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Practical Calculation of Maximum Power Point Voltage for a Photovoltaic Converter

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ABSTRACT

The article presents a simple method for the approximate calculation of maximal power voltage for photovoltaic converters operating in a broad range of temperatures and electric load magnitudes. It has been demonstrated that maximal power voltage for single-transition AlGaAs-based photovoltaic converters is determined mainly by the open-circuit voltage and short circuit current. Practical algorithms for programming the radiation power control adjustment channel in systems supplying power to electronic devices by optical radiation have been obtained.

Key words: volt-ampere characteristic, photovoltaic converter, maximal power voltage.

1. INTRODUCTION

In solar power applications, the task of determining the optimal load at a given level of light flux providing operation of a photovoltaic panel at the maximal power point is resolved. Methods of resolving this task are well known [1]. Unlike this task, for designing high-voltage instrument transformers, in which the measuring electronic module must be powered by optical radiation [2], it is necessary to provide the maximal efficiency of the power supply system at a given load by selecting an optical power level providing operation of the photovoltaic converter (PVC) at the maximal power point. This article is dedicated to elaborating one of the possible solutions to this task.

The power supply system has a powerful source of radiation coupled with a fiber optic waveguide for transmitting it, a photovoltaic converter whose working parameters and conditions define the perfomance of the entire power supply system, voltage drivers providing the voltages necessary for the electronic equipment operation, and an optical feedback channel transmitting data on PVC operation mode for tuning the radiation source power [3]. From the energetical point of view, the most effective performance of the entire measurement system will be accomplished with the electronic device operating at the lowest supply voltage, which for state of the art hardware components is 2.5–3.3 V. In the present article, single-cell photovoltaic converters will be considered.

Their specific feature is the non-compliance of output voltage to parameters required for energy-efficient supply, which makes it necessary to use additional voltage converters in conjunction with them. For example, PVCs [4-5] have output voltages of 4/6-7/1V, and PVC [6] has an output voltage of 1.2V. This makes it necessary to use inductive voltage converters in conjunction with those PVCs, and a specific feature of those is significant current consumption in impulse mode. In this regard, to provide for reliable start-up of those converters, excessive optical power must be supplied to the PVC at the initial moment. If this power is not decreased at transition to stationary mode, the power supply system efficiency will be low, the PVC will be overheated by excessive optical power and the service life of the power supply system will be significantly shortened. The criterion of maximal power supply system performance is PVC operation at the maximal power point, which can be calculated from the PVC's voltage-current characteristic.

2. METHODS

The voltage-current characteristic (VAC) of a PVC, on the premise that shunt resistance is high, is to a great degree of precision described by the expression [7,8]:

$$I = I_{ph} - I_0\left(exp\left(\frac{e(U+IR_S)}{AkT}\right) - 1\right) = I_{ph} - I_0(\exp\alpha(U + IR_S) - 1), \qquad (1)$$

where $I_{ph} - SW$, S – current sensitivity of PVC

0.3-0.5A/W, W – radiation power, $\alpha = e/AkT = 1/U_T$, U_T– “«heat» voltage” (about 17 mV), R_S– series resistance of PVC (for real PVC's – from fractions of an Ohm to several Ohms), I_0 – p-n transition saturation current.

The key parameter for VAC calculation is saturation current I_0, which depends on the semiconductor material parameters (diffusion factor, carrier lifetime etc.) and is, as a rule, unknown. On the other hand, with known VAC parameters I_{sc} and U_{oc}, which are presented in reference data, it can be calculated according to formula [8, 9]:

$$I_0 = \frac{I_{sc}}{\exp(\alpha U_{oc}) - 1} \qquad (2)$$

Series resistance $R_s = \frac{\Delta U}{\Delta I} - (\alpha I_{sc})^{-1}$, where parameter $\frac{\Delta U}{\Delta I}$ is defined in the area $I = 0$. Figure 1 shows the VAC of a PVC based on an AL 118 LED at radiation power about 60 mW, from which according to the formulas above the values $I_0 = 1{,}78\ 10^{-12}\,A$, and $R_s = 1{,}16$ Ома were defined. Taking those values into consideration, the points on VAC calculated according to formula (1) are marked by crosses.

