INVESTIGATION OF THE INFLUENCE OF LIGHT INTENSITY ON THE PHOTOELECTRIC PARAMETERS OF SILICON SOLAR CELLS

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ABSTRACT

This study investigates the influence of light intensity on the main photoelectric parameters of silicon solar cells. An analysis was carried out on the dependences of short-circuit current, open-circuit voltage, fill factor, and conversion efficiency on the level of incident radiation.

The physical processes of charge carrier generation and recombination, which determine the operation of solar cells under different illumination levels, are examined. It was established that the short-circuit current depends linearly on light intensity, whereas the open-circuit voltage follows a logarithmic relationship. It is shown that variations in illumination give rise to nonlinear effects associated with internal losses and the parameters of the p–n junction.

The research results make it possible to identify the factors limiting the efficiency of silicon solar cells and may be used in the optimization of photovoltaic systems.

***Keywords**: solar cell, light intensity, photocurrent, open-circuit voltage, fill factor, efficiency.*

INTRODUCTION

Under conditions of rapidly growing global energy consumption and increasing environmental challenges, the development of renewable energy sources has become especially significant. The limited availability of traditional energy resources, together with the need to reduce greenhouse gas emissions, stimulates the active implementation of alternative energy technologies. In this context, photovoltaic systems based on the conversion of solar energy into electrical energy occupy one of the key positions in modern power engineering.

Among the various types of photovoltaic converters, silicon solar cells have become the most widely used due to their technological maturity, high reliability, and comparatively low production cost. Silicon, as a semiconductor material, possesses optimal physical properties that ensure efficient generation and transport of charge carriers under the influence of solar radiation.

However, the efficiency of silicon solar cells is largely determined by their operating conditions. One of the key factors affecting photoelectric characteristics is the intensity of incident solar radiation. Under real operating conditions, the illumination level can vary over a wide range depending on the time of day, geographical location, atmospheric conditions, and seasonal factors.

Variations in light intensity have a complex effect on the main photoelectric parameters of solar cells, such as short-circuit current, open-circuit voltage, fill factor, and conversion efficiency. Both linear and nonlinear relationships are observed, caused by the complex interaction of charge carrier generation, recombination, and transport processes within the semiconductor structure.

Particular interest is associated with analyzing the influence of light intensity on the parameters of the p–n junction, since this element determines the efficiency of separating photogenerated charge carriers. As the illumination intensity increases, the concentration of nonequilibrium carriers rises, leading to changes in recombination currents and consequently affecting the shape of the current–voltage characteristic.

It should be noted that under low illumination conditions, the relative influence of parasitic effects, such as leakage currents through shunt resistance and recombination losses, becomes more significant. At the same time, under high illumination levels, thermal effects and increased internal losses begin to play an important role, which may lead to a reduction in energy conversion efficiency.

Thus, investigating the influence of light intensity on the photoelectric parameters of silicon solar cells represents an important scientific task aimed at deepening the understanding of physical processes in photovoltaic converters and improving their efficiency under real operating conditions.

Theoretical Foundations

The operation of a silicon solar cell is based on the internal photoelectric effect, in which the absorption of photons with energies exceeding the silicon band gap leads to the generation of electron–hole pairs. Under the influence of the built-in electric field of the p–n junction, these charge carriers are separated, forming a photocurrent.

The functioning of a solar cell is described using an equivalent circuit that includes a photocurrent source, a diode, as well as series and shunt resistances. Such a model makes it possible to account for both ideal and real processes occurring within the semiconductor structure.

The fundamental current–voltage characteristic equation is expressed as follows:

$$I = I_{ph} - I_0 \cdot \left(\exp\left(q \cdot \frac{V + I \cdot R_s}{n \cdot k \cdot T}\right) - 1\right) - \frac{V + I \cdot R_s}{R_{sh}}$$

Where

I_{ph}— photocurrent,

I_0— saturation current,

R_s and R_{sh}— series and shunt resistances,

n— ideality factor.

The short-circuit current is determined by the following expression::

$I_{sc} \approx I_{ph} \sim G$

where G is the light intensity.

The open-circuit voltage is defined as:

$$V_{oc} = \left(n \cdot k \cdot \frac{T}{q}\right) \cdot \ln\left(\frac{I_{ph}}{I_0} + 1\right)$$

Thus, an increase in light intensity leads to a rise in photocurrent and, consequently, to changes in all photoelectric parameters.

