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Development of submerged solar power generation system (Effect of waves on power generation performance of solar panel)

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Abstract

Preliminary experiments have demonstrated that cooling the functional surface of a silicon solar cell module linearly increases its output voltage. Therefore, we succeeded in increasing the output voltage by submerging the solar panels in the ocean. This study elucidates the effects of wave period and wave height on the power generation output of underwater solar panels. First, we submerged solar panels underwater in an actual ocean area to clarify the effect of waves on power generation efficiency. Subsequently, in an indoor pool with a constant amount of sunlight irradiation and controlled water temperature, a wave generator was used to generate waves of various wavelengths and heights, and the effect of waves on power generation efficiency was clarified. It was revealed that the higher the wave height, the larger the maximum pitch angle of the float and the lower the power generation output.

Submerged solar panel, texture, seawater, I-V curve, wave height, wave period

1. Introduction

As shown in Fig.1, the authors found that the output voltage of a silicon solar panel increases when it is submerged in the sea. Additionally, the results demonstrated that as the water depth decreases, the output current increases, as shown in Fig.2 [1].

When the solar panels were installed underwater, it was found that marine organisms attached themselves to their functional surfaces. By applying a fine-textured coating to the cover glass of the solar panels, we successfully suppressed the attachment of barnacles, organisms that typically cause marine pollution[2].

This study helped us elucidate the various problems inherent in the underwater installation of solar panels, improving our understanding of the phenomena underlying each issue and enabling the proposal of appropriate solutions. In this study, we experimentally evaluated the effects of waves on the power generation efficiency of solar panels submerged in sea.

2. Effects of wave on power generation in actual sea arias

2.1. Experimental equipment in actual sea areas

As shown in Fig. 3, a waterproof silicon solar panel was attached to a stainless-steel floating body (1020 mm × 1020 mm × 200 mm) with floats. The buoyancy of the floating body was adjusted such that the solar panel could be installed at a depth of 14–15 mm. The floating body was equipped with a monocrystalline silicon solar panel (GWSSOLAR, GW-050C) at the center of the float, as shown in Table 1. An IMU (TDK InvenSense, ICM-20948) was attached to the back of the solar panel to measure and detect the attitude angle at a sampling frequency of 50 Hz. The output power was measured using an I-V curve measuring device.

2.2. Experimental results in actual sea areas

Figure 4 shows the measured results of the pitching angle and output voltage of the solar panel in the open sea with an air temperature 28.0 °C, seawater temperature 24.9 °C, turbidity 4 mg/L, and solar radiation intensity 434–830 W/m^2. The solid line in the figure represents the output power, and the dashed line represents the pitch angle of the solar panel.

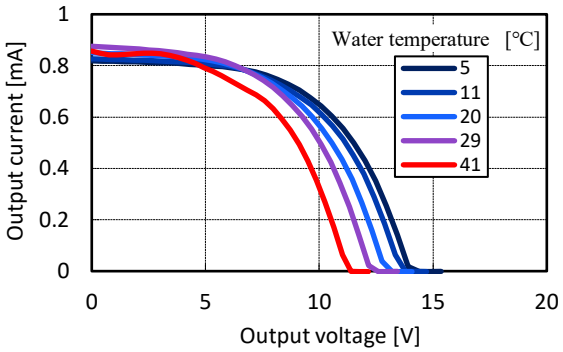
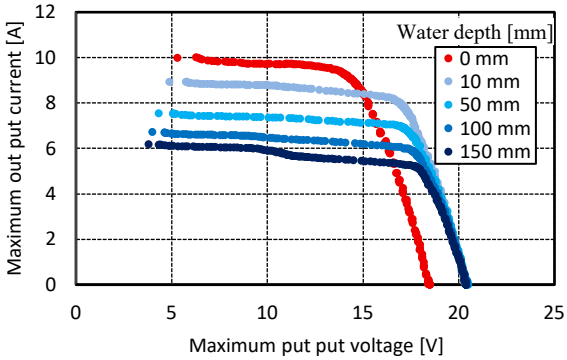


Figure 1. Effect of water temperature on I-V curve [1]



(Air temperature 27.9°C, Water temperature 22.5°C)

Figure 2. Effect of water depth on I-V curve [1]

As the float was installed in the open sea where waves were rough, the float's pitch angle reached ±9°. Furthermore, the output power tended to decrease as the pitch angle increased; however, the effect of this was unclear.

In outdoor experiments, it is challenging to obtain quantitative experimental data owing to fluctuations in solar radiation intensity and wave conditions. Therefore, we will clarified the influence of wave height on the output power in an indoor experiment with more stable conditions.

3. Effects of wave on power generation in indoor pool

3.1. Experimental equipment in indoor pool

The experiment was conducted indoors in a temperature-controlled environment with constant sunlight. Waves of various wavelengths and heights were generated using a wave-making device and applied to a floating structure equipped with solar panels.