As seen from the figure, formula (1) correctly describes the PVC's VAC at low radiation power and can be used for calculating U_{MPP} – the maximum power point of PVC.

To define the voltage at which the PVC operates at the maximal power point, we mutiply (1) by U, differentiate the obtained expression by U and, equating the derivate to zero, obtain an equation for defining voltage at the maximal power point:

$$K(W,T) = x + \ln(1 + x) \qquad (3)$$

where $x = \alpha U_{MPP}$, $K(W,T) = \ln(SW/I_0 + 1) - \alpha I R_s$

At $I = 0$, as follows from (1) $\ln(SW/I_0 + 1) = \alpha U_{oc}$ and $K(W,T) = \alpha(U_{oc} - IR_s)$, where U_{oc} is the PVC open circuit voltage. This voltage is slightly dependent on decreasing power; for example, if at radiation power W_o which we conditionally accept as nominal, open circuit voltage is U_{oc0}, then at power $5W_o$ (considering that $SW/I_0 \gg 1$) this voltage will increase by value of $\alpha^{-1} \ln 5$, which at room temperature will amount to about 27 mV.

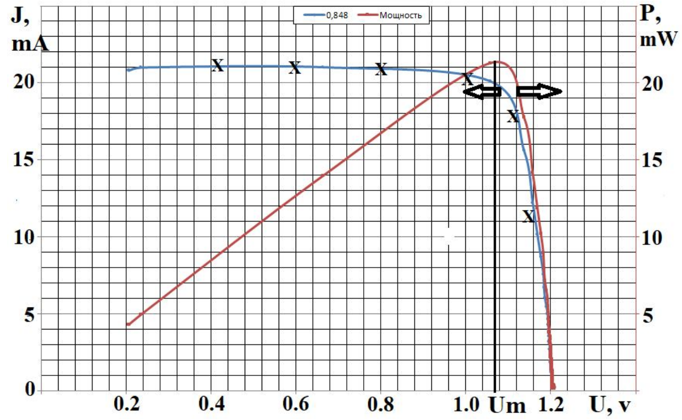

Figure 1: Experimental I(U) and P(U) dependencies for an AL118-based PVC at 60 mW radiation power

This value applies to single p-n transition PVCs, for multi-transition PVCs, for example AFBR-POCxx6L the idle voltage gain will amount to 0.11–0.14 V, which is approximately the same as observed in the characteristics provided by the manufacturer [4].

3. RESULTS

Let us evaluate the magnitude range of value $K(W,T)$, included in equation (3). For evaluation, let us accept: $T_{min} = 213\ ^oK$, $T_{max} = 333\ ^oK$, A=1 [7].

With change in temperature, voltage U_{oc} changes in a linear way from 1.35 ± 0.02 V (at − 60^o C to 1.21 ± 0.02 V at + 60^{o}C) [6], which is wit sufficient precision described by equation $U_{oc}(T) = 1.599 - 1.16 \cdot 10^{-3} T$ (temperature in Kelvin degrees). On condition $U_{oc} \gg IR_s$, which is almost always fulfilled, $K_{min}(U_{oc}, T_{max}) \approx 42$, and $K_{max}(U_{oc}, T_{min}) \approx 73{,}5$. For such values of K the solution of equation (3) will be within bounds of $x = (0{,}913 \div 0{,}942)K$. Since values of x do not differ by more than 4 % in the temperature range from −60 °C to +60 °C, let us approximate this function by a linear dependence: $x = 0{,}99625 - 2{,}5 \cdot 10^{-4} T$, where T is in Kelvin degrees. Also considering that at high values of equivalent shunt resistance in proximity ot the maximal power point $I \approx I_{sc}$, we obtain the final expression for defining the voltage corresponding to the maximal power of PVC:

$$U_{MPP} \approx (0{,}99625 - 2{,}5 \cdot 10^{-4} T) \cdot (U_{oc}(T) - I_{sc} R_s) \qquad (4)$$

