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LOW VOLTAGE PV ARRAY MODEL VERIFICATION ON COMPUTER AIDED TEST SETUP

Low voltage photovoltaic (PV) array delivers electric power to the renewable energy systems which utilize step-up DC-DC converters. The performance of PV array is strictly dependent on environmental conditions such as solar radiation and ambient temperature. In this paper presented is MATLAB model of low voltage 3.2 kWp PV array composed of ten PV panels connected in parallel. The model itself is based on photodiode model and is supported by datasheet parameters of examined PV panels. Presented P-V curves show an influence of solar radiation and temperature on electric power produced by the array. The model simulation results were verified on computer aided laboratory test setup built upon LabVIEW environment. The test setup comprised PV array connected to 6 kW electronic DC load which was controlled by LabVIEW application. Since test conditions should be steady during test time each measurement of real PV array full P-V curve has to be done as quick as possible. This can be assured by computer aided measurement approach where time consumming tests can be easily automated and shortened. This paper presents PV array model, describes test setup and discusses laboratory test results.

KEYWORDS: PV module model, Photovoltaic Systems

1. INTRODUCTION

The new semiconductor technologies have slightly improve PV cells efficiency reaching up to 19%. Such relatively low amount of energy which comes from solar radiation should be carefully converted. Therefore the converter topology and its driving method should assure maximum efficiency. To achieve this goal P-V characteristics of PV array should be known prior to design effective maximum power point tracking (MPPT) algorithm [1].

Simulation model can help determining P-V curves (i.e. MPPT algorithm operation range). In this paper is presented PV array model based on datasheet parameters and its verification in the automated laboratory test setup.

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2. PV ARRAY

2.1. PV array description

Low voltage PV array is composed of ten KYOCERA KD320GH-4YB PV modules in parallel. The PV array is capable to produce 3.2 kW of peak power in Standard Test Conditions (STC) which are T = 25 ºC and S = 1000 W/m^2 of solar radiation at perpendicular direction. Total peak current generated in the panel I_{PV} reaches over 80 A at the voltage V_{PV} in the range of 40 V to 60 V. The amount of power generated in PV module strictly depends on environmental conditions which are solar radiation S [W/m^2], and ambient (precisely PV module) temperature T [ºC]. Because of nonlinear I-V and P-V characteristics PV module cannot be considered neither as voltage nor current source.

Table 1 collates main KYOCERA KD320GH-4YB module parameters [2] whereas in Table 2 are shown suplementary PV array parameters.

Table 1. Specification of KYOCERA KD320GH-4YB PV module (STC)

No	**Parameter**	**Designation [unit]**	**Value**
1.	Peak power	P_{max} [Wp]	320
2.	Open circuit voltage	V_{oc} [V]	49.5
3.	Short circuit current	I_{sc} [A]	8.60
4.	Maximum power point voltage	V_{pm} [V]	40.1
5.	Maximum power point current	I_{pm} [A]	7.99
6.	Open circuit voltage temperature coef.	μ_V [V/ ºC]	-0.178
7.	Short circuit current temperature coef.	μ_A [A/ ºC]	$5.16 \cdot 10^{-3}$
8.	Output power temperature coef.	μ_P [W/ ºC]	-1.45
9.	Number of PV cells within single PV module in series x in parallel	Ns x Np	20 x 4

Table 2. Supplementary parameters of the PV array

No	**Parameter**	**Designation [unit]**	**Value**
1.	Number of PV modules	N	10
2.	Total PV array peak output power	P_{max} [kWp] (STC)	3.2
3.	Total PV array series resistance	R_{ss} [mΩ]	60
4.	Total PV array shunt resistance	R_{pp} [Ω]	95
5.	50 m of 95mm^2 cross-sectional area copper electrical wire resistance	R_w [mΩ]	8.7

2.2. PV array model

Single PV cell can be presented as photodiode model depicted on Fig. 1 [3]. Major source of series resistance R_s is metal contact at the front grid of a PV cell. Shunt resistance R_p reflects PV cell leakage currents.

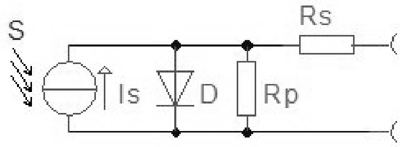

Fig. 1. Single PV cell model [3]

For PV array composed of N = 10 parallel modules the equation for I-V characteristic can be formulated as:

$$I_{PV} = N \cdot I_{SC} - N\{ I_{sat}[e^{\frac{q}{KT}(V_{PV} + R_{SS} I_{PV})} - 1] + \frac{V_{PV} + R_{SS} I_{PV}}{R_{pp}} \} \quad (1)$$

assumming identical diodes within the cells I_{SC} is short-circuit current of PV module, I_{sat} is diode saturation current, q is electron charge, K is Boltzman's constant and T is a PV module temperature. R_{pp} and R_{ss} are total parallel and series resistances seen at PV array output.