Figure 10 shows the indoor wave-making device that was utilized (West Japan Fluid Engineering Research Institute, AUV-BS-TS01, WM-005). A comparison was performed at a pitch angle that was susceptible to the effects of waves. In actual ocean areas, the waves exhibit different wave heights and periods; however, in this study, complex waves were considered to be the superposition of regular wave motions.

To maintain constant illuminance, an artificial solar lighting lamp (SERIC, SOLAX500-3) with an output spectrum equal to that of sunlight was installed above the solar panel (height: 1645 mm). The float equipped with the solar panel was moored in a water tank at a depth of 0.37 m.

3.2. Experimental results in indoor pool

First, we experimentally evaluated the effects of the wave pitch and wave height on the pitch angle of a floating body equipped with solar panels. Second, the effect of the attitude angle of the floating body on the power generation output was evaluated.

Figure 5 shows the effects of wave height and frequency on the maximum pitch angle. The greater the wave height, the larger the maximum pitch angle. When the frequency is 1 s or less, the maximum pitch angle increases as the frequency increases. However, when the frequency is 1 Hz, the maximum pitch angle remains nearly constant. The causes underlying this observation will be reported separately.

Figure 6 shows the effect of the pitch angle on the power output. The maximum output power was not affected by wave height or wave period. However, the minimum output power decreases as the wave height increases and as the wave period.

4. Conclutions

The effects of wave height and wave period on the power generation performance of underwater solar panels were experimentally investigated in actual ocean water and an indoor pool, and the following conclusions were obtained.

1. Submerged solar power generation in offshore areas tends to decrease as the pitch angle increases; however, its effect is unclear.
2. The greater the wave height, the larger the maximum pitch angle. When the frequency is 1 Hz or less, the maximum pitch angle increases as the frequency increases. However, when the frequency exceeds 1 Hz, the maximum pitch angle remains almost constant.
3. The maximum output power was unaffected by wave height or wave period. However, the minimum output power decreases as the wave height increases and as the wave period.

References

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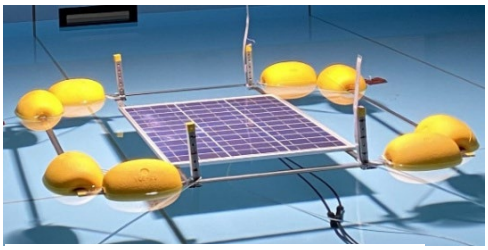

Figure 3. Overview of experimental setup

Table 1. Specifications of the solar panel

Manufacturing company		GWSOLAR
Model		GW-050C
Size	[mm]	507 × 690 × 35
Maximum output power	[W]	50
Nominal open circuit voltage	[V]	22.3
Nominal short circuit current	[A]	2.84

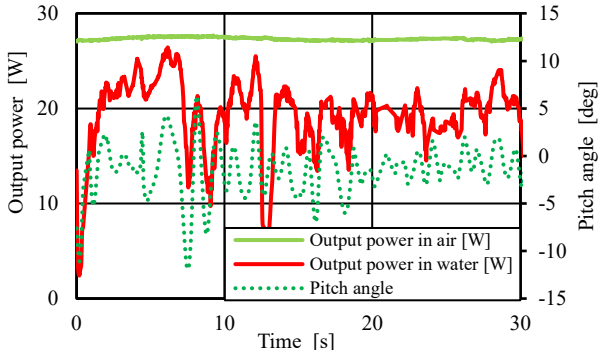

Figure 4 Effect of pitch angle value on output power

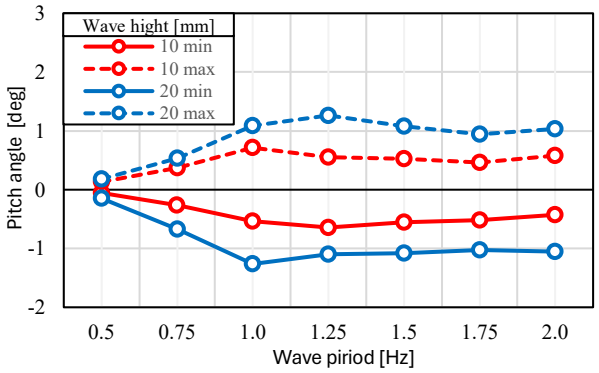

Figure 5. Effect of wave height and wave frequency on pitch angle

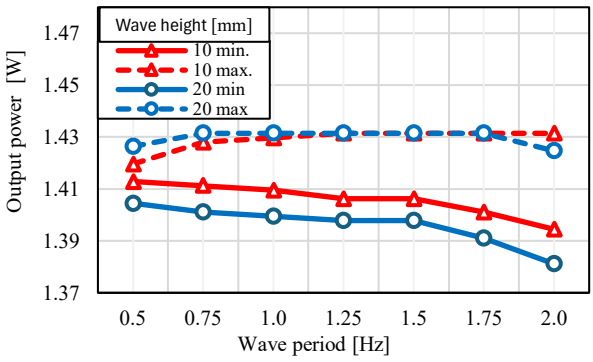

Figure 6. Effect of pitching angle on output power