TEKA Kom. Mot. Energ. Roln. – OL PAN, 2011, 11, 173–180

APPLICATION OF A MICROCONTROLLER IN SIMULATION OF THE PHOTOVOLTAIC GENERATORS

Jacek Kapica

University of Life Sciences in Lublin
Doświadczalna 50A, 20-280 Lublin
e-mail: jacek.kapica@up.lublin.pl

Summary. The solar radiation varies in time and is unrepeatable. For this reason in researches dealing with systems powered by photovoltaic generators a device simulating the current-voltage curve of a real generator may be useful. It consists of a controlling block, which can be made of a micro controller and an output unit – voltage amplifier.

The paper presents a mathematical model of a photovoltaic module, principle of operation of the simulator and results of laboratory measurements which were undertaken to test the designed device.

Key words: solar energy, photovoltaic generator, simulator.

INTRODUCTION

Since the energy crisis in 1970’s a constant growth of photovoltaic power production has been observed [Grubb et al. 1997, Sinha 1998, Lotsch et al. 2005]. One of the areas of solar energy application is agriculture [Luque et al. 2003, Tiwari et al. 2010]. This kind of energy is sometimes considered as “agro-energy” [Roszkowski 2006].

Operating state of devices powered by photovoltaic (PV) generators depends on the solar radiation intensity on the surface of photovoltaic modules. This radiation varies in time and is unrepeatable. When, during research experiments it is needed to compare the performance of various configurations of the photovoltaic system, it is difficult to have the same radiation conditions for each case [Mukerjee et al. 2007].

One of the ways to solve this problem is to apply a device which will model the current-voltage curve of a photovoltaic generator for a given radiation values. Such a device may be also useful in training in the area of photovoltaics because experiments with real PV modules may be impossible in autumn – winter season or after dark.

Recently, a PV simulator with MOSFET technology has been presented [Gonzales et al. 2010]. The main components of the PV simulator presented in this paper are: amplifier in which we can control the output voltage and a microcontroller with a set of analog inputs and outputs.

A microcontroller is a computer which has all the necessary parts of a conventional micro-computer contained in a single electronic chip. Main parts of the microcontroller are: CPU (Central

Processing Unit), memory and input/output interface [James 2001]. The memory of the chip can store algorithms of system behaviour dependent upon many different parameters [Wierzbicki 2006], which enables the device to control different processes.

This paper presents the construction of the simulator and results of the tests which were performed to verify the current-voltage characteristics modelling quality.

CURRENT-VOLTAGE CURVE OF THE PV CELL

Current-voltage curve of a photovoltaic cell is given by the following equation [Kalogirou 2009]:

$$I = I_{PH} - I_0\left(\exp\left[\frac{e\left(V + IR_S\right)}{kT}\right] - 1\right) - \frac{V + IR_S}{R_{SH}}, \tag{1}$$

in which

I is the current generated by the PV cell and flowing through the load circuit,

I_{PH} – photocurrent, current of the short-circuited cell, proportional to the solar radiation intensity,

I_0 – dark saturation current,

V – cell's voltage,

e – electronic charge,

k – Boltzmann's constant,

T – cell's temperature,

R_{SH} – shunt resistance of the cell,

R_S – series resistance of the cell.

This and other models of photovoltaic cells are also presented by Kaddour et al., (2010).

Current-voltage curve modelling by the equation (1) is very difficult. Enough accuracy can be provided by a model with three parameters [Kapica 1998], which can be obtained from eq. (1) assuming $R_{SH} \to \infty$ and $R_S = 0$:

$$I = I_{PH} - I_0\left(\exp\left(\frac{eV}{kT}\right) - 1\right). \tag{2}$$

Parameters of this equation, which are specific for the given cell (I_{PH} with full insolation, I_0) need to be obtained by measurement of the current-voltage curve of a real PV cell or module, which we want to model. Methods to obtain the equation parameters are given by Kim et al. (2010) and Xu Xiao-bing et al. (2009).

For simplicity, influence of the solar radiation upon the cell's temperature has been neglected in the simulator's algorithm, but this functionality can be easily added.

