Temperature and Radiation influence on Photovoltaics Panels Operation.

Jacek Nazdrowicz [1]
(1) Department of Microelectronics and Computer Science
Lodz Univeristy of Technology, Lodz, Poland
jnazdrowicz@dmcs.pl

Abstract

In the paper model in Matlab/SIMULINK of small power energy domain is considered. Author would like to show how two parameters – irradiance and temperature are crucial for such "private power plant" operation – how parameters of the system influence on power energy production. Based on own experience, author discuss it and show how important is to apply dedicated algorithms to obtain as much power as possible by appropriate control of electrical parameter connected to PV cells.

1 Introduction

Because of adverse effects human influence on its environment especially on nature, continuous growth of energy demand (increase by 60% from 2002 to 2030) and the related price increase, renewable energy sources are becoming a very good alternative that allows to replace the existing energy production systems not so much, but to perfectly complement them, and thus reduce destructive human activity and more effectively use the potential of nature in this area.
The main renewable energy sources are sun and wind, and while the methods of producing energy using them have been known for a long time, they have only now become the main source of commercial interest.
The good example of commercial application are photovoltaics systems in closed home energy domain – they become very popular because of their economic advantages, availability and easy adaptation to grid systems.

Figure 1. PV cell mounted in typical home power domain (author's private PV system).

2 Theoretical Background

A photovoltaic system consist of number of semiconductor p-n junction cells mounted on roofs, ground and walls in households (Fig. 1). To produce energy (current during sunny day), this p-n junction is irradiation-sensitive, (Fig.2). The production is based on creation of electron and hole pair by absorbing band gap energy which exceeds photons of PV semiconductor material. These free electron-hole pairs amount are proportional to solar irradiance intensity. In p-n junction an electric field appears and tries to split created pairs.

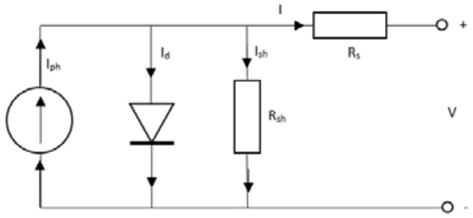

Figure 2. Single cell of PV equivalent circuit and SIMULINK implementation.

During this process current appears which depends on radiation (is proportional). Cell pads gather free electrons and holes from p and n semiconductors respectively and then current flows to energy system.

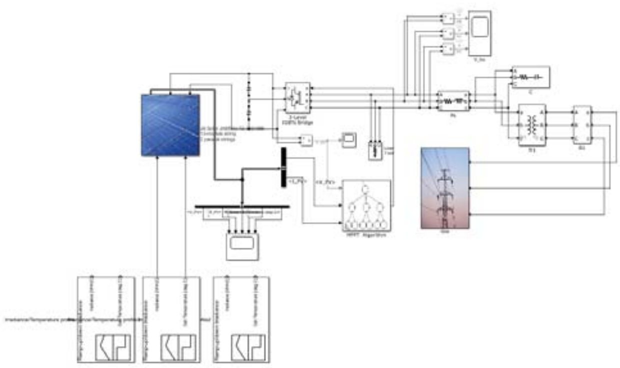

Figure 3. Model of photovoltaic system in power domain.

To reflect behavior of photovoltaic cell, the model of it is commonly used which generally includes current source and diode. This model of photovoltaics cell circuit is presented in Fig. 2 (I_{sh} is shunt current, I_d current of parallel diode, I_{ph} - photocurrent, R_s - series resistance, R_{sh} - shunt resistance, I - output current, V output voltage. According to presented model, the following equations govern of PV cell behavior (output current)[1]:

$$I = I_{ph} - I_0\left\{e^{\frac{q(V+R_S I)}{AKT}} - 1\right\} - \frac{V+R_S I}{R_{sh}}$$
$$I_d = I_0\left\{e^{\frac{V_d}{V_T}} - 1\right\}, I_T = \frac{kT}{q} nIN_{cell} \tag{1}$$

where: V_d - diode voltage, I_0 - diode saturation current, q - electron charge, N_{cell} - number of cells connected in PV module, nI - diode ideality factor (≈ 1), k - Boltzman's constant, T - cell temperature, A - curve fitting factor, I_T – thermal current, V_T – thermal voltage.

