Real-Time 시뮬레이션을 이용한 전기-열 PV 모델링 입증

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Electric-Thermal Photovoltaic Model Validation Using Real-Time Simulations

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ABSTRACT

This paper presents a dynamic, electric-thermal model for a photovoltaic (PV) cell that combines electrical and thermal parameters. In this model, the irradiance and ambient temperature are used to calculate the PV cell temperature based on a five-layer thermal model. The cell temperature is then used in the electrical model to accurately adjust the PV cell output electrical characteristics and power. A custom experimental setup was built to test and verify the electrical and thermal characteristics of the PV cell and its surrounding layers. The electric-thermal model is validated using experimental data in realistic scenarios. This PV model can be scaled up and used to simulate PV systems in wide variety of applications, extreme environmental conditions, and fault conditions in real-time.

1. Introduction

As PV systems become more advanced, a more detailed photovoltaic (PV) cell modeling is needed for more accurate simulations. Real-time simulation is an important tool that has the capability to test and simulate large and complex systems through emulation rather than costly experimental setups. PV system simulation in real-time allows the PV model to interface with power converter hardware, called power hardware in the loop (PHIL), which is a future application of this model. The conventional single-diode PV model is commonly chosen for its simplicity in simulating and calculating PV characteristics in the forward-biased region. However, in order to more fully model a PV cell using real-time simulation, the single-diode model can be enhanced to incorporate dynamic characteristics, accurate electric-thermal performance, and fast processing time [1].

2. Electric-Thermal PV Model

2.1 Electric Model

A dynamic model has been developed, which incorporates parasitic resistances, capacitances and inductances that can be modeled using circuit components, with a current source representing photocurrent. The parameters involved in single-diode model consist of a photocurrent source Iph, forward-biased conducting diode Df, shunt resistance Rsh and series resistance Rs,. This model also includes a series inductance Ls, variable parallel capacitance Cp, reverse-biased conducting diode Dr and breakdown voltage offset Vbd [1], as shown in Fig. 1.

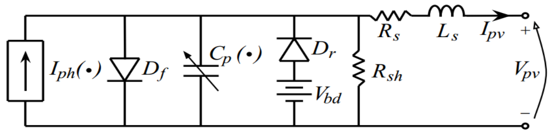

Fig. 1 Equivalent circuit for dynamic PV circuit [1]

2.2 Thermal Model

To accurately determine the electrical power generated from a PV cell, the temperature and heat distribution need to be determined accurately. In this work, the thermal model is composed of five layers: top glass, top air gap, single crystalline PV cell, bottom air gap and bottom glass [2], as shown in Fig. 2.

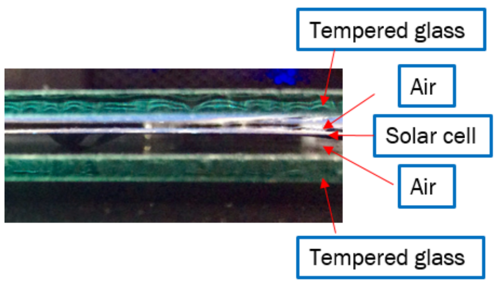

Fig. 2. Cross section of the test setup

The PV cell's temperature is affected by thermal energy exchange of each layer with its surrounding environment, through main heat transfer paths: conduction, convection and radiation. The electrical energy loss, which depends on the PV operating point, is also considered as heat [3]. The resulting temperature change rate for each layer can be described as

$$C_{module}\frac{dT}{dt} = q_{lw} + q_{sw} + q_{conv} + P_{out}$$

Combining the electric and thermal PV models, the combined model was built in Matlab Simulink, which can operate in RT-LAB software for real-time simulation.

3. Electrical and Thermal Model Validation

To verify the model, a 1.3-W single crystalline solar cell and a Keithley 2430 SourceMeter, which can function as either a dc power source or load, was used to obtain the current-voltage (I-V) curve and control the operating point of the solar cell. Also, two Kikusui DME1600 Digit Multimeters were used to measure the cell and glass temperature.

3.1 Electrical Model Validation

The PV cell's I-V curve was measured with an insolation of 700 W/m2, and the model was simulated under the same conditions. The simulated I-V curve compared with the experimental results are shown in Fig. 3.

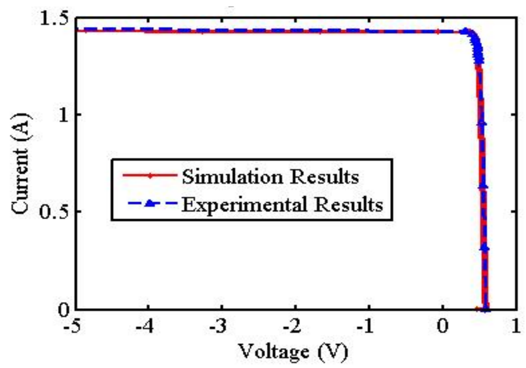

Fig.3. I-V curve comparison between simulation and experimental results under insolation of 700 W/m^2

As shown, the simulation and experimental results are well matched, with an error of 2.1%, which was calculated using the mean relative error method.

3.2 Thermal Model Validation

The thermal model in Simulink is examined under an insolation of 860 W/m2 and the operating point is fixed at a constant voltage level of 0.4 V. The simulation is run under the same conditions for over 1500 s, and the cell's temperature results are compared in Fig.4.

As shown, the simulation cell temperature is 308 K, which is close to results from the experiment (fluctuates between 312 and 306 K). The settling time of the simulation is about 70 s, which is relatively fast compare to the actual temperature settling rate. This proves that the PV thermal model is capable of simulating real solar cell's temperature in normal operating condition with high accuracy, only about 1% error.

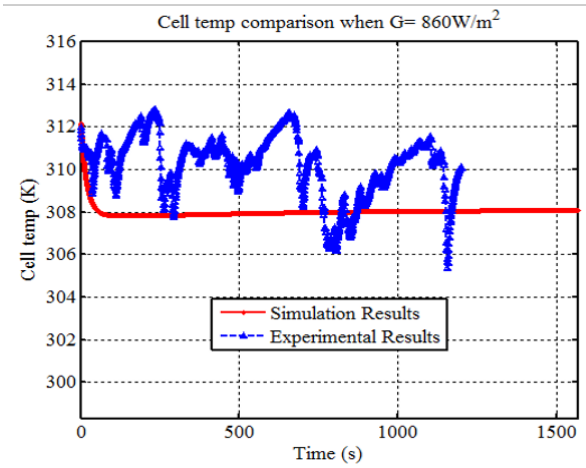

Fig.4. Comparison of solar cell's temperature

4. Conclusion

In this paper, a dynamic electric-thermal PV model was developed. An experimental setup was built and the accuracy of electrical and thermal model was verified. The test setup showed that the electrical part of the model follows the experimental results closely with an error of 2.1% and the thermal part of the model is also is very accurate with an error of about 1%. Ultimately, this model will be used to accurately model common crystalline PV cells and panels and will be utilized in real-time operation to emulate a range of applications.

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