**, and overall efficiency can be determined, providing valuable insights into the solar cell's operational characteristics [5].

3. Factors Affecting Solar Energy Production and performance of PV systems

Manufacturers of PV solar systems typically guarantee a 25-year performance life for their modules. However, solar panels tend to degrade more rapidly in the initial years. On average, their rated power output decreases by approximately 0.5% annually. Degradation can occur due to chemical, electrical, thermal, or mechanical factors. Initial degradation may be caused by design flaws, poor-quality materials, or defects in manufacturing. In most instances, performance losses and module failures are due to the gradual accumulation of damage caused by prolonged exposure to harsh outdoor conditions [6].

3.1 Weather conditions

Solar panel modules are subject to long-term exposure to natural environmental conditions. Factors such as light intensity, wind speed, and temperature variations influence the photoelectric conversion efficiency of solar panels, and some conditions can even damage their functionality and structure. Therefore, it is essential to comprehensively gather meteorological and environmental monitoring data during the design phase of solar power systems [7].

3.2 Inclination angle of solar panel

To maximize photoelectric conversion efficiency, solar panels must capture sunlight at the optimal angle. Figure 2 showes that ideal angle of inclination varies significantly with seasonal changes, geographical locations, and sunlight conditions. Therefore, the tilt of solar panels should be actively modified to account for variations in seasons, latitude, longitude, and sunlight duration. For fixed installations, the inclination angle should be determined based on the angle that yields the highest energy production over the entire year [7].

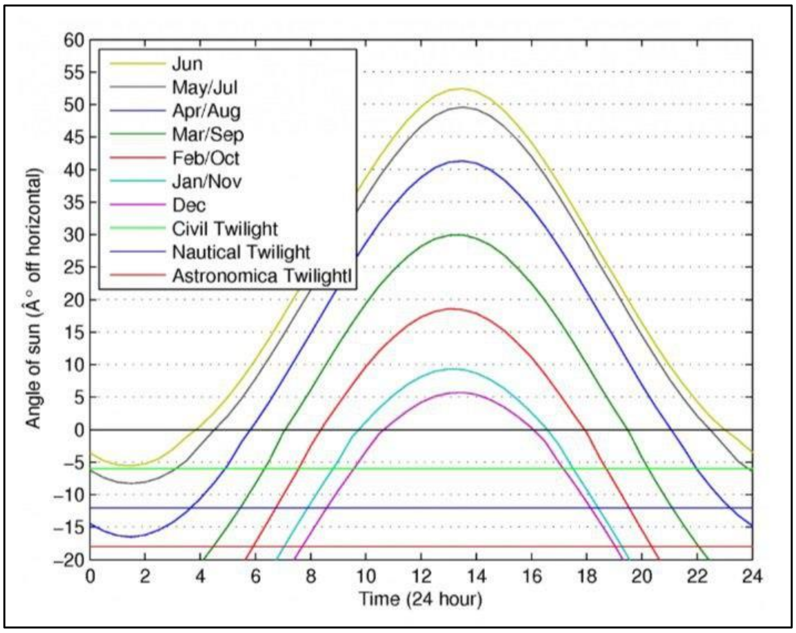

Figure 2: Angle of sun variation at different time of year

3.3 Surface Cleanliness of Solar Panels

The cleanliness of the solar panel surface plays a crucial role in photoelectric power conversion. It's essential to understand how environmental factors contribute to the pollution of solar panels. This includes assessing the effects of strong winds, intense convection, and sandstorms on the panel surfaces. Based on this analysis, the cleaning frequency for the solar panels should be established, taking into account local labor costs [8].

3.4 Solar panel spacing design (Shading considerations)

Sheltering solar panels can significantly impact the energy generation capacity of a solar system. consequently, when designing the spacing of solar panel arrays, it is crucial to account for shading from nearby buildings as well as self-shading among the panels themselves. As sunlight and temperature fluctuate, the output voltage of the solar panels also varies, which in turn affects the output power of the photovoltaic (PV) array as shown in Figure 3. The primary aim of maximum power point tracking (MPPT) in solar inverters is to ensure that the PV array consistently achieves maximum power output despite changes in sunlight and temperature. Consequently, the accuracy of MPPT plays a vital role in the efficiency of the system. Our MPPT solar charge controllers are designed to track the maximum power point of solar generation in real-time. This allows for optimal energy harvesting by adjusting the system's operating voltage and current to maximize efficiency and ensure you get the most power from your solar panels. Our MPPT solar charge controllers, ranging from 20 Amps to 60 Amps, boast a charging efficiency of over 98.5% and a tracking accuracy greater than 99.73% [6].