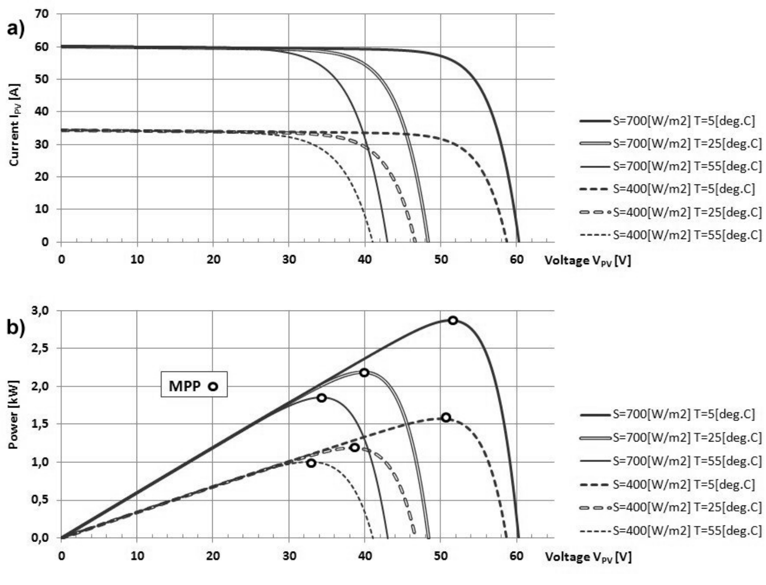

Fig. 2. The PV array a) I-V plots and b) corresponding P-V plots in different environmental conditions S and T

Fig. 2 depicts a range of I-V plots and P-V plots from the PV array MATLAB model for different environmental conditions. The simulation model is based on the assumptions that all PV modules are identical and are not shaded, also includes temperature coeffitients listed in Table 1 (items 6, 7 and 8).

On Fig. 2b outlined are maximum power points (MPP) for each P-V curve. Peak power P_{mp} (MPP) is reached when condition (2) is satisfied.

$$\frac{dP_{PV}}{dV_{PV}} = 0 \tag{2}$$

P-V curves are more informative than I-V curves in terms of amount of power generated by PV array. Moreover MPP is clearly visible on them. P-V curves provide sufficient data for most of maximum power point tracking (MPPT) algorithms [4] implemented within power electronic equipment which usually follows PV-array in whole PV system.

2.3. Series and shunt resistances influence on I-V curves

The rectangle delimited by V_{OC} and I_{SC} datasheet parameters provide the reference to define an operating range of a PV module. The fill factor (FF) is the measure of PV module quality and is always less than 1 (equation 3). The more I-V curve resembles square the better fill factor is.

$$FF = \frac{V_{pm} I_{pm}}{V_{0C} I_{SC}} = \frac{P_{pm}}{V_{0C} I_{SC}} \tag{3}$$

where V_{pm} and I_{pm} are voltage and current respectively at the MPP. P_{pm} is a peak power at the MPP.

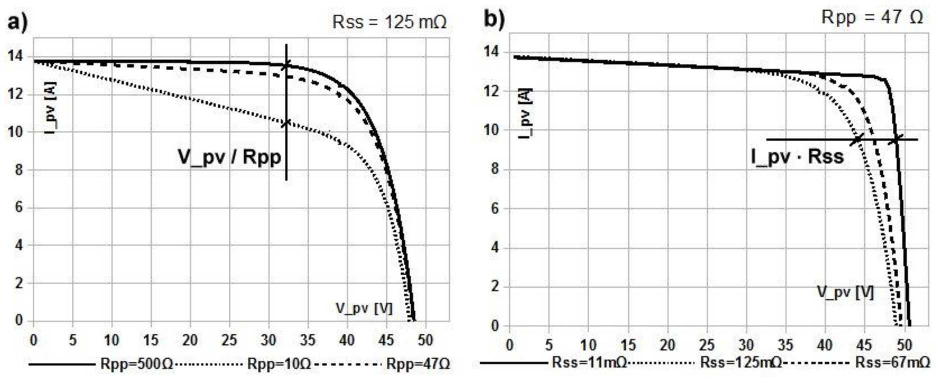

Fig. 3. I-V curve shape dependency on a) shunt resistance R_{pp} at fixed value of R_{ss} = 125 mΩ and b) series resistance R_{ss} at fixed value of R_{pp} = 47 Ω.

Both above mentioned array total shunt resistance R_{pp} and total series resistance R_{ss} are the major sources of fill factor degradation. We can see in equation (1) that the series resistance R_{ss} reduces short-circuit current I_{SC} whereas shunt resistance R_{pp} reduces open circuit voltage V_{OC} having no effect on short-circuit current. Fig. 3 depicts MATLB simulation of R_{pp} and R_{ss} influence on PV panel I-V curves.