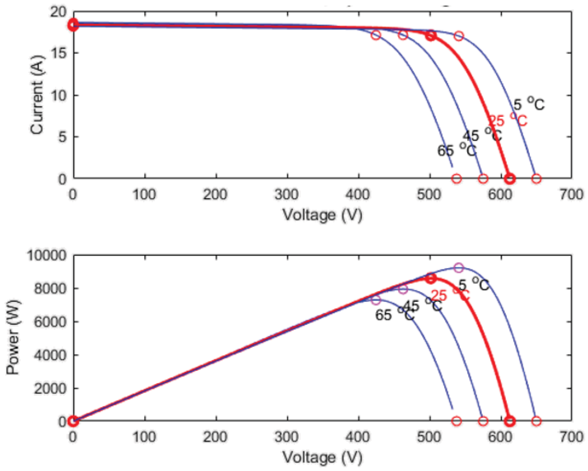

Figure 4. I-V and P-V plots for different temperatures and irradiation environmental conditions for considered PV module type.

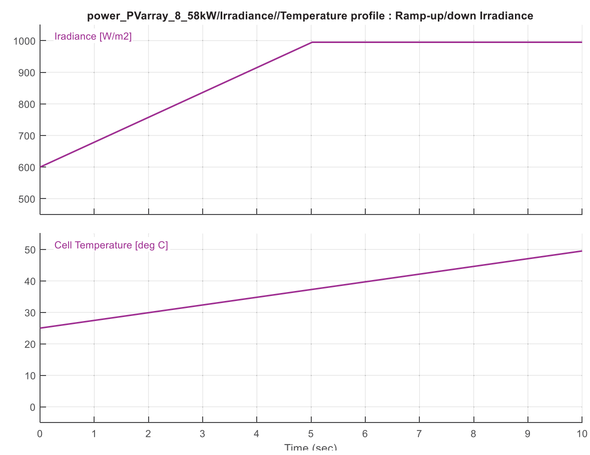

Figure 5. Example irradiance and temperature profile for 10s.

The most common photovoltaic systems include PV modules (array cells), controller, DC-DC converter and – in extended versions - batteries to store energy. Because batteries are very expensive and therefore such energy system maintain become also expensive – the extended solution is rarely used (Fig. 3). The DC-DC converter plays crucial role in the system because it optimizes power produced by the Photovoltaic cells with specified control strategy use.[2,3,4].

According equations (1) we see that current strongly depend on environmental factor like temperature. Therefore when PV system owners observe current production may see that even in sunny day, when temperature is very high – production is lower than expected. In photovoltaics systems it is necessary to continuously monitor irradiance and temperature to find so called Maximum Power Point (MPP) to optimize PV cell power productions [5,6]. The idea of MPP search is about searching maximum power value in current-voltage operation characteristics of PV module (fig. 4). Such characteristic is specified for each type of PV module independently and it depends on technology process, design and materials. Obviously, because strong influence temperature on the PV cell performance, in specification manufacturer provide group of characteristics for different temperatures.

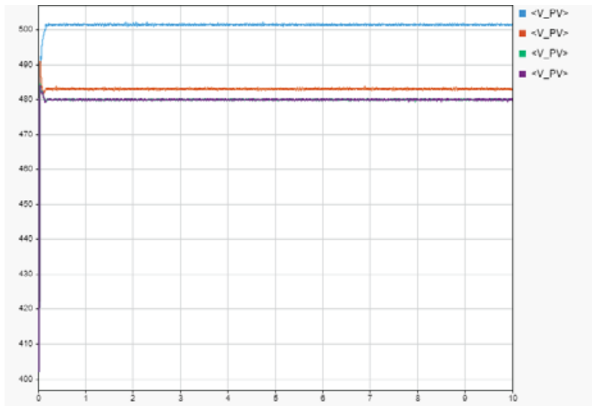

Figure 6. Voltage for constant temperature and irradiance.

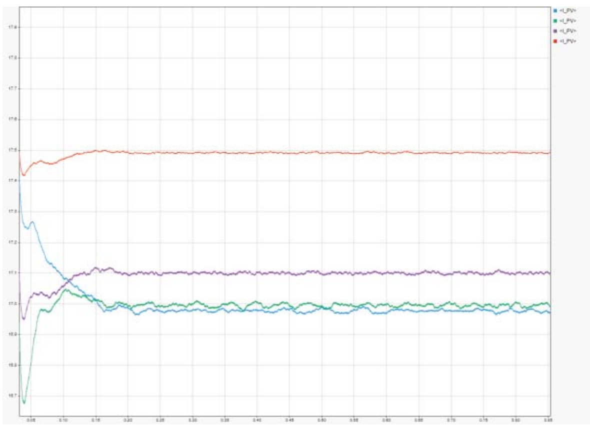

Figure 7. Current for constant temperature and irradiance.

