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Operating Live E! Digital Meteorological Equipments Using Solar Photovoltaics

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***Abstract*—**We installed solar panels and digital meteorological equipments whose electrical power is supplied using PV on July 13, 2011. Then, the relationship between the electric power generation and the irradiation, air temperature, and wind velocity was investigated on a roof at a university. The electrical power generation, irradiation, air temperature, and wind velocity were monitored over two years. By analyzing the measured meteorological data and electric power generation data using PTC, we calculated the size of the solar panel that is most suitable for this system. We also calculated the wasted power generation using PTC with the measured meteorological data obtained in this study. In conclusion, to reduce the "wasted power generation", a smaller-size solar panel is required for stable operation.

***Keywords*—**Digital meteorological equipments, PV, photovoltaic, irradiation, PTC.

I. Introduction

LIVEE!(Live Environmental Information of the Earth) digital meteorological equipments collect meteorological data at various locations and send it to a server through an IP network at 1-minute intervals[1]. The meteorological data acquired by digital meteorological equipments are available to the public. Our project has been analyzing data acquired by digital meteorological equipments for a long time [2]. In the LiveE! Project, we install low-cost digital meteorological equipments equipped with internet connections for measuring temperature, humidity, pressure, wind direction, wind speed, and rainfall. Since 2007, we have been developing the Weather Visualization System, which retrieves data from these digital meteorological equipments and shows the location of each sensor on a map color coded according to these measurements. We used this system in high school and university education projects and evaluated its usability.

By installing multiple digital meteorological equipments in a small area, LiveE! allows for high-level weather monitoring compared to the Automated Meteorological Data Acquisition System (AMeDAS). Using digital meteorological equipments, we can measure micro-meteorological data that AMeDAS cannot acquire. Digital meteorological equipments have multiple advantages. First, the observation interval is short. Secondly, they are easy to set up. Lastly, they cost less for setup and maintenance. However, to operate digital meteorological equipments, a stable electric power supply is essential. Considering these circumstances, although it is easy to set up, it takes considerable time and money to install the power source. Using photovoltaics (PV), which are capable of supplying stable electric power and cost less for setup and maintenance, our goal is the stable operation of digital meteorological equipments. We began the installation of solar panels and digital meteorological equipments whose electrical power is supplied using PV on July 13, 2011, as shown in Fig. 1. In this paper, we calculate the wasted power generation using the measured meteorological data obtained in this study.

Fig. 1 Solar Panel

II. Related Work

Many studies have investigated PV optimization and the evaluation of solar panels [3]-[5]. However, there are still few studies that analyze data acquired during actual operation. Also, there are two ways to evaluate the electric power generation of solar panels. One is the Standard Test Cell Condition (irradiation of 1.0 kW/m^2, cell temperature of 25°C, STC) used in Japan. The other is the PVUSA Test Condition (irradiation of 1.0 kW/m^2, air temperature of 20°C, accuracy of 1.0 m/s, PTC) used in the USA. According to recent studies, it is said that STC has a problem due to the different characteristics betweenthe individual solar panels. Table I shows a sample solar cell module catalogue described using both STC and PTC (using the SHARP ND-167U1 and Panasonic HIP-G751BA2).

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TABLE I
RATED ELECTRIC POWER GENERATION COMPARING STC AND PTC

	STC	PTC
ND-167U1	167 W	146.63 W
HIP-G751BA2	167 W	155.8 W

As the table suggests, despite the fact that the STC-rated electric power generation values are equal, there is some disparity between the two panels using PTC. The cause of this disparity is the difference in the solar panel characteristics. STC cannot distinguish the difference in solar panel characteristics, whereas PTC can. From the above, in this study, we evaluate the electric power generation by PTC and attempt to stably operate LiveE! digital meteorological equipments using PV.

III. METHODS

A. Equipment

We measured the irradiation (measuring range: 0–2000 W), air temperature (measuring range: -52–60°C, accuracy: ±0.3°C), wind velocity (measuring range: 0–60 m/s, accuracy:±0.3%), atmospheric pressure (measuring range: 600–1000 hPa, accuracy: ±1 hPa), and precipitation (accuracy: ±5%) using digital meteorological equipments[6], as shown in Fig. 2. The digital meteorological equipments were continuously monitored at 1-minute intervals. The measurement results were sent to a USB thumb drive and uploaded to the LiveE! server through PHS. Typically, the digital meteorological equipment uploads data via wireless communication; however, we used PHS so as to reduce electrical power consumption. Fig. 3 shows the system configuration diagram used in this study.

