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Vertical Power Generation Technology of Heterojunction Solar Cell

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Abstract: In this study, the power generation difference between the east-west and the north-south orientation of the vertically installed heterojunction solar cell (HJT) modules was deeply discussed. East-west oriented HJT module has 30% higher power generation, especially in desert photovoltaic (PV) with a bimodal distribution. While the south-north one has a single peak, the same as normal PV modules. Vertical power generation technology of HJT also has less land occupation, which is of great significance for optimizing the design of photovoltaic systems.

Keywords: HJT; Vertical power generation; Desert PV; Bimodal distribution

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1. Introduction

As global photovoltaic (PV) installation expands, the growth of Passivated Emitter and Rear Cell and Tunnel Oxide Passivated Contact (PERC/TOPCon) technologies is gradually slowing down. In 2018, it was observed that the installation direction and tilt angles of HJT modules have a significant impact on their power generation performance. In the same year, a study by Fraunhofer ISE showed that HJT modules have a higher bifaciality rate, and vertical installation can reduce the levelized cost of electricity (LCOE) by 20% to 30% [1]. Since then, Norway (as shown in **Figure 1**), Germany, Japan, Qatar, and other places have carried out HJT vertical power generation experiments and achieved positive results. Our study focuses on the power generation performance of HJT under vertical installation and provides a theoretical and practical basis for the innovative application of HJT in northern and desert areas. This is achieved by comparing and analyzing the power generation differences between various orientations.

Figure 1. Small-scale experiment of rooftop HJT vertical power generation in Norway (Source: OverEasySolarAS)

2. HJT vertical power generation principle

Traditional solar modules use horizontal installation, which is simple and easy to implement, but there are problems such as large footprint and limited light receiving angle, which affects the photoelectric conversion efficiency [2]. HJT offers many advantages, such as high conversion efficiency, low attenuation, no Potential Induced Degradation (PID) or Light Induced Degradation (LID) issues, and an excellent negative temperature coefficient, among others. The dual-sided power generation capability of HJT is particularly impressive, reaching up to 95%, far exceeding that of standard bifacial cells. When the HJT module is tilted to 90° (vertical installation), both sides can fully receive light and achieve efficient power generation.

3. Experimental methods

To comprehensively evaluate the vertical power generation performance of HJT modules in different installation directions and geographical environments, a series of experiments were designed in this study. The experimental equipment includes an HJT module (TOOW-H2 210-0BB module), a TOPcon module, an adjustable support system, a high-precision data acquisition device, and analysis software. The experimental procedures are as follows:

(1) Installation preparation: Build a support system in the experimental site to ensure that the HJT modules are installed vertically and fixed firmly.

(2) Data acquisition: During the experiment, the output voltage, current, and power of the HJT module were collected every 5 minutes.

(3) Data processing: Use the data collector to record the original data, collate and analyze it with Excel and other software, and calculate the power generation of each experimental point.

(4) Result analysis: The power generation data of different orientations were compared, and the differences and rules were analyzed.

4. Experimental results and analysis

Through comparative experiments, we conclude the following key findings.

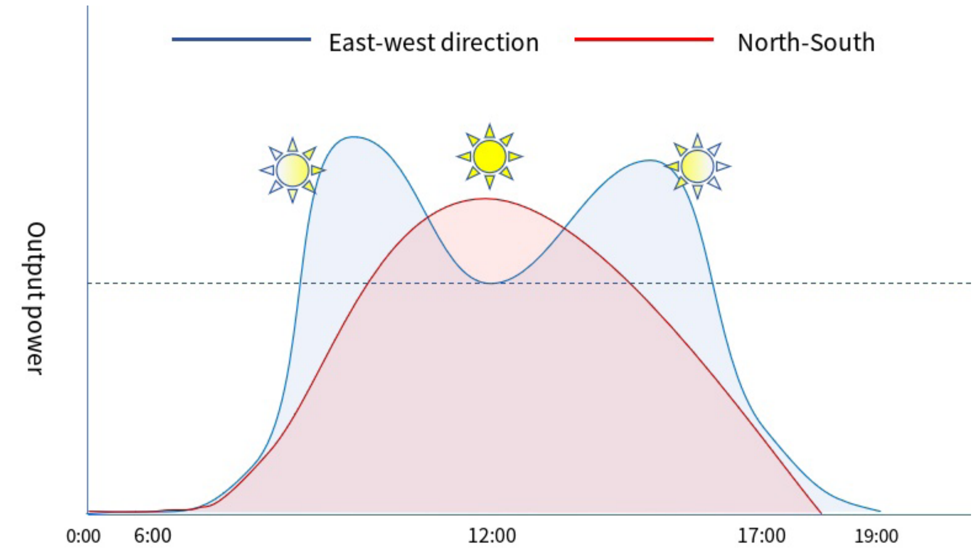

Figure 2. Comparison rendering of different orientations of HJT vertical power generation