3 Modelling and Simulations

Model of a photovoltaic system owning by author was implemented with use of Matlab/SIMULINK package. The blocks applied to this model are (Fig. 9):
photovoltaic array,

- 3-level IGBT controller – which is three-level neutral point clamped power converter. It includes power switching devices and provide selectable topologies. P&O MPPT algorithm is used to optimize possible power gathered from PV cells.
- P&O MPPT algorithm implementation block,
- Internal-domain 7kW load.
- Yd- type transformer.

Four Irradiance-Temperature profiles in time domain were used:

1. constant irradiance=1000 W/m^2, constant temperature=25^{o}C,
2. constant irradiance=1000 W/m^2, constant temperature=35^{o}C,
3. drop irradiance=1000→600 W/m^2, drop temperature=50→25^{o}C,
4. growth irradiance=600→1000 W/m^2, drop temperature=25→50^{o}C.

All options with MPPT enabled and disabled were simulated.

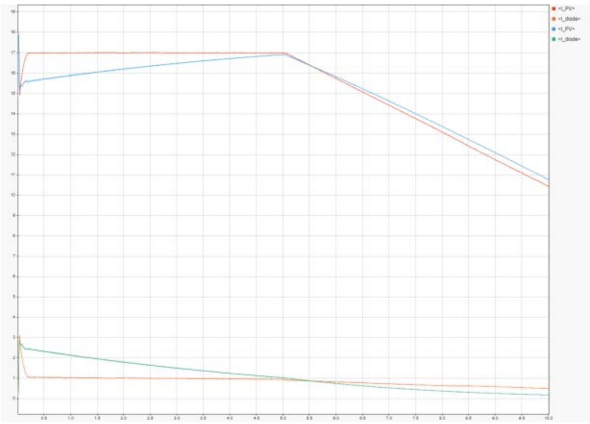

Figure 8. Current for temperature and irradiance drop (red, orange plots – MPPT disabled, blue, green – MPPT enabled).

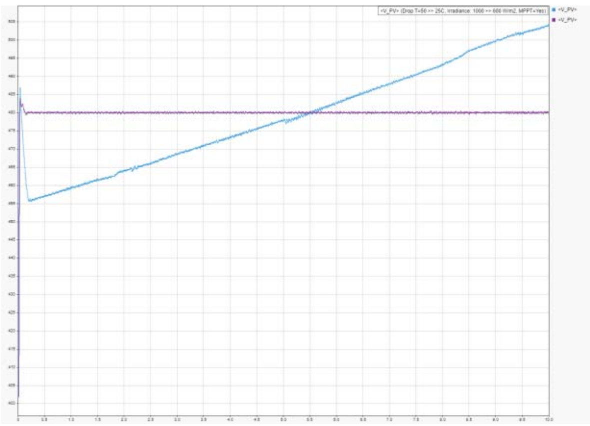

Figure 9. Voltage for temperature and irradiance drop (red plot – MPPT disabled, blue – MPPT enabled).

When we compare for profile 1 and 2 we see that for lower temperature with MPPT enabled (fig. 6 and 7), the currents are comparable, but for higher temperature, current is a bit higher. When MPPT is disabled this difference become extremally large. For T=25^{o}C Current is about 17A, whereas for T=35^{o}C drops to 1A. With MPPT enabled voltage is kept meaningfully lower than for algorithm disabled.

In case of drop irradiance and temperature we observe current drop on diode and photovoltaics. When irradiance is constant system optimizes (MPPT=on) so that system keeps current.constant (fig. 8).

In case of Voltage, MPPT algorithm increases it when temperature drops. For algorithm disabled – voltage is kept constant. The reverse situation is for growth temperature and irradiance - MPPT decreases voltage for whole time period (fig. 9 and 10).

4 Conclusions

This paper presents results of simulation PV system with various irradiance and temperature profile applied. Additionally, data are compared with results obtained with MPPT algorithm, what gives knowledge how, system behaves when “intelligent algorithm” is applied. Presented characteristics shows huge dependency voltage and current on concerned factors. Moreover, when we observe particular plots, we see that in case of MPPT disabled – either V or I are constant too (at the beginning there are some fluctuations – transient state). This of course is not optimal adaptation especially for various environment conditions.

