Introduction

Solar battery is a semiconductor device that generates electric power by input of sunlight. Its merits are: (i) it does not require any fuel during generation, (ii) it does not produce pollutants such as CO₂ and NOₓ, the former causes global warming and the latter causes air pollution, (iii) Energy Payment Time, the ratio of necessary energy to produce solar battery to generated energy during a year by the solar battery, is very short (i.e. 2 years). Solar battery is so-called clean energy because it uses sunlight.

In fishing activities, which uses the ocean space for production, it is necessary to promote clean energy utilization to contribute to marine environmental conservation both directly and indirectly. Among the clean energy, it is urgent to promote solar generator utilization for fishing activities because it is applicable for various generation schemes and purposes.

Sakai et al. and Takeda et al.¹ have studied application of photo voltaic generating system in fishing activities. They reported how to increase output of solar battery (e.g. constant voltage control that fixes output voltage of solar battery and improved constant voltage control with temperature control so that the setting voltage of solar battery is inversely proportioned to the device’s temperature). Their control devices are, however, expensive, increase generation cost, and thus prevent propagation of solar generation. Therefore, it is important to develop a simple photo voltaic generating system of independent power source without control devices.

In the present study we evaluated the performances of a solar battery system by combination of solar battery and storage battery which does not require any control devices. Application for fishing light system was also examined, using bamboo-platform liftnet (Bagan), a common fishing gear for lifting net in Indonesia.

Materials and Methods

Experimental device

The experimental device is a model of fishing light system of independent power source that lights lamps using a combination of solar battery and storage battery. The circuit of the system charges the storage battery with electricity, which is then generated by solar battery during daylight.

Figure 1 shows the configuration of the model. The power source is a series of two solar batteries. Two vessel
lamps of DC 24 V and 100 W, and storage batteries of DC 24 V and 64 Ah (5 h), are connected in a parallel circuit in the side of load, through overcharge prevention devices. A switch shown in Fig. 1 is linked with a timer to automatically control the discharge of stored power, using the lamps. The 'on' period of the switch is 2 h after sunset (19:30 h). Solar battery is a field module of poly crystal silicon devices. They were installed horizontally on the rooftop of one building of Tokyo University of Fisheries (latitude 35° 37.6N, longitude 139° 44.8E). Major dimensions of the solar batteries are summarized in Table 1. Overcharge prevention devices shut the circuit when the voltage of the storage battery increases beyond the capacity. The device has a function to prevent inverse flow from the storage battery during night also.

Measuring devices

Output voltage and electric current of solar battery, solar radiation, atmospheric temperature, temperature of the solar battery devices, and voltage and electric current of the lamps. Solar radiation was measured by solar radiation sensor with an error of ±3% in the wavelength range of 305–2800 nm (PCM-01, Prede Co.). The sensor was also installed horizontally as was the solar battery. Atmospheric temperature was measured by a resistance temperature sensor. Each measured signal was recorded by data recorder (DR-F1, Teac).

Experimental method

The measurement period was 87 days from 8 July to 1 October 1998, for 16 h from 04:00 to 20:00 every day, with 1 min intervals. In Indonesia, solar radiation and atmospheric temperature were measured for 10 days from

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**Figure 1** Test photo voltaic generating system. $E_{out}$, Output voltage of solar battery; $I_{out}$, electric current of solar battery; $E_l$, voltage of lamp; $I_l$, electric current of lamp.

**Table 1** Principal particulars of solar battery

<table>
<thead>
<tr>
<th>Item</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Poly-crystal silicone</td>
</tr>
<tr>
<td>Model</td>
<td>LA361K51S</td>
</tr>
<tr>
<td>No. set</td>
<td>2 sets</td>
</tr>
<tr>
<td>Size</td>
<td>$988 \times 448 \times 36$ mm</td>
</tr>
<tr>
<td>Output power</td>
<td>51.0 W</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>21.2 V</td>
</tr>
<tr>
<td>Maximum voltage</td>
<td>16.9 V</td>
</tr>
<tr>
<td>Maximum current</td>
<td>3.0 A</td>
</tr>
<tr>
<td>(AM1.5, 1.5 kW/m²,</td>
<td>solar battery temperature 25°C)</td>
</tr>
</tbody>
</table>

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RESULTS AND DISCUSSION

Basic performance of solar battery

Figure 2 shows a sample of the measured results (i.e. time series data of output voltage and electric current of the solar battery, solar radiation, atmospheric temperature, voltage and electric current of the lamps on 2 August 1998).

It was cloudy in the morning of the day, and the weather improved after midday to fine. Solar radiation, however, fluctuated significantly because the passing clouds often block out sunlight. The maximum voltage was 27 V, the maximum electric current was 3.6 A and the maximum solar radiation was 0.70 kW/m², atmospheric temperature was 27.9°C.

