Chapter 25
Solar Simulator Using Halogen Lamp for PV Research

Aryuanto Soetedjo, Yusuf Ismail Nakhoda, Abraham Lomi and Teguh Adi Suryanto

Abstract This paper presents the development of solar simulator using the halogen lamp for PV research. The proposed simulator simulates both the irradiation level and the movement of the sun. The sun irradiation was simulated by varying the brightness of halogen lamp using a lamp dimmer controlled by the microcontroller. While the sun's movement was simulated by rotating the lamp on a frame actuated by a DC motor. A computer was employed to control the simulator in the manual mode where the user could input the desired position and irradiation level of the sun, or in the automatic mode where the desired position and irradiation level were calculated automatically based on the predefined data. The experimental results show that the proposed simulator works appropriately in simulating the sun's movement while varying the irradiation level. The average error of irradiation measurement between the sun and the solar simulator was 7.196 %.

Keywords Halogen lamp · Irradiation level · Solar simulator · PV

25.1 Introduction

Nowadays, the renewable energy resources, such as the PV system is widely used. The research and development of the PV system increase significantly. Naturally, the experiments on PV system require the sun light. Therefore, to provide the flexibility of testing and validating the PV system, the solar simulator was utilized [1–6]. The solar simulator uses the different kind of light sources such as carbon arc lamp, metal oxide arc lamp, quartz halogen lamp, xenon arc lamp, mercury xenon lamp, argon arc lamp, and LED (Light Emitting Diode) to simulate the solar lighting [6]. The halogen lamp is widely used due to inexpensive and the excellent

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F. Pasila et al. (eds.), *Proceedings of Second International Conference on Electrical Systems, Technology and Information 2015 (ICESTI 2015)*,
Lecture Notes in Electrical Engineering 365, DOI 10.1007/978-981-287-988-2_25

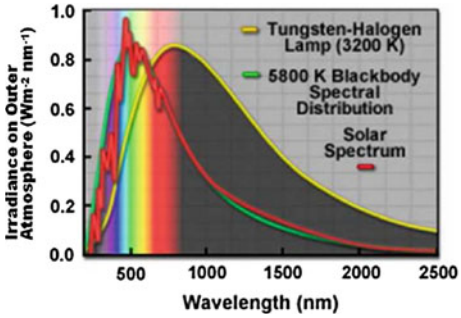

Fig. 25.1 Halogen lamp spectrum distribution [4]

light output [4]. However it radiates the weak output in the blue and ultraviolet spectrum and strong output in infrared spectrum as illustrated in Fig. 25.1.

A simple solar simulator using the halogen lamp was developed in [5]. The developed solar simulator was used to measure the I-V characteristic of the PV module. In the experiments they changed the distance between the lamp and the PV module to vary the irradiation level. The irradiation level of 1 Sun (1000 Watt/m^2) was achieved when the distance is 80 cm with the 4000 W halogen lamp.

The LED based solar simulator was developed in [2]. The objective of their research is to match the spectrum of solar simulator according to the ASTM E927-05 Standard Specification for Solar Simulation for Terrestrial Photovoltaic Testing. They used five types of high power LEDs having the wavelengths of 470, 505, 530 and 655 nm, and white color. The spectral matching was carried out by controlling the intensity of LEDs using the PWM signal controlled by a microcontroller.

The combination of halogen lamp and LED for solar simulator was proposed in [1, 3]. The advantages of LED are the high efficiency and low cost. But for NIR (Near Infra Red) spectrum, the emission band is narrow and very expensive. Therefore, they used the halogen lamp to replace the LED in the NIR spectrum.

In this paper, we propose a simple solar simulator using the halogen lamp. Our proposed solar simulator has two main contributions, i.e.: (a) It provides the varying irradiation by changing the lamp intensity; (b) It simulates the movement angle of the sun from rising time in the morning until sunset time in the afternoon. The computer software is utilized to operate such system in the automatic mode and manual mode.

The rest of paper is organized as follows. Section 25.2 presents the proposed system. Section 25.3 presents the experimental results. Conclusion is covered in Sect. 25.4.

