Description of the dynamics of work of amorphous photovoltaic panels using process models

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Abstract

The work investigates the dynamic parameters of an amorphous photovoltaic panel. The models were determined on the basis of actual meteorological data from the photovoltaic research stand located at the Institute of Mechanical Engineering at Warsaw University of Life Sciences. Models were developed using System Identification Toolbox (Matlab&Simulink Software). Presentation of the dynamic parameters was given by graphs of step responses and frequency characteristics. The results show that more complex model analyzes with the highest fit should be performed and the model structure changed.

Keywords

Photovoltaic panel, system identification, dynamic parameters, process model

1. Introduction

Every day usual sources of energy and the technologies associated with them are no longer relevant and are giving their place to a new kind of alternative energy [1]. The most important source of this energy is the light emitted by the sun – solar energy. The shift from conventional energy to solar energy is taking place because the resources used by humans to supply themselves with electricity have simply begun to run out. Nowadays, the most popular in this area are photovoltaic panels.

The first advantage of photovoltaic panel is that it does not need to be connected to the grid. This means that by installing photovoltaic panel, the investor can become completely independent of conventional electric energy.

Another advantage is its long life [2, 3]. The disadvantages of used photovoltaic panels are the dependence on the climatic conditions of the region and the use of a large area for mounting the panels (but they can be mounted on water and in the mountains) [4, 5].

Despite all drawbacks, photovoltaic panels are a promising area for energy development and are gaining popularity not only locally but also nationally. Therefore, the dynamic properties of photovoltaic panels need to be properly identified so that they can be implemented into more complex systems, such as hybrid energy systems.

Process models are popular for describing system dynamics in many industries and are applicable in various manufacturing environments. The advantage of these models is that they are simple and the determined model parameters have an easy interpretation as poles and zeros, i.e., roots of the numerator and denominator of the polynomial transfer function [6, 7].

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2. Materials and methods

Research object and research method were presented in that paragraph. The main purpose of the study is identification of amorphous photovoltaic module dynamic properties. The result of those study could be implemented in the proper developing of control algorithm for photovoltaic system.

2.1. Research object

For research purposes in this work, photovoltaic panels were used. The test stand, presented in Figure 1, is located at the Warsaw University of Life Sciences, at the Institute of Mechanical Engineering. Also, the institute has its own meteorological station.

Figure 1: The test stand with photovoltaic panels

The subject of the research was the amorphous photovoltaic (PV) panel SCG62-HV-L, produced by the German manufacturer Sulfurcell. The PV panels are IEC certified; their parameters were described in Table 1. The unit power of the panel is 62,5 Wp. One panel was on the following structure (U2) and the second one was horizontally mounted on the ground (U4).

Table 1
The amorphous photovoltaic panel parameters

Description	Value and unit
Rated power	62.5 Wp
Efficiency	7.7%
Voltage at maximum power point V_{MPP}	41.5 V
Current at maximum power point I_{MPP}	1.51 A
Open circuit voltage V_{OC}	53.7 V
Short-circuit current I_{SC}	1.76 A
Positive power tolerance	+ 8%

2.2. Research method

To develop the model, the measurement of voltage [V] on the analyzed panel and the measurement of the irradiance [W/m^2] were used. Measurement data were recorded every 15 seconds. The created xls files with daily measurements were input and output signals for the analyzed model. The Kipp & Zonen CM3 model pyranometer was used to measure the irradiance. The analyzed model is a single-input single-output (SISO) model [8, 9]. The structure of the model is shown in Figure 2.

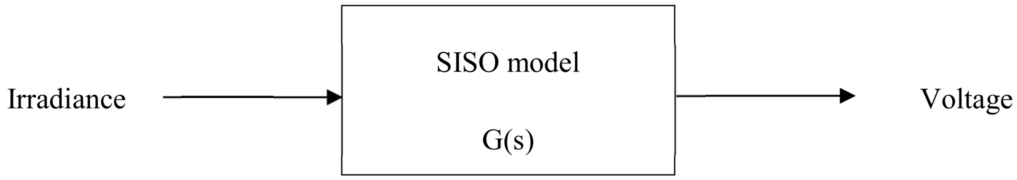

Figure 2: Structure of the analyzed model

Based on the object identification in the Matlab & Simulink System Identification Toolbox, process models were developed [10-14]. The structure of a process model is a simple continuous-time transfer function that describes linear system dynamics in terms of one or more of the following elements:

- gain factor k,
- one or more time constants Ts,
- possible time of delay Td before the system output responds to the input (dead time),
- possible enforced integration [12].