When the lamps were lit after sunset, the voltage and electric current were 22 V and 8.5 A, respectively. The voltage of the lamps (i.e. the voltage of the storage battery) was decreased because the quantity of electricity in the storage battery was decreased by the discharge and this caused the terminal voltage decrease.

Using the results of measured voltage and electric current, power generation by the solar battery and power consumption of the lamps were calculated. Figure 3 shows power generation of the solar battery and power consumption by the lamps on 2 August 1998. A positive in the vertical axis shows the former, $P_s (= E_{out} \times I_{out})$, while the negative side shows the latter, $P_l (= E_{l} \times I_{l})$. In this case, the former is equal to the charged power of the storage battery, the latter is equal to discharged power of the storage battery. Under these assumptions, power generation by the solar battery and power consumption by the lamps represent the charge and discharge of the storage battery (i.e. a characteristic of the storage battery). To understand the following charge and discharge characteristics of the storage battery, lighting period of the lamps was arranged to discharge more quantity of electricity than the daily charged quantity of electricity. In the present study the lighting period is 2 h by 200 W lamps (100 W $\times$ 2) and this makes it possible to gain a maximum of 1440 kJ ($= 200 \ W \times 2 \ h \times 3600 \ s$).

As shown in Fig. 3, the integrated electric power per day was 1816 kJ/m² for power generation and 1119 kJ/m² for consumption. The difference between the generation and the consumption is due to the efficiency of the storage battery. In the present study, we considered that the efficiency is represented by the ratio of discharged power to charged power and used the ratio 0.616 as the battery coefficient.

Converting efficiency of solar battery is the ratio of sunlight energy input to generated energy output. Generated energy is represented as power per unit area (kW/m²) and sunlight energy is solar radiation (kW/m²).
The vertical axis shows the latter, $P_{sa}$ (kJ/m²). Converting efficiency based on the integrated values are thus shown in Fig. 6 and the following equation is given by the result.

$$P_{sa} = 0.1478Q_a + 221.58. \quad (2)$$

According to the report by Takeda et al., the converting efficiency of $Q_a$ was 13.2% and the studied device increased the converting efficiency by 1.6 point.
Efficiency of the storage battery

Figure 7 shows time series data of daily power generation by the solar battery, $P_{sa}$, and power consumption by the lamps, $P_{la}$, for the observed 87 days. The broken line shows power generation, while the solid line shows power consumption. During the first 10 days after the experiment started, it is clearly shown that the power discharge above 1500 kJ/m² existed continuously. The reason for the continuous discharge is that the storage battery was fully charged before the experiment started. The storage battery had enough power for discharge that it was independent of power supply from the solar battery.

Figure 8 shows the battery coefficient, $C_b = \frac{P_{la}}{P_{sa}}$, the ratio of discharged power, $P_{la}$ to charged power, $P_{sa}$. During the first 10 days after the experiment started the coefficients have been above one for the same reason. After that, there was no significant change by the 69th day. Average battery coefficient, $m$, is 0.492 and standard deviation, $\sigma$, is 0.114. Therefore, when the battery coefficient is set to be $m - \sigma = 0.378$, the storage battery can discharge 37.8% of the charged power from the solar battery. This value is about a 50% decrease than that of lead storage battery, of which efficiency is usually 71–79%.

Application on Bagan in Indonesia

We examined the application of this system for fishing light on Bagan, which is a bamboo-made floating structure with lift net in Indonesia. Figure 9 shows the compass directions of a Bagan in Pelabuhan Ratu, Indonesia, for 24 h from 10:00 h on 18 August to 10:00 h on 19 August 1998. An electronic magnetic compass was used to measure the movement of direction. The variation was 0.5° W by a chart of West Jawa. The Bagan is fixed by anchor ropes. As shown by the measurement, Bagan was revolved in about 24 h by influences of current, wind and other factors. Therefore, installment for solar battery should be horizontal so as to get enough solar radiation independent of Bagan’s revolvement.

Figure 10 shows the amount of integrated solar radiation both in Tokyo and Pelabuhan Ratu. These amounts of integrated solar radiation and average temperature in the two places are substituted into the equation 1 to estimate the power generation by solar batteries in each place. Figure 11 shows the estimated output of solar battery. In both Figs 10 and 11, triangles indicate values in Pelabuhan Ratu while circles indicate values in Tokyo. The average for 10 days was estimated output
is feasible to install the solar battery on a standard type Bagan, and continuous operation is possible under the above conditions. Although this simulation is done for the solar battery installment on Bagans, the method is applicable for both land and sea. The method will promote clean energy introduction in various areas and will contribute to the prevention of both marine and air pollution.

REFERENCES