25.2 Proposed System

The block diagram of proposed system is illustrated in Fig. 25.2. It consists of a computer, a microcontroller unit, a servo motor, a dimmer unit, a DC motor, a halogen lamp, and the mechanical parts. The computer is used by the user to control

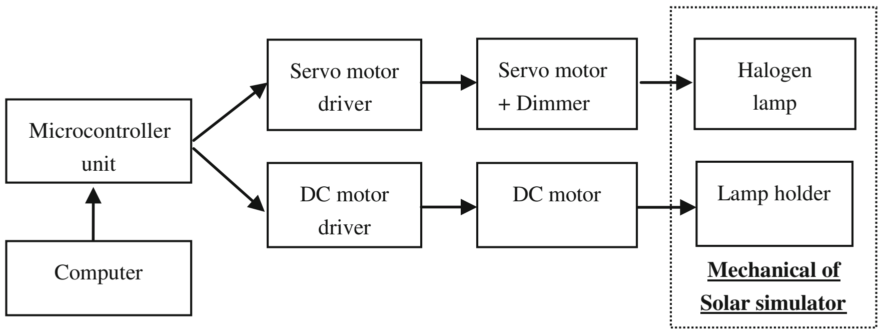

Fig. 25.2 Block diagram of solar simulator

the solar simulator. The microcontroller unit is employed for interfacing between the computer and the motors. It receives the command for rotating the DC motor and servo motor from the computer. The DC motor is used to rotate the lamp frame for simulating the sun rotation. The motor is equipped with the gear reduction and is driven by the driver that provides the high current.

The dimmer unit is a device used to control the light intensity of the lamp. Commercially, the dimmer is equipped with a potentiometer for adjusting the lamp intensity. In the research, we adopt the existing dimmer by modifying it with a servo motor coupled with the potentiometer. Using this arrangement, the rotation of potentiometer could be controlled by the microcontroller.

The halogen lamp is installed on a rotating frame that moves 180^0 from the left to right, vice versa. The rotating frame is installed above the base where the PV module is placed. Using this construction, we could simulate the movement of sun rising and sunset by moving the rotating frame controlled with the DC motor.

In the research, the solar simulator is designed to simulate the sun rotation from 07:00 until 17:00. In this experiment, the start position of halogen lamp is set to 15^0, and the final position is set to 165^0. Therefore the position of 90^0 is achieved when the lamp is located in the above middle of the PV module. This position represents the position of the sun at noon (12:00).

The computer software is designed to control both the lamp position and brightness. Two modes are available, i.e. manual mode and automatic mode. In the manual mode, the user enters the lamp position and the required irradiation level. In the automatic mode, the system will run automatically by reading the predefined values of lamp position and the corresponding irradiation level.

25.3 Experimental Results

The hardware of proposed solar simulator is illustrated in Fig. 25.3. Several experiments are conducted to validate the proposed system. In the first experiment, the relationship between the potentiometer position (i.e. the servo position) and the

Fig. 25.3 Hardware of solar simulator

brightness level represents the irradiation level is observed. To measure the irradiation level, the Solar Power Meter (Tenmars TM-206) is employed. The measurement result is given in Table 25.1 and Fig. 25.4. From the figure, it is clearly shown that the relationship is almost linear. Thus the irradiance level for a certain value could be determined easily based on the position of servo motor.

From the table, the relationship between servo position and irradiation level could be expressed using the following equation

$$y = 8.204x - 334.6 \tag{25.1}$$

where, y is the irradiation level in Watt/m^2 and x is the servo position in degree.

In the second experiment, we compare the irradiation level of the sun and the solar simulator. At first, the sun irradiation level is measured from 07:00 until 17:00 with 15 min interval. This measurement is conducted during the sunny day. The measurement result is listed in Table 25.2. Then the solar simulator is run in the

Table 25.1 Relationship between servo position and irradiation level

Servo position (degree)	Irradiation level (Watt/m^2)	Servo position (degree)	Irradiation level (Watt/m^2)	Servo position (degree)	Irradiation level (Watt/m^2)
45	60	90	340	135	812
50	92	95	442	140	804
55	120	100	490	145	885
60	155	105	502	150	875
65	200	110	563	155	940
70	245	115	625	160	973
75	282	120	646	165	1005
80	315	125	713	–	–
85	335	130	750	–	–