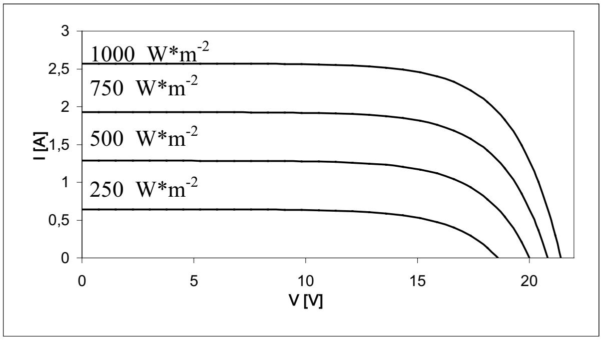

Fig. 1. Example of a current-voltage curve of a photovoltaic module for different insolation levels

THE PHOTOVOLTAIC SIMULATOR

Photovoltaic simulator is a device which is able to model current-voltage curve of a PV module or generator. Its main part is an operational amplifier, whose output voltage is proportional to the voltage applied to the input (Fig. 2). In the prototype device a high output current operational amplifier OPA 541 has been used [Texas Instruments 2000].

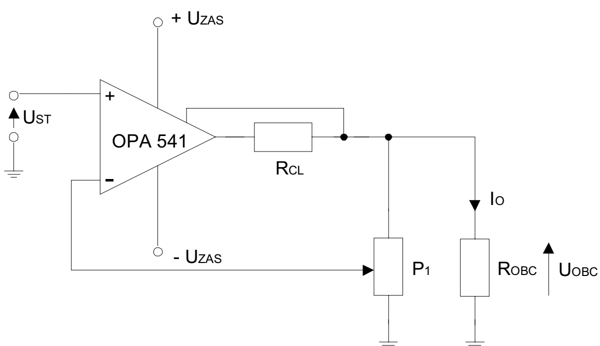

Fig. 2. Schematic diagram of a voltage amplifier used in the simulator [Marciniuk 2000]

A single chip microcomputer (microcontroller) with analog input and output circuits is used to control the amplifier. In the prototype device a ATmega8535 chip with external A/C and D/C converter chip has been used [Atmel 2006]. The analog input is connected to a Hall effect current transducer. The output voltage is fed to the input of the amplifier.

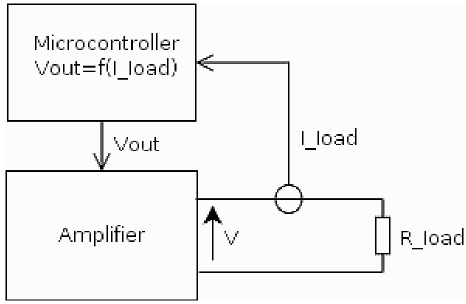

Fig. 3. Diagram of photovoltaic generators' simulator

The microcontroller sets its output voltage (Vout – see Fig. 3) based on measurements of the amplifier load current (I_load). The voltage is calculated according to the current – voltage curve equation for the simulated PV module or generator.

The current-voltage curve of the generator has been divided into two parts. In the part where the load current is lower or equal to 0.85 I_{PH}, the microcontroller's output voltage is calculated directly from the curve equation after transforming the equation (2) into a form of V=f(I).

Because the second part of the curve – for currents greater than 0.85 I_{PH} – has a large gradient of current as a function of voltage, it was necessary to employ a different procedure of the output voltage calculation. In this case, the output is changed stepwise until the working point on the current-voltage curve is reached iteratively.

TESTING PROCEDURE

In order to test the device a series of measurements have been done. All the experiments were conducted with help of the computer applications created in LabView - a graphical programming environment which is especially useful in creating software for measurement circuits [Buczaj et al. 2007].

In the first step it was checked whether the proposed single chip computer will be fast enough to calculate the required parameters in real time. This was achieved by exposing the device to rapid load resistance change when the input solar radiation was constant and by rapidly changing the input solar radiation with the load resistance unchanged. The measurement circuit is presented on Fig. 4. The time needed to set the working point was in the range of few milliseconds and on exceptional occasions to approx. 300 ms. The longer values were recorded for low radiation levels combined with low load resistance values. This is the result of the simulator working in the second part of the current-voltage curve and the iterative procedure of the working point calculation. However such cases were not frequent. Taking into account that the rate of radiation change is usually much slower, the tested microcontroller may be implemented in the simulator.