To operate this system, the performance of the solar panel and the operating system battery was calculated using the calculation method generally used in Japan. The electrical power consumption (for 1 hour) of the equipment used in this system is summarized in Table II[7].

The necessary amount of electricity power generation of solar panel is summarized in Table III.

The necessary amount of electricity power generation of battery is summarized in Table IV.

Fig. 2 Digital meteorological equipment

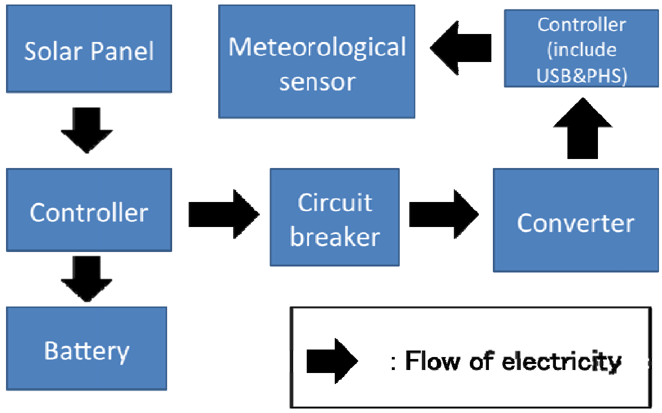

Fig. 3 System configuration diagram

TABLE II
ELECTRICAL POWER CONSUMPTION OF EQUIPMENT (1 HR)

Equipment	Electrical current consumption	Voltage	Electrical power consumption
Digital meteorological equipment	3 mA	12 V	0.0036 W
Controller (Armadillo-220)	180 mA	5 V	0.9 W
USB	100 mA	5 V	0.5 W
PHS	160 mA	5 V	0.8 W
Total			2.236 W-①

TABLE III
NECESSARY AMOUNT OF ELECTRICITY POWER GENERATION OF SOLAR PANEL

	Electrical power consumption in one day	Necessary amount of electricity power generation in one day	Necessary number of sheets	Decided number of sheets
Calculation formula	① * 24	② * 1.1 * 4/4	③/80	
Result	53.664-②	59.03-③	0.74	1-④

TABLE IV
NECESSARY AMOUNT OF ELECTRICITY POWER GENERATION OF BATTERY

	Capacity requirement	Necessary Ahr
Calculation formula	53.664 * 4/0.8	268.32 * 2/12
Result	268.32-⑤	44.72-⑥

As listed above, to operate this system, the electrical power consumption needs to be 2.236 W per hour. The conditions necessary for stable operation of this system were calculated to always fulfill ①, as shown in from Tables II to IV.

①: Electrical power consumption was calculated.

②: To calculate the electrical power consumption in one day, multiply ① by 24 (day load).

③: To calculate the necessary amount of electric power in one day, multiply ② by 1.1 (loss) and 4 (day) and divide by 4 (hour) (necessary amount of electric power generation in one day).

④: Maximum output.

⑤: To calculate the necessary capacity, the electrical power consumption in one day (②) is multiplied by 4 and divided by 0.8.

⑥: The voltage of the battery in this study is 12 V, so the capacity requirement (⑤) is divided by 12 and, to have a surplus, is multiplied by 2.

Therefore, the rated electric power generation of the solar panel is 80 W, and the capacity of the battery is 105 Ahr.

B. Characteristics of Battery and Solar Panel

1. Characteristics of Solar Panel

The electrical current value of the solar panel depends on the irradiation as shown in Fig. 4. The electrical current of the solar panel is maximum when the voltage is near 0. The reverse is also true (this is the current–voltage characteristic). According to this characteristic, the controller is designed to control the system such that the voltage of the solar panel is automatically at its maximum power point at sunrise (maximum power point tracking, MPPT).

2. Characteristics of Battery

The life of the battery decreases when it is overcharged. Accordingly, the controller is designed to control the power generation of the solar panel so as to avoid overcharge when the battery comes close to full charge.

3. Current–Voltage Characteristics

The voltage of the solar panel is determined by the current–voltage characteristics. The current–voltage characteristics are explained below.