Research Methodology and Modeling

To investigate the influence of light intensity on the photoelectric parameters of silicon solar cells, a numerical simulation method based on a single-diode equivalent circuit model was used.

Within the framework of the simulation, the light intensity was varied, which is equivalent to changing the photocurrent I_{ph}. At the same time, the remaining model parameters, such as saturation current, ideality factor, as well as series and shunt resistances, were assigned in accordance with typical values for silicon solar cells.

The simulation makes it possible to reproduce current–voltage characteristics under various illumination conditions and to analyze changes in the key parameters. Particular attention was paid to the investigation of transient operating conditions under low and high illumination levels, where nonlinear effects become apparent.

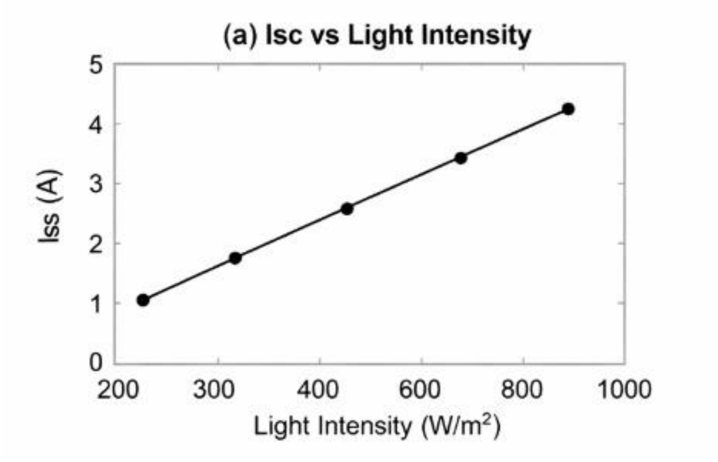
During the simulation process, the following dependences were obtained:

short-circuit current versus light intensity;
open-circuit voltage
fill factor
conversion efficiency.

The obtained data are presented in the form of graphical dependences and are used for subsequent analysis.

Results and Discussion

Figure 1 (a–d) presents the dependences of the main photoelectric parameters of a silicon solar cell on light intensity



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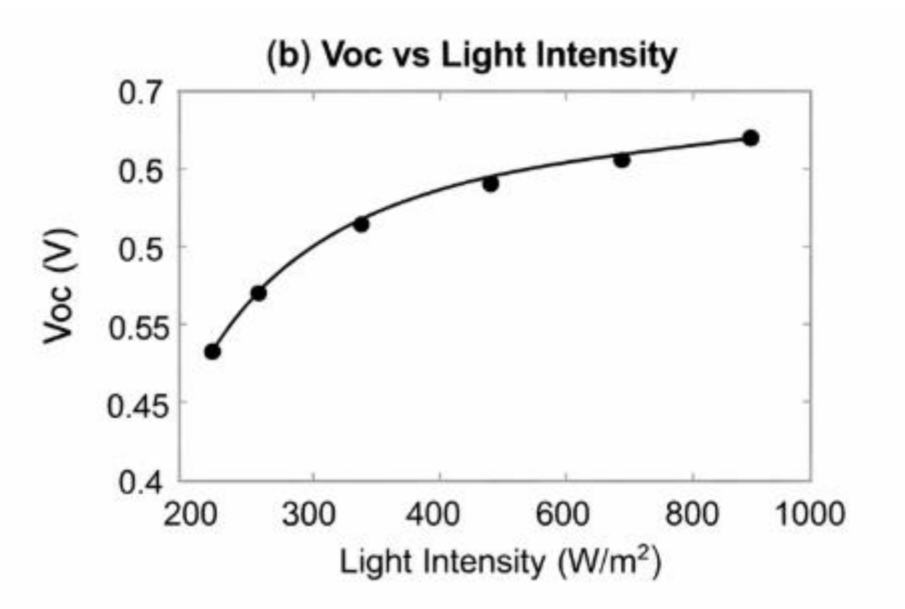