The following model structure is a first-order continuous-time process model, where k is the static gain, T_s is a time constant, and T_d is the input-to-output delay [12]:

$$G(s) = \frac{k}{1+sT_s} \cdot e^{-sT_d}. \tag{1}$$

After verifying the fit of the models by mean square error (MSE higher than 80 %), the transfer function was obtained in the form:

$$G(s) = \frac{\mathrm{U}}{\mathrm{P}} = \frac{\text{voltage}}{\text{irradiance}}. \tag{2}$$

Based on the obtained transfer function, the step and frequency characteristics of the analyzed amorphous panel were plotted. For step characteristics the following dynamic parameters were determined:

- Gain factor k,
- Time constant T_s,
- Time of delay (if applicable) T_d.

For frequency characteristics the following dynamic parameters were determined:

- Cut-off frequency ω_0,
- Period of signal change T.

The database contains measurements from several years. The most suitable models were selected for the article. In the following paragraphs the results for five days, 26/09/2019, 11/11/2019, 15/11/2019, 01/12/2019 and 07/12/2019, were described.

3. Results and discussion

3.1. Photovoltaic panel U2

Taking into account the day of 11/11/2019, the transfer function of subsequent models of the amorphous panel has the form:

$$P1 = \frac{0.04924}{0.4397 \cdot s+1}, \tag{3}$$

$$P1DZ = \frac{0.256 \cdot s+0.0921}{12.66 \cdot s+1}, \tag{4}$$

$$P1Z = \frac{0.04036 \cdot s+0.04923}{2.075 \cdot s+1}. \tag{5}$$

The step characteristics of the model is inertial (Figure 3). When analyzing the frequency characteristics (Figure 4), the cut-off frequency (ω_0) of the model at P1 was 2.2688 Hz, which corresponds to the period of signal change T was 0.441 sec, for P1DZ ω_0=0.1167 and T=8.569sec, for P1Z ω_0=0.5795 and T=1.726 sec. These are definitely too low values taking into account the nature of the work of the amorphous photovoltaic panel.

