A real-time simulator of a photovoltaic module

Linfeng Zhang
Department of Electrical Engineering
University of Bridgeport, CT 06604

Abstract

In order to improve the efficiency of the photovoltaic system, converters and inverters with maximum power tracking are developed to get the maximum power since the PV systems are passive power source and their outputs are affected by the external load. However, in order to develop and test of these power electronics, current-voltage curve of the PV module should be controllable. This is not possible due to the fluctuation of solar insolation and temperature. In this work, a PV module simulator is designed and tested to generate power output and it can work in two modes: constant condition (solar irradiance and temperature) mode and real-time condition (real-time weather conditions and solar position) mode. This simulator consists of four modules: weather condition collection, solar position calculation, insolation calculation, and solar module. The solar module interacts with the other three modules and also one physical instrument, a programmable DC power source. In addition, a LabVIEW program is developed to process the information, monitor system, and control the output. Through the testing, the output voltage and current from the simulator follow the current-voltage curves in the two modes. Therefore, the simulator can be widely used to replace a real PV module for the development of MPPT converters and inverters.

Key words: renewable energy, PV module, maximum power point tracker, converter, inverter

1. Introduction

PV module price has fallen 75% to below $1/w since 2008 [1, 2]. There are over 17,500 MW of cumulative solar electric capacity operating in the U.S., enough to power more than 3.5 million average American homes, 36%, over 49,000 installations, of all new electric capacity is from solar in Q3 2014. It means that a new solar project has been installed every 3 minutes. The growth of solar industry boosts the economy and creates 174,000 jobs in the U.S. [3]. As a part of PV system, module-level, string, and central power electronics are well developed and the market for global PV micro-inverters and power optimizers will more than triple in the coming years, rising to more than $1 billion in 2018. The development and testing of the power electronics needs to input solar energy to be controllable, so the output PV module follows one current-voltage curve. This is hard to get from a real PV module [4].

In order to maintain this growth and meet the future demands of this industry, a skilled workforce is necessary. Therefore, solar-energy related courses are offered by more and more universities. In the education, especially in some experiments, it is hard to repeat results since weather significantly affect the PV system. Some labs may have to be cancelled in the Spring semester for the bad weather.

In order to facilitate the power electronics development and solar energy education, a system is needed to simulate the output from a PV module and the output from this system should follow the typical current-voltage curves of a PV module. In this paper, a simulator is developed with a programmable DC power source, which is controlled by the programs. The inputs to the simulator are zip code, date, and time. The orientation of the PV module can also be specified. The simulator can operates in two modes: constant solar irradiance and temperature mode, real-time solar irradiance and temperature mode.

2. System

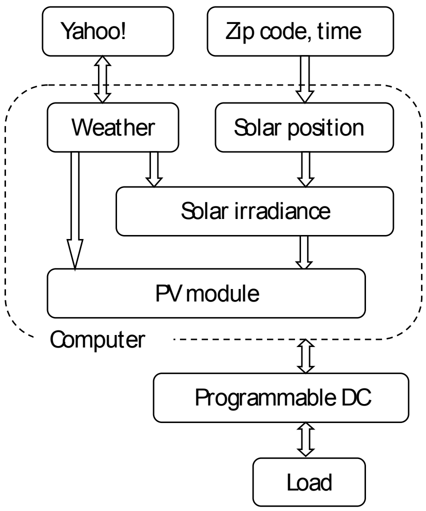


Figure 1 The structure of the PV module simulator

Figure 1 shows the structure of the system. The inputs include the zip code, date, and initial time. The output is the power to the load. The software controlling the system includes four modules: the weather module, the solar position module, the solar irradiance module, and the PV module. The power output generated is from programmable DC power source which communicates with the software.

The structure in Figure 1 is implemented as a program in LabVIEW with the front panel as in Figure 2. The system can run in two modes: real-time weather and constant weather. In the first mode, the system power output is affected by the local weather. While in the second one, the solar irradiance is set as any constant.