In the second step, a series of measurements were undertaken in order to compare the performance of the simulator with a real PV module. First, the voltage, current and insolation were registered over a period of several days for a real PV module connected to a load resistance. The circuit diagram is presented on Fig. 5. As a voltage transmitter a potentiometer (voltage divider) was used. The current was measured through a Hall-effect transducer. The insolation is obtained through measurement of the short-circuit current of another module which is parallel to the tested module. Also in this case a Hall-effect transducer was used.

Than the measurements for the PV simulator were performed. As the solar radiation data, the data obtained during measurements with the real module were used. In the electrical circuit used previously, the solar module was replaced with the simulator and the insolation data were fed to the simulator from a digital-to-analog converter card plugged into a computer (Fig. 4). The tests were planed in such a way that the voltage and current were saved 0.5 s after the insolation level had been set to allow time for the microcontroller to set the working point.

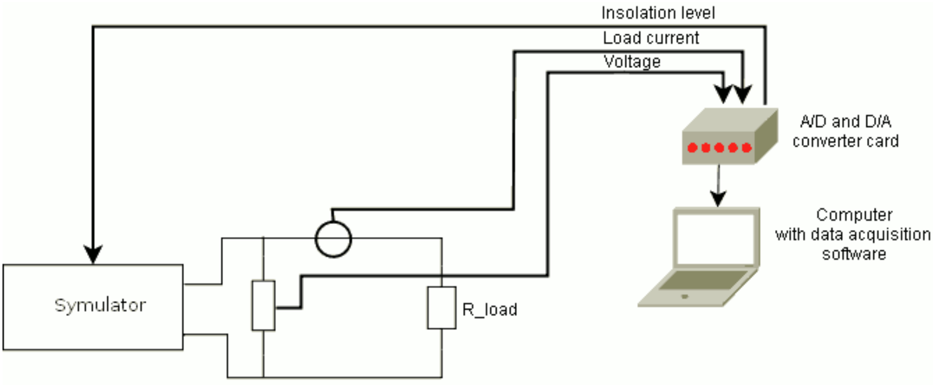

Fig. 4. Diagram of the measurement circuit for tests of the simulator of the photovoltaic generators

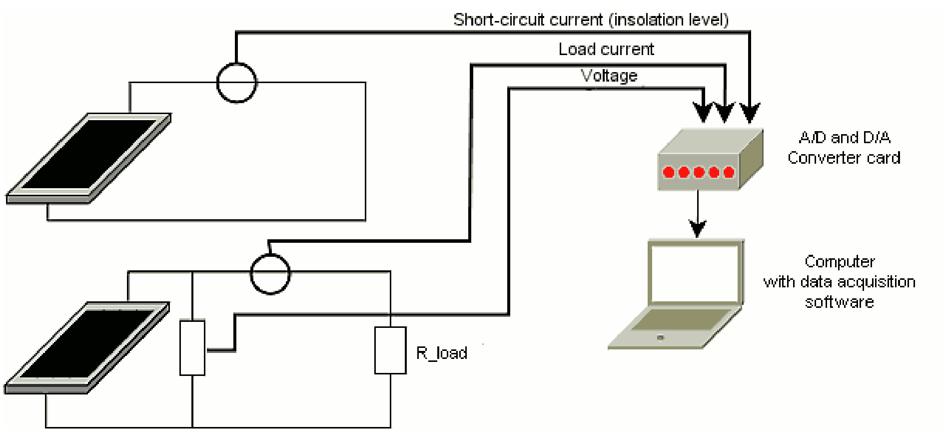

Fig. 5. Diagram of the measurement circuit for tests of a real photovoltaic module

The measurements were done in April 2010. Figures 6-9 present the results of the comparative tests from April 9th. One of the black lines shows the current or voltage of the real module whereas the grey line – of the simulator. Additionally an absolute error is presented (the other black line with lower values). For convenience, Fig. 8 to 9 present curves for a selected part of the day.