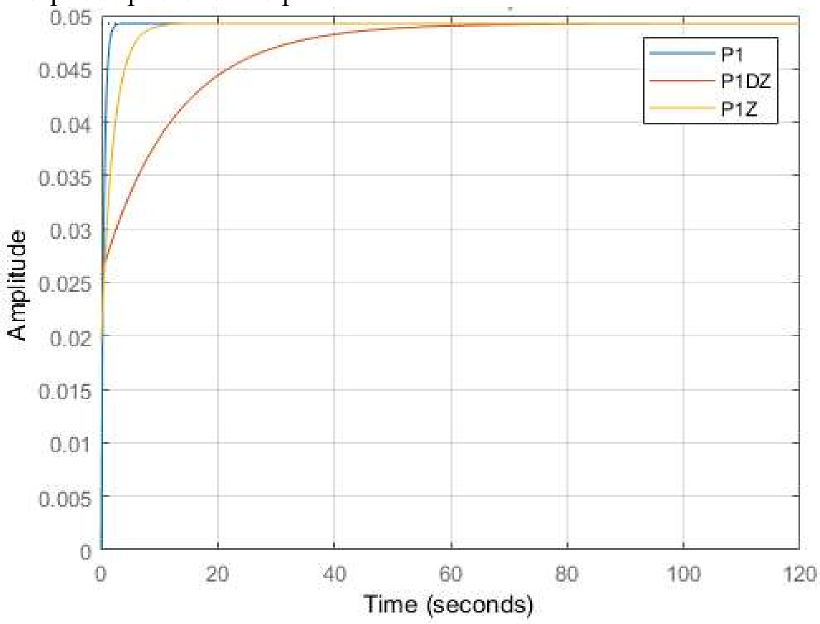

Figure 3: The step characteristics of the models from 11/11/2019

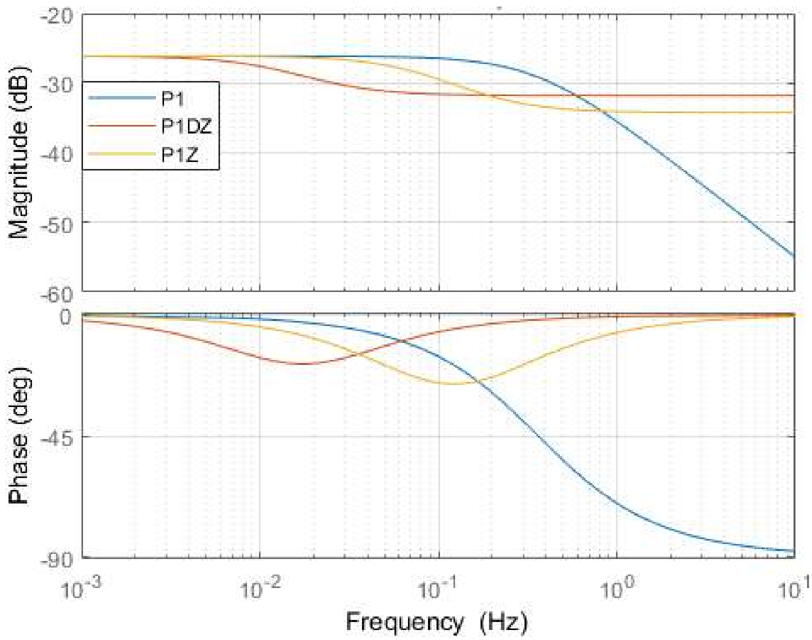

Figure 4: The frequency characteristics of the models from 11/11/2019

Taking into account the day of 26/11/2019, the transfer function of subsequent models of the amorphous panel has the form:

$$P1 = e^{-0.045*s} * \frac{0.04515}{4.287*10^{-6}*s^3+0.0008611*s^2+0.05361*s+1}, \tag{6}$$

$$P1D = \frac{0.04515}{0.1622*s+1}, \tag{7}$$

$$P2DZ = e^{-9.3*s} * \frac{14.27*s+0.04487}{0.8643*s^2+306.8*s+1}, \tag{8}$$

$$P2Z = \frac{10.18*s+0.04501}{3229*s^2+238.7*s+1}, \tag{9}$$

$$P3ZD = \frac{14.4*s+0.04479}{2.101*10^4*s^3+6388*s^2+341*s+1}. \tag{10}$$

The step characteristics of the model is also inertial (Figure 5). When analyzing the frequency characteristics (Figure 6), the cut-off frequency (ω_0) of the model P1 was 26.9884 Hz, which corresponds to the period of signal change T equal to 0.037sec, for P1D ω_0= 0.163, T=0.163 sec, for P2DZ ω_0=379.74, T=0.0026 sec, for P3DZ ω_0=0.0605, T=16.53 sec, for P2Z ω_0=0.0705, T=14.184 sec.