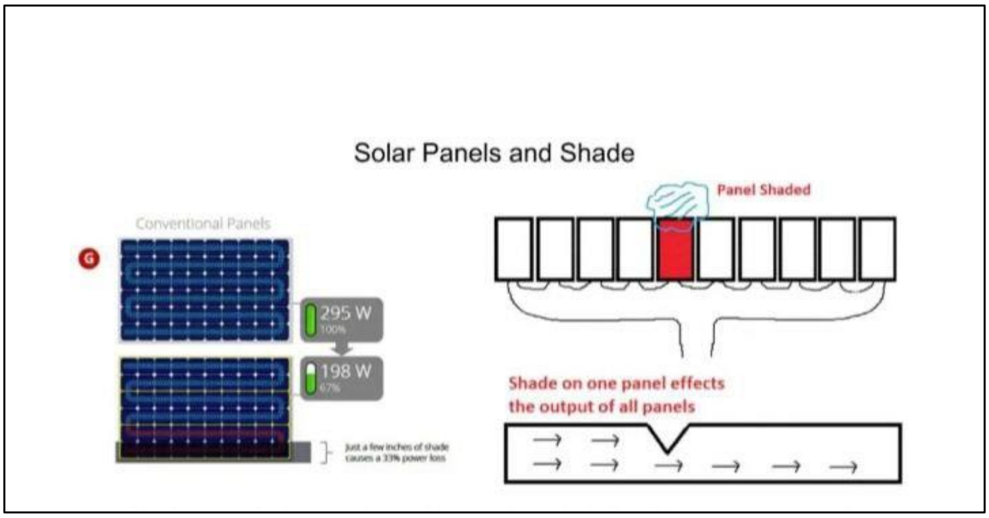

Figure 3: Shading effects on solar panel

3.5 Power loss of each part

The power loss in an RV system during energy conversion and transmission process includes several key factors: solar panel matching loss which occurs when the characteristics of the solar panels do not align optimally with the load or the inverter, loss of deviating from the maximum power point, This loss arises when the solar charge controller fails to accurately track and maintain the system at its maximum power point (MPP)., DC line loss, conversion loss of solar inverter, loss of AC grid connection [9].

3.6 Module Temperature in solar panels

A PV cell, similar to other semiconductor devices, is highly sensitive to temperature changes as shown in Figure 4. As the temperature rises, both the efficiency and power output of the cell decrease. Based on normalized values at 25°C, an increase in temperature causes a slight rise in current but results in a more significant drop in voltage, leading to a larger reduction in power output. Conversely, if the cell temperature drops below 25°C, the current decreases slightly, but both the voltage and power output increase. In general, silicon solar cells experience about 0.5% loss of efficiency for each degree Celsius increase in temperature is typical in silicon cells [10].

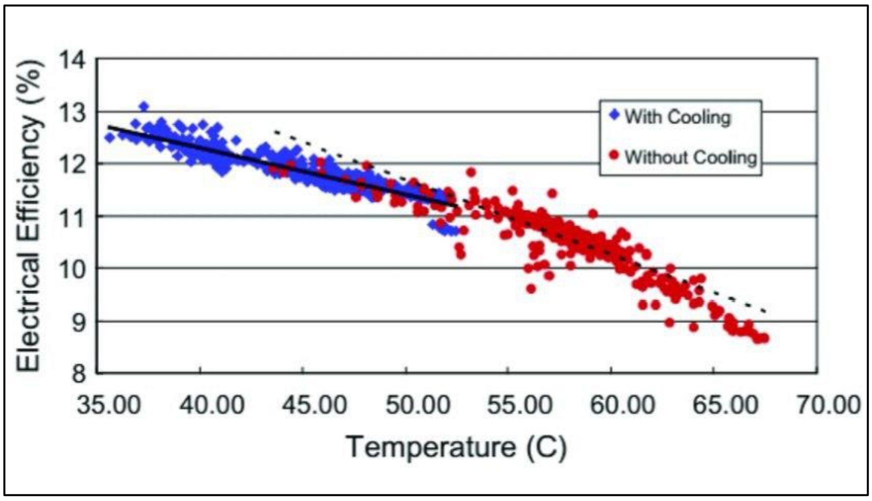

Figure 4: The relationship between solar cell efficiency and temperature (Adapted from Elsevier)

3.7 Filling factor in solar panel

The fill factor of a PV cell is defied as the ratio of its maximum power output to the product of the open-circuit voltage (V_oc) and short-circuit current (I_sc). A high-quality PV module typically has a fill factor above 70%. A lower fill factor suggests higher resistance (R), increased recombination current in the space charge region, and a rise in the reverse saturation current (I_o) of the junction, all of which indicate higher energy losses.

3.8 Parasitic Resistances in solar panels

The series and shunt resistances in a PV cell, known as parasitic resistances, are important factors that affect the efficiency and performance of the solar cell. The series resistance (R_s) reflects the internal resistance of the solar cell, encompassing the resistance from metal contacts, finger connections, impurities, and the semiconductor material itself. This resistance can affect the current flow within the cell and ultimately impact its efficiency and power output. The shunt resistance (R_h) accounts for leakage resistance and is responsible for leakage current. These resistances reduce the area of the I-V curve, leading to a decrease in the fill factor and, consequently, a drop in the cell's overall efficiency.

3.9 Potential Induced Degradation in solar panels

Potential Induced Degradation (PID) is a process that leads to performance decline in PV systems, caused by stray currents, and can result in power losses of up to 30% or more. PID typically occurs in systems with ungrounded inverters. It poses two main issues: a reduction in the useful generated power and the degradation of the front surface passivation, which increases recombination and damages the cells. PID usually manifests a few years after the PV system's installation [11].

4. CONCLUSION

In this paper, we examined various issues surrounding PV solar cells, focusing on their characteristics and an evaluation of key factors that impact their efficiency. Weather conditions and location were identified as the most significant factors affecting both the efficiency and energy output of solar cells. Adjusting these factors is essential for improving solar cell performance, as optimal conditions can significantly enhance the benefits of solar electricity while reducing costs. Therefore, it is recommended that a thorough analysis be carried out during the design phase of any solar cell project to ensure optimal installation and maximize system efficiency

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