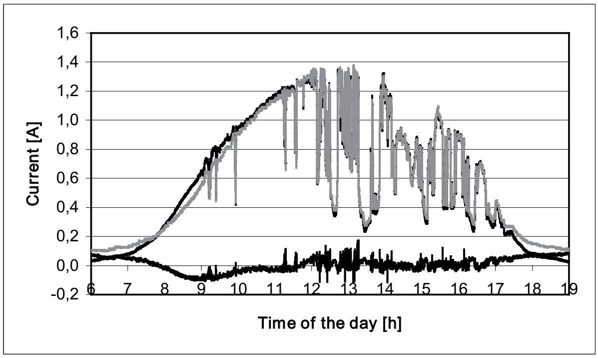

Fig. 6. Current – time curve of a real module and of the simulator for April 9th 2010

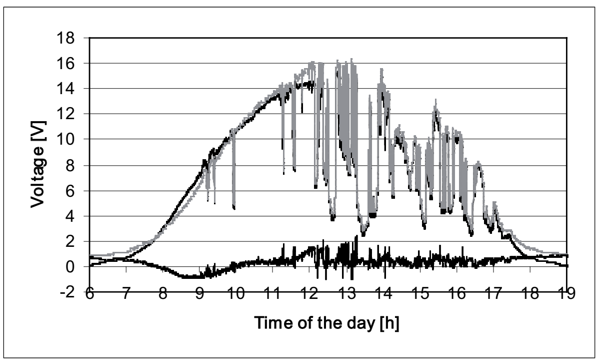

Fig. 7. Voltage – time curve of a real module and of the simulator for April 9th 2010

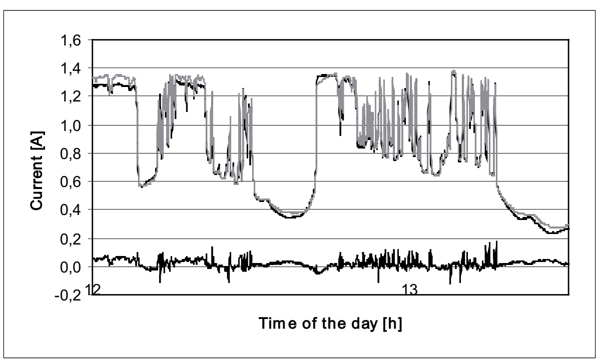

Fig. 8. Current – time curve of a real module and of the simulator for a selected part of April 9th 2010

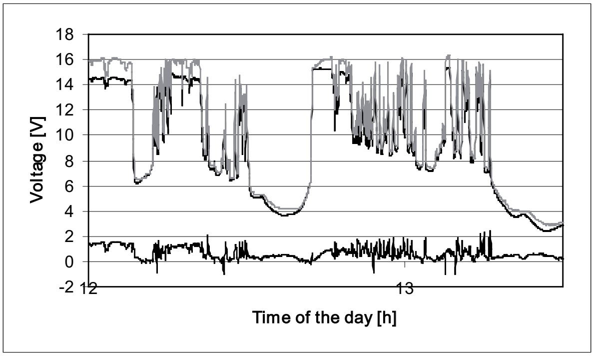

Fig. 9. Voltage – time curve of a real module and of the simulator for a selected part of April 9th 2010

After the measurements, maximum differences between the values obtained from the real module and from the simulator were calculated. Maximum absolute error for the current simulation was 0.18 A and for the voltage – 2.4 V. Additionally, the daily energies produced by the real module and the simulator were evaluated. The maximum difference was 8300 J (5 % of the value produced by the real PV module).

CONCLUSION

As the comparative tests show, the simulator resembles closely the current-voltage curve of a real PV module. The precision can be improved by employing a more accurate model and – primarily – by taking into account temperature change of the solar module with the insolation.

The time to set the working point is fair and it could be improved by using a faster CPU.

Proposed simulator of the photovoltaic generators can be used in researches aimed at performance analysis of circuits powered from photovoltaic power sources. Another area is education. In both cases application of the device gives an advantage of opportunity to repeat the tests for identical insolation curve, independent on current weather conditions and season of the year.

Additional advantage which was revealed during the tests of the device is a possibility to decrease the time needed to perform the test in case when the insolation sampling period is greater than the time needed to set the simulator's working point – which is true for most of the cases. For example, for the results presented in this paper, the simulation of the whole day was finished in less than two hours. This is because the simulator does not have to wait the full time between the points in time but only the time needed to set the working point.