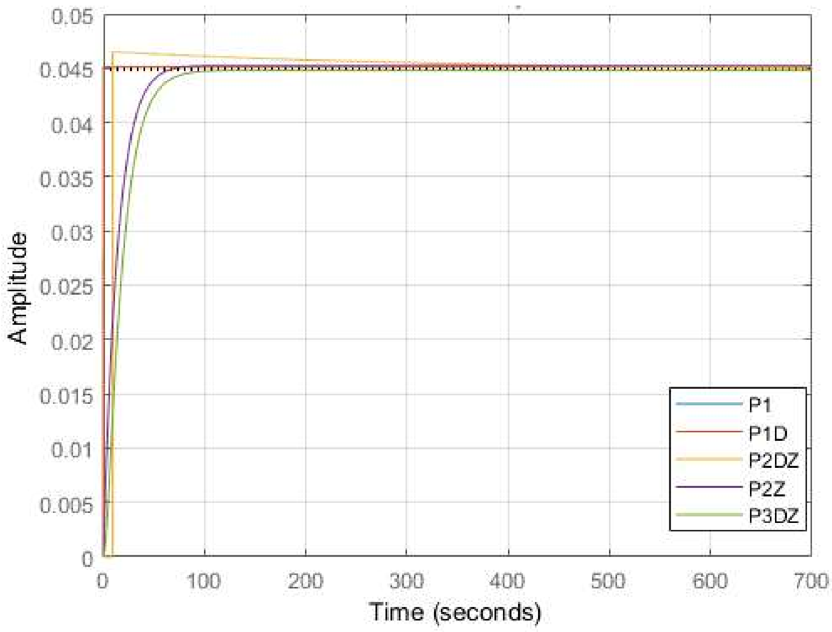

Figure 5: The step characteristics of the models from 26/11/2019

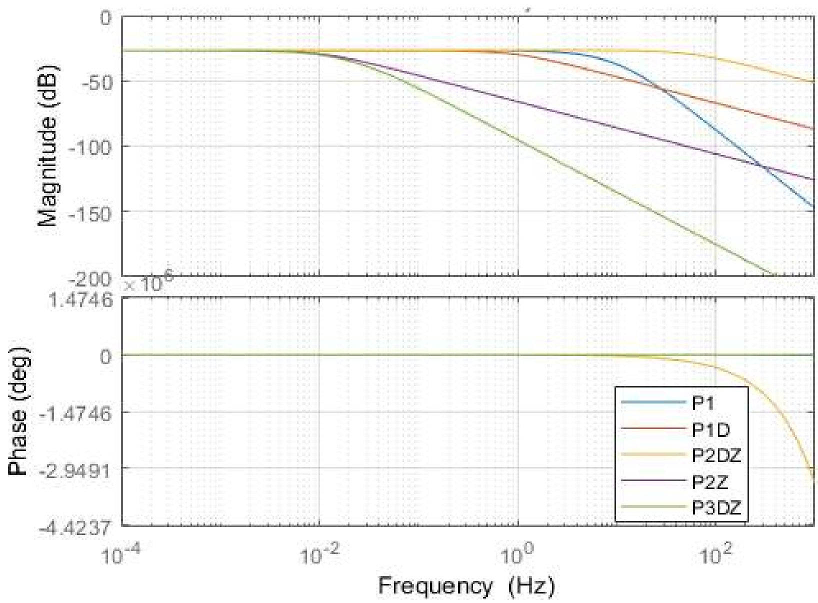

Figure 6: The frequency characteristics of the models from 26/11/2019

3.2. Photovoltaic panel U4

Taking into account the days 15/11/2019, 01/12/2019 and 07/12/2019, the transfer function of subsequent models of the amorphous panel has the form:

$$P2DZ_{15/11} = e^{-3{,}99*s} * \frac{643.7*s+0.5592}{4379*s^2+1557*s+1}, \tag{11}$$

$$P2Z_{1/12} = \frac{319*s+0.6645}{696.7*s^2+654.6*s+1}, \tag{12}$$

$$P3Z_{1/12} = \frac{361.7*s+0.6645}{0.01065*s^3+33.44*s^2+696.4*s+1}, \tag{13}$$

$$P1DZ_{7/12} = \frac{901.6*s+0.5976}{1986*s+1}, \tag{14}$$

$$P2DZ_{7/12} = \frac{1899*s+0.615}{1.096*10^4*s^2+3913*s+1}, \tag{15}$$

$$P3Z_{7/12} = \frac{1890*s+0.6149}{0.2101*s^3+92.72*s^2+3894*s+1}. \tag{16}$$

The step characteristics of the model is also inertial (Figure 7). When analyzing the frequency characteristics (Figure 8), the cut-off frequency (ω_0) of the model P2DZ15/11 was 0.109 Hz, which corresponds to the period of signal change T equal to 9.17 sec, for $P2Z_{1/12}$ ω_0=0.2595, T=3.85 sec, for $P3Z_{1/12}$ ω_0=9.8104, T=0.102 sec, for $P2DZ_{7/12}$ ω_0=0.176, T=5.682 sec, for $P3Z_{7/12}$ ω_0=22.9744, T=0.044 sec.

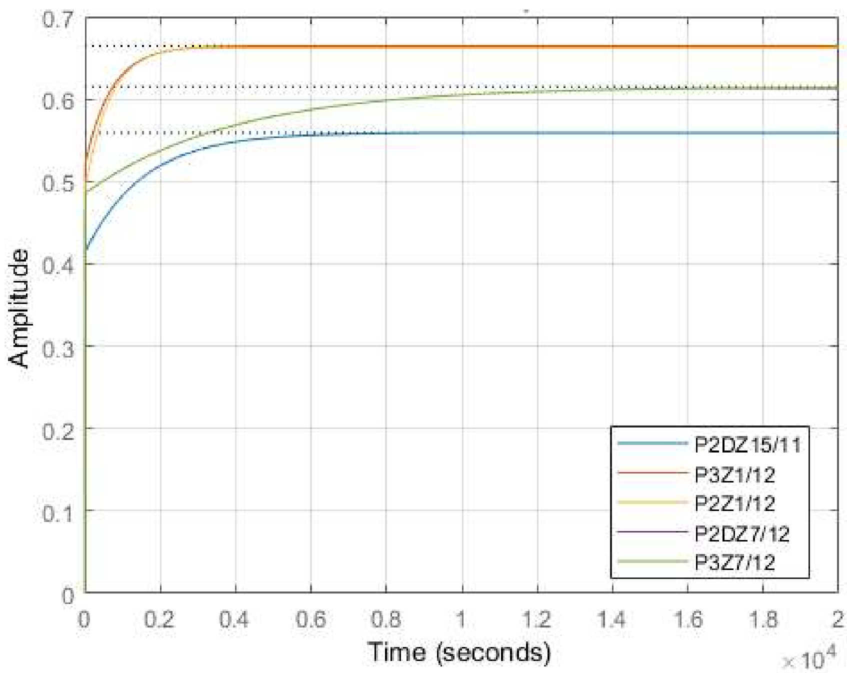

Figure 7: The step characteristics of the models from 15/11/2019, 01/12/2019 and 07/12/2019