4.1. East-west orientation (1P vertical, azimuth 90°)

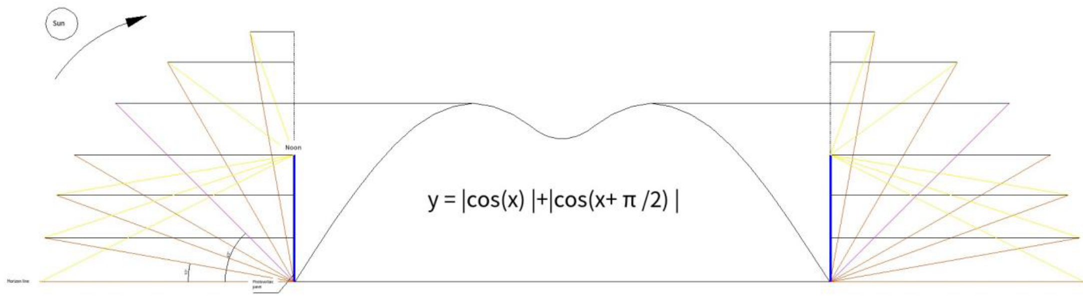

Figure 3. Vertical power generation curve of HJT modules with east-west orientation

(1) As shown in **Figure 3**, we shrink the power generation to a 2D model, and invent the curve to be expressed by **Equation (1)** for semi-qualitative analysis:

$$y1 = |\cos(\theta)| + \beta * |\cos\left(\theta + \frac{\pi}{2}\right)| \quad \text{Equation (1)}$$

In which, $\boldsymbol{\beta}$ represents the contribution rate of power generation on the back side and $\boldsymbol{\theta}$ represents the angle between the sun and the horizon.

(2) As shown in **Figure 2**, at sunrise and sunset, the power generation is significantly higher than that in the north-south orientation, showing a bimodal distribution.

(3) At noon, the power generation decreases with the change of solar elevation angle, which is similar to the performance of the traditional modules such as PERC/TOPCon at sunset. When the sun is located directly above the east-west orientation modules, the power generation reaches a low point but still maintains the average power level. In the internal structure of the HJT, the pyramid passivated layer and indium tin oxide (ITO) layer which is the first negative refractive index material discovered by mankind, form a light-trapping structure that can capture light at a wider angle of incidence [3]. Including reflected, diffuse, and scattered light whether from the ground or the air, it reduces reflection losses.

(4) When the angle $\boldsymbol{\theta}$ reaches 45° or 135°, the power generation reaches its peak. If setting the $\boldsymbol{\beta}$ to 100%,

the peak value is 41.4% higher than the average power level by calculation. The rapidly rising electricity curve after sunrise, positive directly facing the sun, is the result of the component of the incident light power contribution being almost the same (sunlight perpendicular basic unchanged for modules), and on the back, positive receiving scattering light and diffuse light is changed according to the angle of the sun. Similarly, the power generation curve decreases rapidly before sunset.

(5) The generation time at sunrise is earlier than that in the north-south orientation, and the sunset is later too. The daily generation hours are about one hour longer, which means that the generation hours and power generation are higher than the design value of conventional PV systems throughout the year.

4.2. North-south orientation (1P vertical, azimuth Angle 0°)

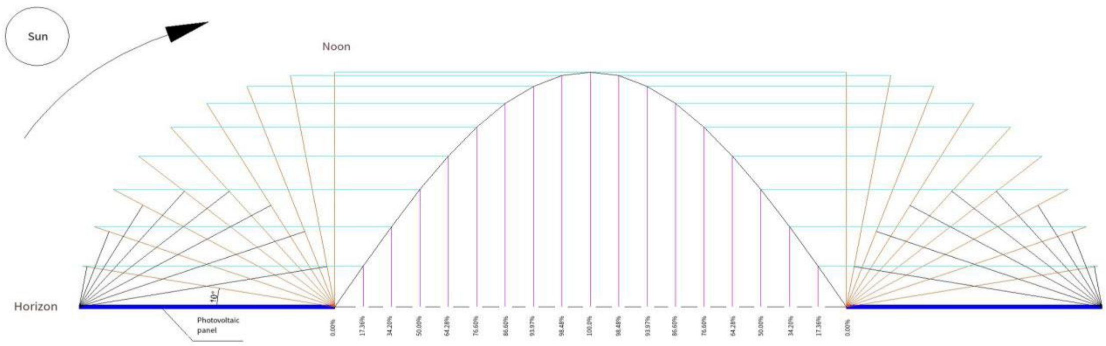

Figure 4. Horizontal power generation curve of conventional modules

(1) At noon, the power generation reaches the highest value, which is consistent with the horizontal placement of conventional tilted PV modules as shown in **Figure 4**, and is sinusoidal to the angle θ between sunlight and modules [4].