3-1) Short Circuit Current (I_{SC})

The short circuit current (I_{SC}) is the electrical current when the voltage is 0.

$$I(V=0) = I_{SC}$$

3-2) Open Circuit Voltage (V_{OC})

The open circuit voltage (V_{OC}) is the voltage when the electrical current is 0.

$$V(I=0) = V_{OC}$$

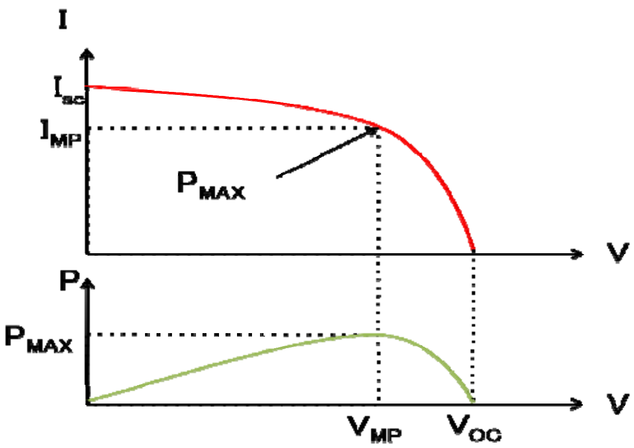

Fig. 4 Maximum output in current–voltage characteristics

3-3) Maximum Output (P_{MAX})

The output is calculated as P=IV. The output is 0 at I_{SC}=0or V_{OC}= 0. However, the maximum output is between these two points.

C. Data Analysis

We evaluate the electric power generation using PTC with the measured data (power generation of solar panel, irradiation, air temperature, wind, and velocity). By evaluating the power generation using PTC, we can obtain the theoretical power generation value of the solar panel used in this study using the measured data (irradiation, air temperature, wind, and velocity). Also, by comparing the qualified power generation of the solar panel using the measured data according to the characteristics of the battery and the theoretical power generation value of the solar panel, we can find the wasted power generation.

1. Evaluation Method Using PTC

In the evaluation method using PTC, using the following procedures, we calculate the electric power generation P_{ptc} of the solar panel in normal conditions:

(I) We measure the outdoor exposure and power generation data of the solar panel (P kW), irradiation (I_{rr}kW/m^2), air temperature (T_a°C), and wind velocity (W_sm/s).

(II) Using the measured data obtained in phase (I), we calculate the regression coefficients (A–D) by regression analysis.

(III) By substituting the calculated regression coefficients (II), irradiation, air temperature, and wind velocity in Equation (1), we can calculate the electric power generation of the solar panel in normal conditions.

$$P = A * Irr + B * Irr^2 + C * Irr * Ta + D * Irr * Ws \quad (1)$$

2. Analysis Method

We calculate the theoretical power generation value of the solar panel used in this study as described in calculation method 1.We compare the calculated theoretical power generation with the measured power generation and calculate the wasted power generation. Also, to improve the accuracy of the regression analysis, we try to compile the irradiance data in three patterns (over 0.3 kW/m^2, over 0.5 kW/m^2, over 0.8 kW/m^2)[8]. When the battery is fully charged, electric current does not flow and generate electricity, so we exclude such data. There were 191 irradiance data points over 0.8 kW/m^2, which is not enough to analyze.

(A) Over 0.3 kW/m^2 irradiance data

The over 0.3 kW/m^2 irradiation data is summarized in Table V. There were not enough data points over 0.3 kw/m^2 in May, and October.

(B) Over 0.5 kW/m^2 irradiance data

The over 0.5 kW/m^2 irradiation data is summarized in Table VI. There were only two irradiation data points over 0.5 kw/m^2 in December, which is not enough to analyze.

(C) Over 0.8 kW/m^2 irradiance data

The number of over 0.8 kW/m^2 irradiance data is 191, which is not enough to analyze.

TABLE V
OVER 0.3 KW/M² IRRADIANCE DATA

	Correlation coefficient	intercept(A)	Irradiation coefficient(B)	Air temperature coefficient(C)	Wind velocity coefficient (D)
January	0.6209	0.2286	-0.434	-0.0036	0.0048
February	0.4962	1.5722	-2.478	-0.0297	-0.0374
March	0.4556	1.0801	-1.711	-0.0082	0.0079
April	0.7231	0.1722	-0.205	-0.0013	0.0008
June	0.7260	0.1431	-0.205	0.0001	-0.0066
July	0.6125	1.9157	-1.531	-0.0272	-0.0822
August	0.6333	3.0525	-1.935	-0.0583	-0.0406
Sept.	0.7733	3.5361	-2.238	-0.0744	-0.0527
Nov.	0.4177	1.1112	-6.837	0.1014	-0.0427
Dec.	0.4227	0.1528	-0.386	0.0041	0.0172
1 Year Total	0.3455	0.5733	-0.675	0.0030	-0.0207