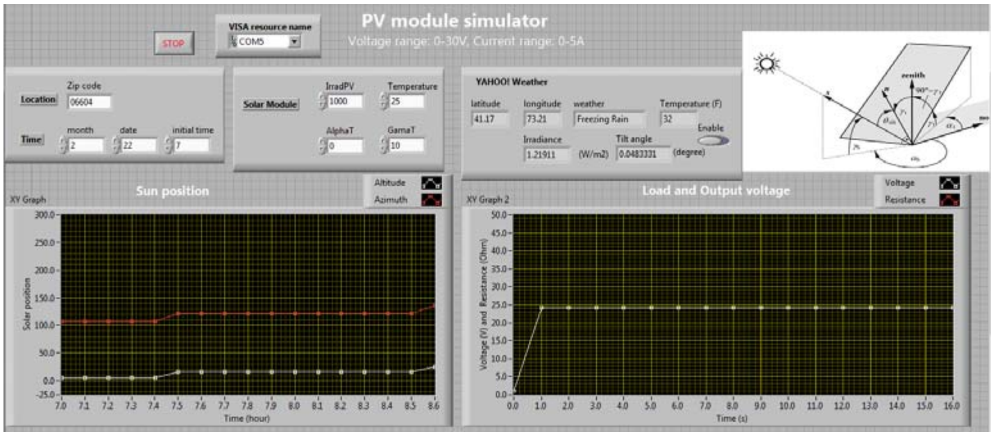


Figure 2 The front panel of the LabVIEW program

2.1 PV module

The PV module simulated in this work is close to real one, Ameresco Solar BP 90 Watt [5], and the characteristic data under different irradiance is shown in table 1 and the temperature coefficients in table 2.

Table 1 Characteristic parameters of the PV module

Irradiance (w/m^2)	V_{oc} (V)	I_{sc} (A)	V_{mp} (V)	I_{mp} (A)
1000	22.1	5.21	17.9	5.03
800	21	4	17.5	3.5
600	20.5	3	17.5	2.5
400	20	2	17.5	1.5
200	19	1	17.5	0.7

Table 2 Temperature coefficient

	%/°C
Voc	-0.36
Isc	0.105
Vmpp	-0.408
Impp	-0.0281

The equation of the IV is:

$$I = I_{sc} - A(e^{BV} - 1)$$

Where, A, B, and I_{sc} vary with solar insolation or irradiance. Linear interpolation is used to get the IV curve under irradiance.

The temperature effect on the module is considered in the following equation,

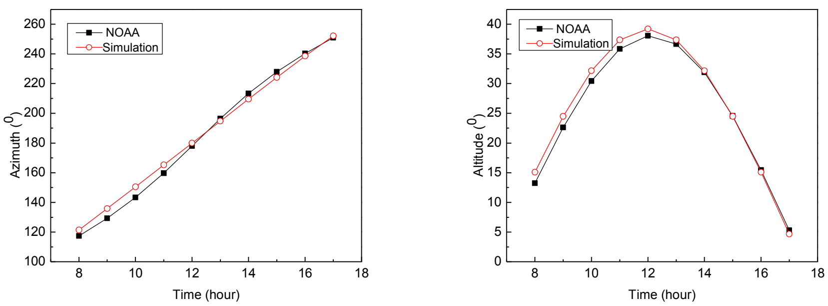
$$X_{ambient} = \left(\gamma (T_{STC} - T_{ambient}) + 1\right) X_{OC,rated}$$

Here, α is a temperature coefficient from table 2 and X is open-circuit voltage, short–circuit current, voltage at MPP, or current at MPP.

2.2 Weather

The real time weather condition is obtained through Yahoo! Weather RSS Feed [6]. The information from the XML file of Yahoo! includes weather, temperature, wind, and weather forecast. The weather condition affects the solar irradiance and the temperature affects the PV module output. Thus, both of them are the inputs to the Solar Irradiance and PV module in Figure 1.

2.3 Solar position



(a) (b)

Figure 3 Azimuth (a) and solar altitude (b) on Feb. 20, 2014[7]

The solar position is calculated based on the local altitude and time through Julian Day, declination angle, and hour angle. Figure 3 shows the comparison of the solar altitude and azimuth between the calculation and the data from National Oceanic and Atmospheric Administration (NOAA). This comparison indicates that the calculation is quite close to the one from NOAA.

3. Results and discussion

The hardware, in the system implementation and testing, includes a Programmable DC Power Supply (BK Precision 1788 with voltage range 0-32V and current range 0-6A) and a Programmable DC Load (TekPower 3711A). Since the voltage and current are unstable when the load from the Programmable DC load is less than 4Ω, 10W ceramic resistors are used.