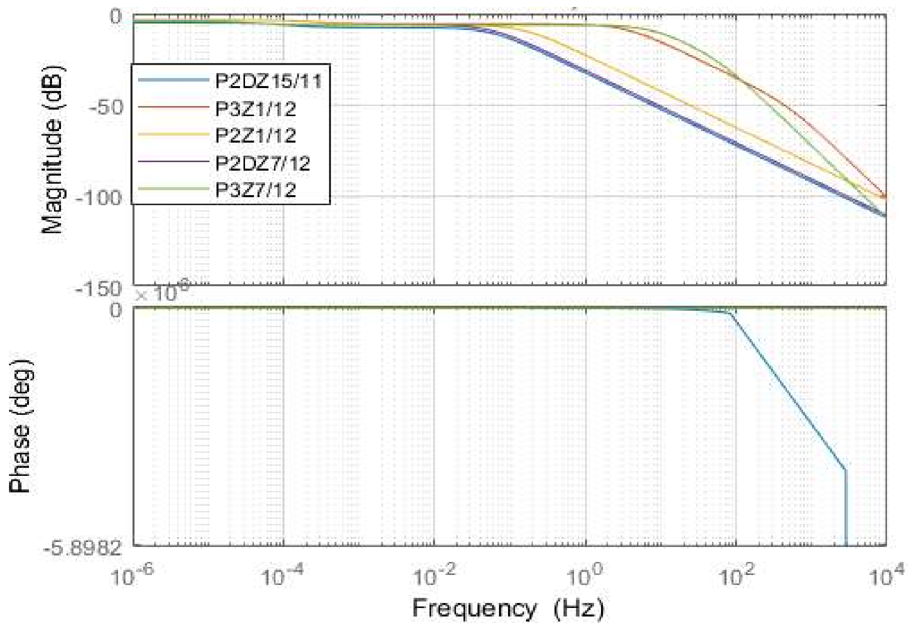

Figure 8: The frequency characteristics of the models from 15/11/2019, 01/12/2019 and 07/12/2019

3.3. Photovoltaic panel U2 and U4 dynamic parameters description

Based on the step characteristics determined from the transfer function, the dynamic characteristics of the analyzed photovoltaic panels are described in the Table 2 and Table 3.

Table 2
The amorphous photovoltaic panel U2 dynamic parameters (based on step characteristics)

Date	Model	Gain factor k	Time constant T_s	Time of delay T_d
26/09/2019	P1	0.0451	0.102	0
	P1D	0.0451	0.157	0
	P2DZ	0.045	9.32	1.73
	P2Z	0.0451	13.4	0
	P3DZ	0.0448	20.5	1.38
11/11/2019	P1	0.0492	0.451	0
	P1DZ	0.0492	3.19	0
	P1Z	0.0492	1.08	0

Table 3
The amorphous photovoltaic panel U4 dynamic parameters (based on step characteristics)

Date	Model	Gain factor k	Time constant T_s
15/11/2019	P2DZ	0.559	9.24
01/12/2019	P2Z	0.661	2.02
	P3Z	0.664	0.11
07/12/2019	P2DZ	0.612	4.14
	P3Z	0.614	0.559

The gain factor k is similar for the analyzed days for U2 panel (from 0.0451 to 0.0492) and for the U4 panel (from 0.559 to 0.664). There is no similarity in time constant T_s.

4. Conclusions

This report presents one of several examples of tests that have been carried out. The study shows that the process models, developed with the Matlab & Simulink System Identification Toolbox, made mostly really have high fits – over 80%. Most step characteristics of analyzed photovoltaic panels are an inertial type. There are different results for both panels on the following structure (U2) and for that horizontally mounted on the ground (U4). Both, the formulas of transfer functions and the dynamic parameters, are different.

For panel U2 the maximum value of T_s is 50.5 sec. For panel U2 the maximum value of T_s is about 9 sec. Time of the delay T_d is short for two days in U2 panel modeling. For U4 panel modeling the time of delay is equal to 0. The reaction of the voltage of the photovoltaic panel to changes in the irradiance is really fast. The models analyzed in the paper and their detailed results seems to support this conclusion.

However, the parameters of the models, i.e. gain factor, time constant, cut-off frequency, do not best reflect the dynamics of the analyzed photovoltaic panels, as the common sources indicate [15]. Ultimately, it can be concluded that more complex analyzes of the models with the highest fit should be performed and the model structure should be changed, e.g. by adding another input or output parameter.

5. Acknowledgements

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