TABLE VI
OVER 0.5 KW/M² IRRADIANCE DATA

	Correlation coefficient	intercept (A)	Irradiation coefficient(B)	Air temperaturec oefficient(C)	Wind velocity coefficient (D)
January	0.4949	0.2967	-0.5621	-0.0049	-0.0024
February	0.1424	0.7354	-0.7200	-0.0085	-0.0291
March	0.4556	1.0801	-1.7116	-0.0082	0.0080
April	0.4498	0.1369	-0.1607	-0.0001	-0.0035
June	0.8271	0.0841	-0.0933	-0.0003	0.0048
July	0.2570	0.8577	-0.5899	-0.0091	-0.0365
August	0.3781	1.6288	-1.0589	-0.0273	-0.0073
Sept.	0.4574	1.7502	-0.7067	-0.0381	-0.0283
Nov.	0.4339	0.9607	-0.7266	-0.0328	-0.0515
1 Year Total	0.2724	0.3751	-0.4132	0.0012	-0.0080

IV. ANALYSIS RESULTS

An average correlation coefficient for the over 0.3 kW/m² irradiance data was 0.5881. From the above, the power generation, irradiance, and wind velocity are relatively high. Also, an average of the correlation coefficient for the over 0.5 kW/m² irradiance data was 0.4329. From the above, it is less than the average correlation coefficient for the over 0.3 kW/m² irradiance data. However, the power generation, irradiance, and wind velocity have some relationship.

By evaluating the generated power using monthly regression analysis, we can calculate the original generated power of the solar panel used in this study. By taking the difference between the calculated original power generation and the measured power generation, we can calculate the loss according to the full charge and optimize the experimental device. Given the above, we calculate the original power generation using the PTC calculation formula.

The PTC test condition is an irradiation of 1.0 kW/m², an air temperature of 20°C, and a wind velocity of 1.0 m/s. We substitute the PTC test conditions into (1).

$$P = A * 1.0 + B * 1.0 + C * 1.0 * 20 + D * 1.0 * 1.0$$
$$\Leftrightarrow \; P = A + B + C * 20 + D \qquad (2)$$

If we substitute the irradiation, air temperature, and wind velocity into (1) and perform regression analysis, the coefficients A–D can be calculated. If we substitute the regression analysis coefficients into the equation, the theoretical electric power generation values for each month of solar power are calculated.

Also, the measured electric power generation value subtracted from the theoretical electric power generation value gives the "wasted electric power generation". The theoretical electric power generation value, measured electric power generation value, and "wasted electric power generation" for each month are compiled in Table VII.

June is the month when the "wasted electric power generation" was maximum at about 40020 [W]. In contrast, December is the month when the "wasted electric power generation" was minimum at about 1950 [W]. Since the "wasted electric power generation" values of all months were positive, it can be said that there is "wasted electric power generation" in all months. Also, the measured electric power generation values divided by the theoretical electric power generation values represent the required sizeof the solar panel for each month. From the above, the size of the solar panel necessary for stable operation throughout the year was revealed to be 0.8 times that of the currently installed solar panel.

TABLE VII
MEASURED AND THEORETICAL OF ELECTRIC POWER GENERATION (2012)

	Electric power generation measured(Wh)	Electric power generation theoretical(Wh)	Remainder (Wh)	measured value /theoretical value
January	3291	5513	2222	0.60
February	27358	38057	10699	0.72
March	24291	39325	15034	0.62
April	3595	41842	38247	0.09
June	2611	42631	40020	0.06
July	31009	42258	11249	0.73
August	32823	45302	12480	0.72
September	19204	24004	4800	0.80
November	21833	41280	19447	0.53
December	2881	4831	1950	0.60

V.CONSIDERATIONS

When we consider Table VII, only April and June had more "wasted electric power generation" than the other months andrequired a smaller-size solar panel for stable operation throughout the year than the other months. It can be considered that a voltage measuring apparatus cannot measure more than 15 [V] until June. The maximum voltage of the solar panel is about 20 [V]. To calculate the electric power generation of a solar panel, one multiplies the voltage by the electrical current, which causes us to conclude that we have calculated a less than real electric power generation using a voltage measuring apparatus that cannot measure more than 15 [V].

VI. CONCLUSION

We calculated the wasted power generation using PTC with meteorological data actually measured in this study. As a conclusion, to reduce the "wasted power generation", a smaller-size solar panel is required for stable operation. However, there are other methods of optimizing this system, such as changing the size of the battery and remodeling the controller.

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