Detection System of Foreign Objects Coverage on PV Panels

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Abstract. Power output will decline when foreign objects covered on PV panels. In this paper a system designed to detect the power output decline caused by foreign objects in different situations effectively. It is mainly composed by temperature detection module, irradiance detection module, power detection module, and embedded minimum system module. A power output model of foreign objects on surface is analyzed and a number of experiments were conducted in indoor and outdoor. The result shows that characteristic measured is consistent with the theoretical model compared with that of a clean panel. Therefore, this system can detect the coverage of the foreign objects on panel correctly.

1. Introduction
As a typical form of renewable generation, the installed capacity of photovoltaic (PV) generation has been growing at an average annual rate of 20%~25% over the past 20 years. However, the efficiency of PV generation is relatively low due to many factors. Therefore, how to reduce loss and improve efficiency has always been the focus of PV generation. Power output will decline caused by foreign objects covered on PV panels [1-4]. In order to study the change of characteristics and drop rate of efficiency, a system is designed and implemented to detect foreign objects on surface such as bird droppings, artificial things, etc.

2. Power Output Model of Foreign Objects Coverage on PV Panels
A photovoltaic module consists of many solar cells in series. The output performance of the whole module will be affected if one of the cells is covered. We supposed that the photocurrent of two solar cells is I_{ph1} and I_{ph2}. I_{ph1} will be not be equate to I_{ph2} when one of the cells is covered by some foreign objects. The bypass diode connecting this two cells is probably blocked or guided as the external load increasing gradually. The I-V characteristics of these two cases can be represented by the piecewise function (1),

\[
U = \frac{nkT}{q} \ln \left( \frac{I_{ph1} - I}{I_0} + 1 \right) - \frac{n_{b}kT_{b}}{q} \ln \left( \frac{I - I_{ph1}}{I_{0b}} + 1 \right) - IR_s, I_{ph1} < I \leq I_{ph2} \\
U = \frac{nkT}{q} \ln \left( \frac{I_{ph1} - I}{I_0} + 1 \right) + \frac{nkT}{q} \ln \left( \frac{I_{ph2} - I}{I_0} + 1 \right) - IR_s, 0 < I \leq I_{ph1}
\]

Where I_0 is reverse saturation current, n is diode impact factor, q is charge constant, q=1.6×10^{-19}C, T is temperature, k is boltzmann constant, k=1.38×10^{-23} J/K, Rs is series resistance of cells, I_{0b}, n_{b}, T_{b} are reverse saturation current, influence factor and temperature of bypass diodes [5, 6].
According to formula (1), the standard PV characteristic equation is not suitable any more. At the same time, the intersection point between piecewise functions is the turning point of bypass diode conduction and blocking. According to \( P=U*I \), the power equation is also a piecewise function which can be represented by formula (2),

\[
P = \frac{nkTI}{q} \ln\left(\frac{I_{\text{ph}2} - I}{I_0} + 1\right) - \frac{n_kkT_I}{q} \ln\left(\frac{I - I_{\text{ph}1}}{I_{0b}} + 1\right) - I^2R_S, \quad I_{\text{ph}1} < I \leq I_{\text{ph}2}
\]

\[
P = \frac{nkTI}{q} \ln\left(\frac{I_{\text{ph}1} - I}{I_0} + 1\right) + \frac{nkTI}{q} \ln\left(\frac{I_{\text{ph}2} - I}{I_0} + 1\right) - I^2R_S, \quad 0 < I \leq I_{\text{ph}1}
\]

Two values of maximum power can be solved for the piecewise function when \( \frac{dP}{dI} = 0 \). Thus, the traditional P-V characteristic with only one single peak isn’t suitable either when the panel covered by foreign objects. The number of peaks on the P-V curve will be decided by the number of batteries covered [7].

3. System Design
The main controller of this system is a high-performance embedded ARM chip produced by TI. The hardware circuit mainly includes minimum system module, irradiance detection module, temperature detection module, power detection module, power module and clock module [8-9]. When a panel covered by foreign objects, power output is mainly affected by incident irradiance and panel temperature. Therefore we collected these data through irradiance detection module and temperature detection module. By comparing V-I and P-V characteristic with those of a clean panel in the same circumstances, we can get the efficiency drop rate of the covered panel.

3.1. Power Detection Module
Power detection module includes voltage detection circuit and current detection circuit cause power could be calculated by \( P=U*I \). We choose HBV05A5 as Holzer sensor in voltage detection circuit with rated input current of 5mA. Sampling resistance of 5K\( \Omega \) is chosen while the output voltage range of HBV05A5 be from 1.65V to 2.275V. We choose HBC05PS3.3 as Holzer sensor in current detection circuit with measuring range from -12A to 12A. Sampling resistance of 100\( \Omega \) is chosen while the output signal range be from 0.4V to 2.9V correspondingly. The back end of both voltage and current Holzer sensor circuit are connected with a following module aimed at isolating and buffering. Subsequently, a clamp module is designed to control the amplitude of final output signal be within 3V.