$$y2 = |\sin(\theta)| \quad \text{Equation (2)}$$

(2) At sunrise and sunset, the power generation curve is relatively gentle, while the east-west is steep, and the total power generation of the latter is larger by integral calculation.

(3) The power generation has unimodal distribution.

After the experiment, the east-west orientation generated 30% more electricity than the north-south in August and September. Although the PV simulation software PVsyst also gives similar and better results, due to the lack of an accurate model of 1P vertical generation, its simulation results should be taken with caution, and the relevant models need to be further improved in the future.

5. Discussion

The experimental results of HJT vertical power generation have important implications for the design and application of PV systems.

5.1. Improve space utilization

The dense layout of vertically installed HJT power stations requires only 1,318 acres for a 1 GW scale, compared to the 3,460 acres needed for traditional modules, significantly reducing land occupancy. This makes it particularly beneficial for owners with limited land resources. Vertically installed HJT modules can not only fully utilize building facade spaces, such as exterior walls, but also maximize the dual use of land for photovoltaic power generation without altering its original economic purpose, such as agricultural or livestock use.

5.2. It is convenient for operation and maintenance management

Dust is one of the key factors that affect photovoltaic performance. Vertically installed HJT modules, which experience the least dust or snow coverage, can reduce the frequency of cleaning and operational costs. An experiment conducted in Qatar shows that the power loss from dust pollution in conventional modules reaches 60% for single-sided modules and 45% for double-sided modules, while the pollution loss in vertically installed HJT modules is nearly negligible [5].

5.3. Higher power generation efficiency

The vertical installation of HJT modules enables better utilization of reflected and scattered sunlight. In northern desert regions, the reflected light from sand and snow during both summer and winter can provide additional light resources for the HJT module, increasing power generation by about 30%[6], which aligns with our experimental results. Combined with the excellent negative temperature coefficient of HJT, the power generation loss of HJT modules is lower at high temperatures. Therefore, the vertical power generation technology of HJT can achieve a gain of more than 100% at high latitudes [7].

5.4. Optimize the power generation curve

The bimodal generation curve of HJT vertical power generation helps optimize the supply and demand balance of the power grid by reducing peak demand and filling valleys. This generates more revenue during high-price periods and reduces power abandonment during low-price periods. Additionally, it decreases energy storage demand, shifting from the conventional 1 kW PV system equipped with a 2 kWh battery to a 1 kW:1.5 to 1.8 kWh ratio. These features enhance the economic efficiency of PV plants and improve the stability of the electrical grid.

5.5. Improve the comprehensive utilization rate of solar energy

The overall optical characteristics and design of the vertically installed HJT module and the packaging glass effectively reduce the reflection of light, and the light reflected to other HJT module arrays can be reused, improving the comprehensive utilization efficiency of solar energy.

5.6. Noise reduction and environment integration

The coated glass of the HJT module has the micro-structure of porous silica, which is able to absorb and reflect part of the sound waves, thereby reducing the environmental noise. Vertically installed HJT modules are easier to integrate into the building structure, realizing the design concept of Building Integrated Photovoltaics (BIPV). This design is not only aesthetically pleasing but also improves the overall energy efficiency and environmental performance of the building.

5.7. Wide range of application scenarios

In addition to the two prominent application scenarios of desert PV and building exterior walls, the vertical power generation technology of HJT can also be widely used in places where conventional modules such as walls, fences, and guard rails do not perform well. The expansion of the application scenario for the development of HJT provides a broader market space and development opportunities.

6. Conclusion

In this study, the vertical power generation performance of the HJT module under different installation directions was deeply explored through comparative experiments. The experimental results show that the east-west oriented HJT module has higher power generation at sunrise and sunset, and the overall power generation is better than that of the north-south orientation. In specific environments such as the northern desert, the power generation of the vertically installed HJT module is more than 30% higher than others. These findings provide an important reference for optimizing the design of PV systems and help the rapid development and wide application of HJT in the future PV market.

Disclosure statement

The authors declare no conflict of interest.

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