Evaluation of U_{MPP} by formula (4) provides for a sample with characteristics presented in Figure.1 a value of 1.08 V, which practically matches the experimental value of U_{MPP} in Fig.1. It must be pointed out that the semi-empirical dependence (4) performs well not only for the considered PVC type, but for multi-transition PVCs, e.g. AFBR POC206-204, as well. Measured values of U_{oc} and U_{MPP}, as well as values calculated according to formula (4), are presented in Table 1. The calculation did not take into account the component with PVC series resistance, since, as follows from the measured characteristics of AFBR converters, their series resistance does not exceed 0.3–0.5 Ohm, which corresponds to a contribution to value of U_{MPP} not exceeding 0.01 V.

Table 1: Measured values of U_{oc} and U_{MPP}

AFBR206, No.	Power, mW	U_{oc}, meas., V	U_{MPP}, meas., V	U_{MPP}, calc., V
1	100	6.62	6.15	6.102
	500	6.8	6.36	6.268
2	100	6.6	6.1	6.085
	500	6.8	6.48	6.268
3	100	6.62	6.1	6.102
	500	6.79	6.38	6.26
4	100	6.63	6.2	6.113
	500	6.8	6.35	6.268
5	100	6.61	6.1	6.094
	500	6.79	6.36	6.26

Comparison of calculated and measured UMPP values shows that the maximal error of maximal power voltage definition does not exceed 3.5 %. This, considering the shallow sloping of curve P (U) in the vicinity of maximum, is quite acceptable for practical use of ratio (4) for automatic power tuning in optical power supply systems.

4. CONCLUSION

Thus, for automatic tuning of radiation power in an optical power supply system [2] it is sufficient to know the initial characteristics of the PVC - U_oc, I_sc, as well as current characteristics of PVC voltage and temperature for adjusting the optical radiation power providing a PVC voltage corresponding to the maximal performance of the photovoltaic converter.

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REFERENCES

1. D.A. Kozyukov, B.K. Tsygankov. **Charging-discharging controllers of solar photovoltaic power plant accumulator batteries.** *International scientific journal "Innovative science"* no. 8, p. 41, 2015.
2. A.A. Sokolovsky, A.V. Otchertzov, V.V. Moiseev. **A combined fiber optical voltage and current transformer of the 100kV class for digital measurement systems.** *Elektrichestvo* no. 12, pp. 26-30, 2015.
3. Sokolovsky A.A., Moiseev V.V., An optical system of power supply for electronic devices, patent RU 2 615 017, 03.04.2017 Bulletin No 10.
4. Bibliographic reference Manual for photovoltaic converter AFBR-POCxxxL-DS. 2019. Retrieved from: https://docs.broadcom.com/ doc/AFBR-POCxxxL-DS
5. Bibliographic reference Manual for photovoltaic converter YCH-L240. 2020. Retrieved from: http://www.mhgopower.com/images/PPC_Product_Brief_Rev_2.4_03-12-2020_EN.pdf
6. A.A. Sokolovsky. **Photovoltaic characteristics of LEDs based on AlGaAs**. Technical Physics Letters vol. 44 no. 4, pp. 341-343, 2018. https://doi.org/10.1134/S1063785018040259
7. A. Fahrenbruch, R. Bube. **Solar cells**. Moscow: Energoatomizdat, 1987.
8. M.M. Koltun. **Optics amd metrology of solar cells**. Moscow: Nauka, 1985.
9. V.F. Gremenok, M.S. Tivanov, V.B. Zalessky. **Solar cells based on superconductor materials.** Minsk: BSU publishing center, 2007.