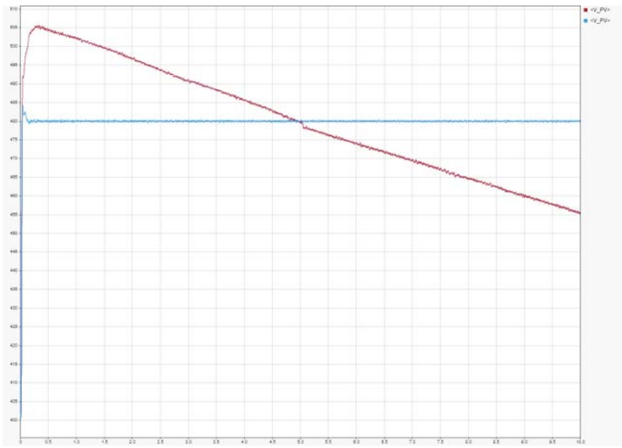

Figure 10. Voltage for temperature and irradiance growth (red plot – MPPT enabled, blue – MPPT disabled).

When MPPT is enabled – it can be observed that Voltage linearly drops or growth for whole period of time, whereas current plots are more complex – it may be seen, that current plays main role and adapts its values to get maximum performance of PV cells. These quite simple profiles were applied just to reflect I-V characteristics in the face of environmental changes. The four cases provide good knowledge especially time of simulation is very short. It is obvious, that for 24hours profile, performing simulation is time and resource consuming therefore author decided to consider cases separately in such 10s periods and thanks to it – it is possible to verify how I and V may change during extended time.

7 References

1. J.A. Gow, C.D. Manning: "Development of a photovoltaic array model for use in power-electronics simulation studies". IEE Proc. on Electric Power Applications, vol. 146, no.2, , March 1999, pp. 193-200.
2. C. Hua, C. Shen: "Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system". 29th Annual IEEE PESC, IEEE Computer Soc. Press, New York 1998, pp. 86-93.
3. M.A.S. Masoum, H. Dehbonei, E.F. Fuchs: "Theoretical and experimental analyses of photovoltaic systems with voltage-and-current-based maximum power-point tracking". IEEE Transactions on Energy Conversion, vol. 17, no. 4, December 2002.
4. K.H. Hussein, I. Muta, T. Hoshino, M. Osaka: "Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions". IEE Proc. Gener. Transnm. Distrib. vol. 142, no.1, January 1995, pp. 59-64.
5. V. Salas, E. Olıas, A. Barrado, A. Lazaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems", Solar Energy Materials & Solar Cells, 2006, Vol. 90 , pp. 1555–1578.
6. A. M. Atallah, A. Y. Abdelaziz, R. S. Jumaah, "Implementation of perturb and observe mppt of pv system with direct control method using buck and buckboost converters", Emerging Trends in Electrical, Electronics & Instrumentation Engineering: An international Journal (EEIEJ), 2014, Vol. 1, N. 1, pp. 31-44.
7. M. A. de Blas, J. L. Torres, E. Prieto, A. García: "Selecting a suitable model for characterizing photovoltaic devices". Renewable Energy, vol. 25, no. 3, pp. 371-380, March 2002.
8. B. G. Bahgat, N. H. Helwa, G. E. Ahamd, E. T. El Shenawy: "Estimation of the maximum power and normal operating power of a photovoltaic module by neural networks". Renewable Energy, vol. 29, no. 3, March 2004, pp. 443-457.
9. A. K. Abdelsalam, A. M. Massoud, S. Ahmed, and P. Enjeti, "Highperformance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids," IEEE Trans. Power Electron., vol. 26, no. 4, Apr. 2011, pp. 1010–1021.
10. B. Bendib, H. Belmili, F. Krim "A Survey of the Most Used MPPT Methods: Conventional and Advanced Algorithms Applied For Photovoltiac Systems", Renewable and Sustainable Energy Reviews Vol. 45, May 2015, pp. 637-648.
11. T. P. Sahu, T.V. Dixit, R. Kumar, "Simulation and Analysis of Perturb and Observe MPPT Algorithm for PV Array Using ĊUK Converter", Advance in Electronic and Electric Engineering. , 2014, Vol. 4, N. 2, pp. 213-224.