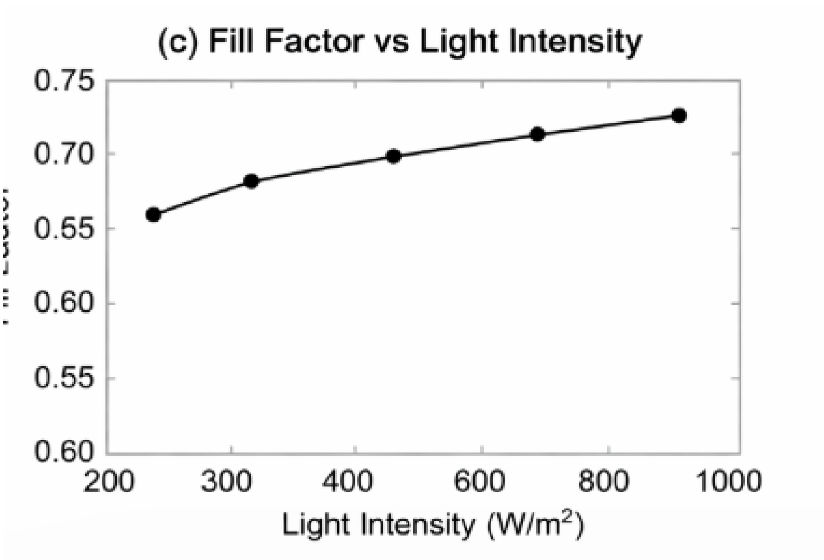

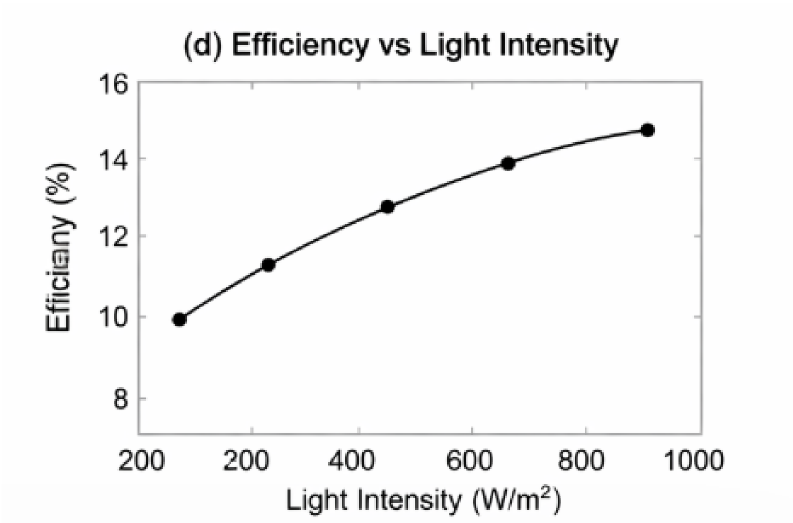

Figure 1 – Dependence of photoelectric parameters on light intensity:

a) short-circuit current;

b) open-circuit voltage;

c) fill factor;

d) conversion efficiency.

Figure 1a shows that the short-circuit current increases almost linearly with increasing light intensity. This is due to the fact that as the density of incident radiation increases, the number of generated electron–hole pairs in the semiconductor also rises, leading to an increase in photocurrent.

The analysis of Figure 1b shows that the open-circuit voltage increases much more slowly and follows a logarithmic dependence on light intensity. This behavior is associated with the exponential dependence of diode current on voltage and the enhancement of recombination processes at high illumination levels.

Figure 1c indicates that the fill factor increases with increasing illumination intensity. This can be explained by the improvement in the shape of the current–voltage characteristic and the reduction in the relative influence of internal losses as the photocurrent increases.

As can be seen from Figure 1d, the conversion efficiency increases with increasing light intensity. However, at high illumination levels, a tendency toward saturation is observed due to increased internal losses and thermal effects.

CONCLUSION

In this work, a comprehensive study of the influence of light intensity on the photoelectric parameters of silicon solar cells was carried out based on theoretical analysis and numerical simulation.

It was established that the short-circuit current increases linearly with increasing light intensity, whereas the open-circuit voltage demonstrates a logarithmic dependence. It was shown that the fill factor and conversion efficiency significantly depend on the illumination level and the internal parameters of the solar cell.

It was revealed that under low illumination conditions, the influence of recombination losses and parasitic resistances increases, whereas under high illumination levels, thermal effects and characteristic saturation begin to play a significant role.

The obtained results provide a deeper understanding of the physical processes occurring in silicon solar cells and may be used to optimize their performance under real operating conditions.

The practical significance of this work lies in the possibility of applying the obtained dependences in the design and optimization of photovoltaic systems, as well as in the development of new high-efficiency solar cells.

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