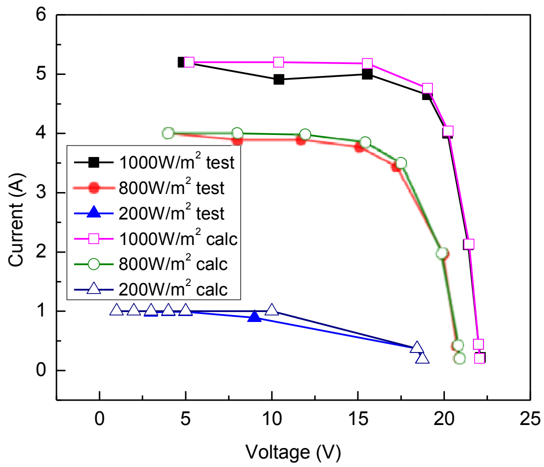


Figure 4 The current-voltage curves from the system and calculation under different irradiance

Figure 4 shows the current-voltage curves from the system and the calculation under 1000, 800, and 200 W/m^2. As the solar irradiance drops, the IV curve shifts to the lower left. The pairs of curves indicate that the real output is close to the one from calculation.

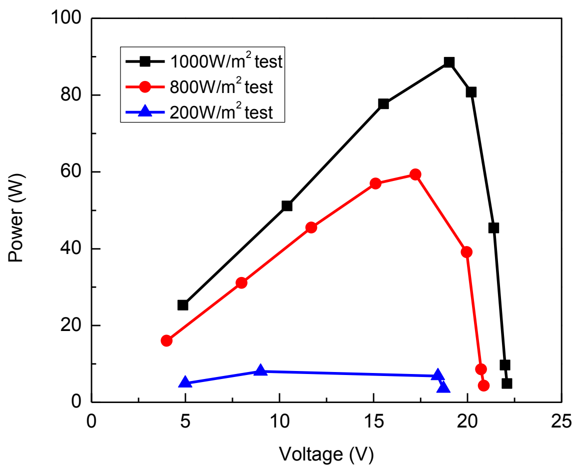


Figure 5 Power output under different irradiance

Figure 5 shows the experimental power-voltage curves under 1000, 800, and 200 W/m^2. On each curve, there is a maximum power point and this point drops from 90W to around 10W as the irradiance decreases from 1000W/m^2 to 200W/m^2. Thus, the system can be used to test power electronics, such as maximum power point trackers, converters, and inverters.

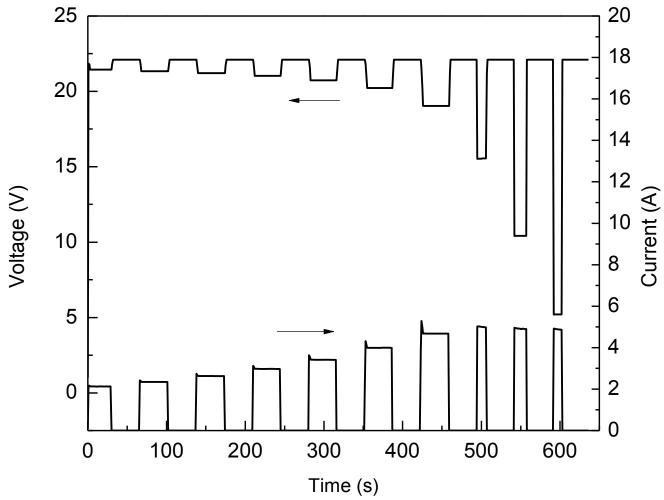


Figure 6 The voltage and current outputs at irradiance 1000w/m^2

Figure 6 is the dynamic response from the system as the resistance decreases from 10Ω to 1Ω. Here, the sampling time is one second. The response is relatively short and the maximum overshoot is 11%.

4. Conclusion

The simulator can generate power with the current-voltage characteristics as a real PV module with maximum power points under different solar irradiances. It can be used for the development of maximum power point trackers, converters, and inverters. More tests will be done on the response time and overshoot.

References

1. Arnaud de La Tour, M.G., Yann Ménière, Predicting the costs of photovoltaic solar modules in 2020 using experience curve models. Energy, 2013. **62**: p. 341-348.
2. Liebreich, M., Investment, infrastructure & innovation for green growth. Bloomberg New Energy Finance, 2012.
3. Solar Energy Industries Association, Q3 2014 SMI Fact Sheet. 2014.
4. Minwon Park, I.-K.Y., A Novel Real-Time Simulation Technique of Photovoltaic Generation Systems Using RTDS. IEEE TRANSACTIONS ON ENERGY CONVERSION, 2004. **19**(1): p. 164-169.

5. http://www.altestore.com/store/Solar-Panels/Ameresco-BP490J-90W-12V-Solar-Panel-with-J-Box/p10175/.
6. http://weather.yahooapis.com.
7. http://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html.

Linfeng Zhang obtained his Ph.D. from the Department of Electrical and Computer Engineering at Wayne State University. He is an associate professor in the Department of Electrical Engineering at the University of Bridgeport. His research area is focused on chemical sensor, renewable energy, and energy management.