REFERENCES

Atmel Corporation. 2006. 8-bit AVR Microcontroller with 8K Bytes In-System Programmable Flash.

Buczaj M., Sumorek A. 2007. Simulation of motor vehicles instrument panels in LabView environment. Teka Komisji Motoryzacji i Energetyki Rolnictwa VII. p. 52.

Gonzalez, S. Kuszmaul, S.; Deuel, D.; Lucca, R. 2010. PV array simulator development and validation. Photovoltaic Specialists Conference (PVSC), 35th IEEE. ISBN: 978-1-4244-5890-5.

Grubb M., Vigotti R. 1997. Renewable Energy Strategies for Europe: Electricity systems and primary energy sources. Royal Institute of Internetional Affairs. ISBN: 1-85383-284-7.
James M. 2001. Microcontroller cookbook. Newnes. ISBN 0-7506-4832-5. p. 4.
Kaddour A., Merad Boudia, M, Lemerini, M. 2010. Simulation and Modelling of the PEDOT/PSS Layer Effect for Organic Solar Cells with One and Two Diode Models, International Review on Modelling & Simulations.
Kalogirou S. A. 2009. Solar Energy Engineering: Processes and Systems. (p. 477). Elsevier. ISBN: 978-0-12-374501-9
Kapica J. 1998. The Influence of selection of the Solar Cell's Model on the Accuracy of Calculation of the Current-Voltage Characteristic, Proceedings of the 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion, Vienna, Austria. ISBN 92-828-5179-6.
Kim W., Woojin C. 2010. A novel parameter extraction method for the one-diode solar cell model. Solar Energy 84.6.
Lotsch H.K.V., Goetzberger A., Hoffman V.U. 2005. Photovoltaic Solar Energy Generation. Springer Series in Optical Sciences Volume 112.
Luque A., Hegedus S. 2003. Handbook of photovoltaic science and engineering. John Wiley & Sons. p. 54.
Marciniuk K. 2000. Construction of a device to simulate the photovoltaic modules. Akademia Rolnicza w Lublinie (in Polish).
Mukerjee A.K., Dasgupta N. 2007. DC power supply used as photovoltaic simulator for testing MPPT algorithms, Renewable Energy, Volume 32, ISSN 0960-1481.
Papadopoulou E. 2011. Photovoltaic Industrial Systems: An Environmental Approach. Springer. p. 3.
Roszkowski A. 2006. Agriculture and fuels of the future. Teka Komisji Motoryzacji i Energetyki Rolnictwa VI. p. 132.
Sinha P.C. 1998. Energy Crisis. Anmol Publications. p. 184.
Texas Instruments Incorporated. 2000. OPA541 High Power Monolithic Operational Amplifier.
Tiwari G. N., Dubey S. 2010. Fundamentals of Photovoltaic Modules and their Applications. Royal Society of Chemistry. ISBN: 978-1-84973-020-4. p. 118.
Xu Xiao-bing, Wang Jian-ping, Zhang, Chong-wei. 2009. An analytical method of silicon solar cell model parameters. Chinese Journal of Power Sources, vol.33 no. 6.
Wierzbicki S. 2006. Diagnosing microrpocessor-controlled systems. Teka Komisji Motoryzacji i Energetyki Rolnictwa VI. p. 182.

ZASTOSOWANIE MIKROKONTROLERA DO SYMULACJI GENERATORÓW FOTOWOLTAICZNYCH

Streszczenie. Promieniowanie słoneczne jest zmienne w czasie i niepowtarzalne. Z tego względu w badaniach naukowych nad układami zasilanymi z generatorów fotowoltaicznych użyteczne może być urządzenie symulujące przebieg charakterystyki prądowo – napięciowej rzeczywistego generatora. Składa się ono z bloku sterującego, którym może być mikrokomputer jednoukładowy oraz bloku wyjściowego, którym jest wzmacniacz napięciowy. W artykule przedstawiono model matematyczny modułu fotowoltaicznego, zasadę działania symulatora oraz wyniki pomiarów mających na celu sprawdzenie poprawności pracy prezentowanego urządzenia.

Słowa kluczowe: energia słoneczna, generator fotowoltaiczny, symulator