3. MEASUREMENT SETUP

3.1. Measurement test setup description

The measurement setup consists of 6kW electronic DC load (EL 6000/400/200 [5]) driven through GPIB interface from LabVIEW application on a PC computer. Fig. 4 shows simplified diagram along with the measurement bench picture.

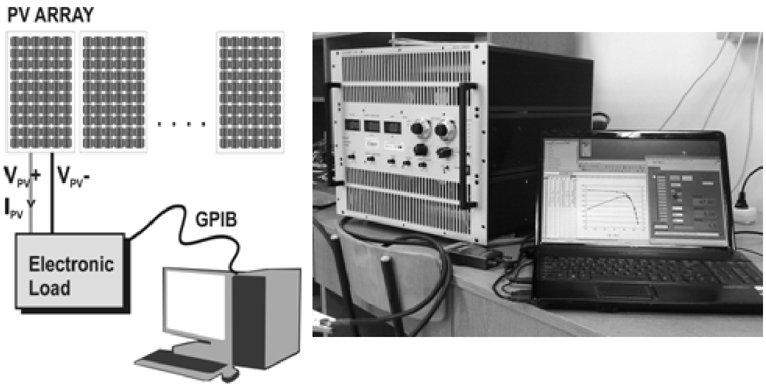

Fig. 4. Measurement setup: diagram and the laboratory bench picture

3.2. The LabView application

The electronic DC load acts as adjustable resistance. In presented LabVIEW application it was set to be used in constant current mode. Consecutive load current values can be set by user in „Set Currents" section (Fig. 5). Single PV array P-V curve measurement consists of each consecutive current value setting and immediate voltage, current and power readout. The data read is stored immediately in a spreadsheet file for the purpose of further analyses. Ambient temperature as well as solar radiation does not change rapidly. Single measurement consisting of 13 current settings lasts for no more than 3 seconds which leeds to assume that single measurement is carried out in settled environmental conditions. Current values of solar radiation and PV module temperature were read from auxilary equipment mounted near the PV array.

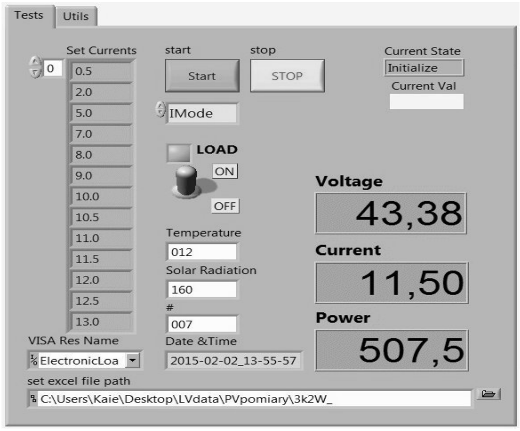

Fig. 5. The LabView application screenshot

4. TEST RESULTS

Fig. 6 shows test results for three values of peak power (i.e. P_{pm1} = 2000 W, P_{pm2} = 540 W and P_{pm3} = 300 W) corresponding to three solar radiations levels (S_1 = 600 W/m^2, S_2 = 160 W/m^2 and S_2 = 90 W/m^2 resprctively) at PV module temperatures of T = 21 ºC for P_{pm2} and T = 15 ºC for P_{pm2} and P_{pm3}. The R_{ss} and R_{pp} values were 60 mΩ and 95 Ω respectively. It can be seen that simulation based P-V curves are correlated with laboratory test results. Slight differences on the both sides from MPP reflect the influence of electrical wire resistance (Table 2, parameter no. 5) on the measurement results (not considered in the simulation) as well as R_{pp} and R_{ss} mismatches to real PV array resistance values.

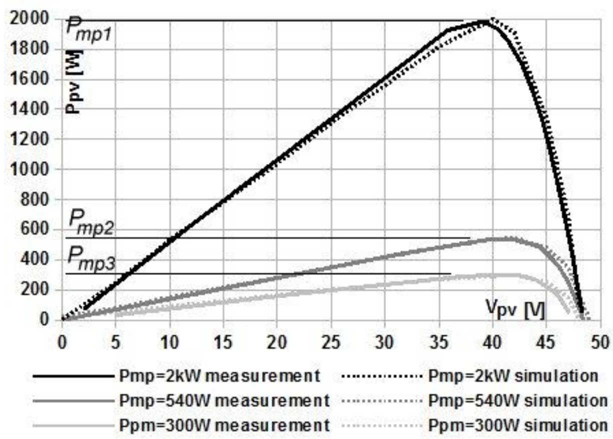

Fig. 6. Comparison plots between simulation results and laboratory measurements of PV array P-V curves

5. CONCLUSION

The I-V and P-V characteristics have been discussed to bring the understanding of performance of the PV array and to draw the inputs to design MPPT algorithms. Described was the influence of solar radiation and PV module temperature on PV array performance. Discussed were the impact of parasitic shunt and series resistances on a quality of the PV array. The simulation model reflects laboratory test results and it can be effectively accommodated to the simulations based on datasheet parameters of different PV arrays.

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