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Analysis of series resistance and P–T characteristics of the solar cell

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Abstract

In this paper, based on the fact that the output power of a solar cell monotonically decreases with its temperature, we investigate the specific expression of the series resistance. Further, applying the specific expression of the series resistance, we analyze the relationship characteristics between the power and the temperature, and correspondingly present the operating temperature condition of the ideal maximal power.

Keywords: Solar cell; Series resistance; P–T characteristics

1. Introduction

The series resistance R_S of a solar cell is an important parameter that affects its efficiency. There are various methods for the measurement of such a resistance [1–6]. However, the theory expression of R_S is still unknown and has not been clearly disclosed in previous research. So the purpose of the paper is to present a method to determine the specific theory expression of the series resistance. Once we know the specific expression of R_S, we may obtain the characteristic curve of the output power with respect to its temperature of the solar cell, and get some significative conclusions.

2. Series resistance of the solar cell

At the steady state of I–V characteristics, the standard expression of the current density in the solar cell under the condition of a uniform illumination is generally described by [5]

$$I = m\phi - I_0(e^x - 1), \tag{1}$$

$$x = \frac{qI(R_L + R_S)}{AkT}, \tag{2}$$

where m is the photoelectric conversion factor, ϕ is the illumination intensity, I_0 is the reverse

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saturation current density, R_S is the series resistance, R_L is the load resistance, k is the Boltzmann constant, T is the absolute temperature, q is the elementary charge, and A is the diode ideal factor. And we define a new variable form

$$x_0 = \frac{qI_0(R_L + R_S)}{AkT}. \tag{3}$$

Generally, the output power of a solar cell is expressed by

$$P = I^2 R_L. \tag{4}$$

Taking the full differentials of Eqs. (1), (2) and (4), respectively, yields

$$\mathrm{d}I = m\,\mathrm{d}\phi - I_0 \mathrm{e}^x\,\mathrm{d}x, \tag{5}$$

$$\frac{\mathrm{d}x}{x} = \frac{\mathrm{d}I}{I} + \frac{\mathrm{d}R_L + \mathrm{d}R_S}{R_L + R_S} - \frac{\mathrm{d}T}{T}, \tag{6}$$

$$\mathrm{d}P = I^2\,\mathrm{d}R_L + 2IR_L\,\mathrm{d}I. \tag{7}$$

Combining Eqs. (5)–(7), we get the new full differential equation of the output power

$$\begin{aligned}\mathrm{d}P = {} & I^2\left(1 - \frac{2R_L}{R_L + R_S} \times \frac{x_0\mathrm{e}^x}{1 + x_0\mathrm{e}^x}\right)\mathrm{d}R_L \\ & + 2IR_L\,\frac{m\,\mathrm{d}\phi}{1 + x_0\mathrm{e}^x} + 2I^2R_L\,\frac{x_0\mathrm{e}^x}{1 + x_0\mathrm{e}^x} \\ & \times \left(\frac{\mathrm{d}T}{T} - \frac{\mathrm{d}R_S}{R_L + R_S}\right).\end{aligned} \tag{8}$$

Rewrite Eq. (8) as

$$\begin{aligned}\frac{\mathrm{d}P}{\mathrm{d}T} = {} & I^2\left(1 - \frac{2R_L}{R_L + R_S}\frac{x_0\mathrm{e}^x}{1 + x_0 e^x}\right)\frac{\mathrm{d}R_L}{\mathrm{d}T} \\ & + \frac{2IR_L m}{1 + x_0\mathrm{e}^x}\frac{\mathrm{d}\phi}{\mathrm{d}T} + \frac{2I^2R_Lx_0\mathrm{e}^x}{1 + x_0\mathrm{e}^x} \\ & \times \left(\frac{1}{T} - \frac{1}{R_L + R_S}\frac{\mathrm{d}R_S}{\mathrm{d}T}\right).\end{aligned} \tag{9}$$

In applications, it is a clear fact [7] that the output power P monotonically decreases with the temperature of the solar cell, that is,

$$\frac{\mathrm{d}P}{\mathrm{d}T} < 0. \tag{10}$$

There is an implicit condition in applications of Eq. (10) that is R_L and ϕ are constant with respect to the temperature T,

$$\frac{\mathrm{d}R_L}{\mathrm{d}T} = 0, \quad \frac{\mathrm{d}\phi}{\mathrm{d}T} = 0. \tag{11}$$

Hence, according to the condition of Eqs. (10) and (11), Eq. (9) may be simplified as

$$\begin{aligned}\left.\frac{\mathrm{d}P}{\mathrm{d}T}\right|_{R_L,\phi} = {} & \frac{2I^2R_Lx_0\mathrm{e}^x}{1 + x_0\mathrm{e}^x}\frac{1}{T} \\ & - \frac{2I^2R_Lx_0\mathrm{e}^x}{(1 + x_0\mathrm{e}^x)(R_L + R_S)}\frac{\mathrm{d}R_S}{\mathrm{d}T} < 0.\end{aligned} \tag{12}$$

Due to

$$2I^2R_L\,\frac{x_0\mathrm{e}^x}{1 + x_0\mathrm{e}^x}\,\frac{1}{T} > 0$$

R_S must be relevant to T. It means $\mathrm{d}R_S/\mathrm{d}T \neq 0$ must be satisfied. The analysis is significant to determine the specific theory expression of the series resistance.

As we know, there are only three types of thermal sensitive resistances [8]: conductor type, negative temperature coefficient type and positive temperature coefficient type. Consequently, the form of R_S, relevant to T, must belong to one of the above three types. In the following, we will discuss this issue in more detail, based on three types of thermal sensitive resistances.

Conductor type

$$R_S = R_0(1 + \alpha T), \tag{13}$$

where α is the conductor temperature coefficient ($\alpha > 0$) and R_0 is the condition resistance. We get

$$\begin{aligned}& \frac{\mathrm{d}R_S}{\mathrm{d}T} = \alpha R_0 > 0, \\ & \left.\frac{\mathrm{d}P}{\mathrm{d}T}\right|_{R_L,\phi} = \frac{2I^2R_Lx_0\mathrm{e}^x}{1 + x_0\mathrm{e}^x}\left(\frac{R_L + R_0}{R_L + R_S}\right)\frac{1}{T} > 0\end{aligned} \tag{14}$$

Eq. (14) contradicts the requirement of Eq. (12), so R_S does not belong to the conductor type.

Negative temperature coefficient type

$$R_S = R_0\mathrm{e}^{B/T}, \tag{15}$$