3.2. Temperature Detection Module
Temperature detection module is based on DHT11 sensor with accuracy of ±2°C and measuring range from 0°C to 50°C. DHT11 is serial single line and two-way interface. Pin of ‘DATA’ is for communication and keeping synchronization between microprocessors and DHT11 by single bus data format. A complete data transmission includes 40 bit while high bit first out. We should wait for 1 second to pass through the unstable state after DHT11 powered on. Then microcontroller should send a start signal to DHT11 to trigger DHT11 from low power mode to high speed mode. After waiting for the host to start the signal, DHT11 will send out the corresponding signal and data with 40 bits successively [10].
3.3. Irradiance Detection Module

This module is mainly composed by digital sensor BH1750FVI which the range of input light intensity is from 1lx to 65535lx. BH1750FVI is shown in Figure 2. The photodiode of BH1750FVI will generate photocurrent when it is illuminated by light. The stronger the light intensity, the larger the photocurrent is. The integrated operational amplifier of BH1750FVI will convert photocurrent into optical voltage signal. This analog signal will be converted to digital signal by ADC in the next step. The final digital signal will be transmitted through I2C interface.

4. Experimental Results

4.1. System Performance Test

In case of the nonlinear characteristic of the Holzer element in the power detection module, it is necessary to correct the DC voltage and DC current collected by software [11]. The standard instruments for correction are electronic voltmeter with accuracy of 0.5% and electronic ammeter with accuracy of 1.6% correspondingly. The error of power detection module is less than 1% after correction which could meet the requirement of power detection accuracy. Data record of irradiance and temperature detection module is shown in Table 1.

| No. | Time  | light intensity/Lux | Temperature /°C |
|-----|-------|---------------------|-----------------|
| 1   | 14:30 | 21.1k               | 35.0            |
| 2   | 14:40 | 20.3k               | 36.0            |
| 3   | 14:50 | 21.7k               | 35.4            |
| 4   | 15:00 | 21.1k               | 35.4            |
| 5   | 15:10 | 22.3k               | 35.3            |

4.2. Simulation Experiment

In order to verify that the system can detect output power decline caused by various foreign objects correctly, several simulation experiments including panel covered by bird droppings and artificial things are conducted. Detected output characteristics are compared with that of clean panels.

Several pieces of thin paper are used as foreign objects covered on the surface of the tested panel. Characteristics of I-V and P-V were measured in three cases including panel with no covered, with area A covered and with area B covered. The length of the A area is 0.56 meters and the width is 0.2 meters. The length of the B area is 0.4 meters and the width is 0.28 meters. A and B are covered by the edge of the panel. The light intensity was maintained at 3000Lux while the ambient temperature at 24°C during experiment. The measurement results are shown in Figure 3 and 4.

Output voltage and power is decreased obviously when some areas are covered. The trend of I-V and P-V are similar with the situation of ‘covered by nothing’ and ‘covered by area B’. Data of ‘covered by area A’ is not obviously different from data of ‘covered by nothing’ when the external load resistance is less than 16Ω, and the output voltage and power are obviously different when the external resistance greater than 16Ω. The output current drops by 68.7%. The output power decreases
by 60% and then slowly rises when the output voltage be from 15V to 33V. The peak power loss rate is 68.2% compared with that of ‘covered by nothing’ in the same output voltage range.

The curves of I-V and P-V are consistent with the theoretical analysis of the power output model in the above. Due to the effect on the output current by external load, the I-V and P-V equations are represented.

By a piecewise function according to the conduction state of bypass diode connecting two cells. The traditional P-V characteristic with only one single peak was not suitable. The number of peaks on the P-V curve was decided by the number of batteries covered. Dissimilarly, characteristics for ‘covered by area A’ presented different from the other curves because of that the number of cells affected by longitudinal coverage is different from lateral coverage according to the arrangement of the internal batteries.

5. Conclusion
This paper designed and implemented a detection system of foreign objects coverage on PV panels which mainly composed by power detection module, irradiance detection module, temperature detection module, and embedded minimum system module. Output characteristics and power peak loss rate are measured and calculated through experiment simulating situation of panel covered by bird droppings and artificial things. According to the results, the measurement accuracy of each module could meet the requirements of design, and the characteristics experimented are consistent with the theoretical analysis of the power output model. The system is practicable and reliable and achieves the design purpose expected.

Acknowledgments
This work was financially supported by construction project of practical teaching in Shanghai University of Engineering Science.

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