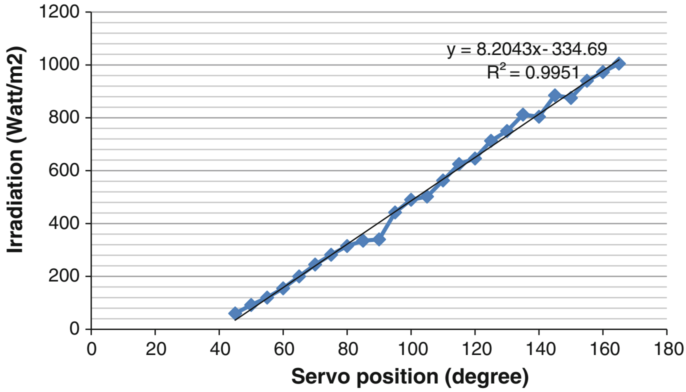

Fig. 25.4 Linearity between servo position and irradiation level

Table 25.2 Measurement of irradiation level of the sun and solar simulator

Time	Lamp position (degree)	Irradiation level (Watt/m2)		Time	Lamp position (degree)	Irradiation level (Watt/m2)	
		Sun	Solar simulator			Sun	Solar simulator
7:00	15	375	340	12:00	90	935	1005
7:15	18.75	395	442	12:15	93.75	917	885
7:30	22.5	519	502	12:30	97.5	943	885
7:45	26.25	527	502	12:45	101.25	922	885
8:00	30	678	646	13:00	105	924	885
8:15	33.75	893	804	13:15	108.75	917	885
8:30	37.5	901	890	13:30	112.5	899	804
8:45	41.25	911	890	13:45	116.25	873	804
9:00	45	921	900	14:00	120	892	792
9:15	48.75	929	896	14:15	123.75	827	785
9:30	52.5	947	896	14:30	127.5	818	771
9:45	56.25	893	858	14:45	131.25	854	746
10:00	60	904	930	15:00	135	790	772
10:15	63.75	841	791	15:15	138.75	603	565
10:30	67.5	874	793	15:30	142.5	655	565
10:45	71.25	862	804	15:45	146.25	645	565
11:00	75	964	875	16:00	150	613	565
11:15	78.75	923	880	16:15	153.75	498	440
11:30	82.5	1134	973	16:30	157.5	404	400
11:45	86.25	1016	1005	16:45	161.25	238	205
12:00	90	935	1005	17:00	165	212	145

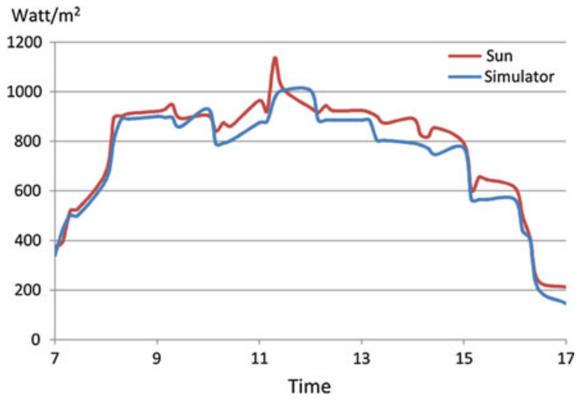

Fig. 25.5 Comparison of Sun irradiation versus solar simulator irradiation

automatic mode. Thus it will rotate and vary the brightness of halogen lamp automatically. During this movement, the irradiation level of the simulator is measured and listed in Table 25.2.

Figure 25.5 illustrates the measurement results of the irradiation level of the sun and the solar simulator. From the figure, it is obtained that the result of the solar simulator is almost the same with the sun. The error between the real measurement of the sun irradiation and the solar simulator is calculated as

$$\frac{|Lamp\ irradiation - Sun\ irradiation|}{Sun\ irradiation} x100\% \tag{25.2}$$

From the table, the average error for the data given in Table 25.2 is obtained as 7.196 %.

Two important results are achieved by our proposed system. The first is a method to change the lamp intensity by utilizing the the simple lamp dimmer coupled with the servo motor. This simple arrangement offers the linear relationship between the servo position and the irradiation level produced by the halogen lamp. The second is the capability of the proposed system to simulate the irradiation level generated by the sun during the sunny day. It is validated by the experiment that the proposed solar simulator is able to move while varying the lamp intensity closely to the real sun.

25.4 Conclusion

The simple and low cost solar simulator is developed. The main objective of the proposed simulator is to simulate the sun irradiation and the sun movement. The solar simulator could be used to examine and test the research on PV system. The irradiation of solar simulator could be controlled using the computer and almost the same as the real measurement of the real sun irradiation.

In future, the simulator will be extended in the size which is used by the larger PV module. Further the software simulation will be improved and integrated with the PV system.

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