Journal of Engineering Research and Reports

Volume 25, Issue 6, Page 77-83, 2023; Article no.JERR.102212
ISSN: 2582-2926

Factors Affecting the Efficiency of Photovoltaic System

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2023/v25i6924

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/102212

Review Article

Received: 24/05/2023
Accepted: 02/07/2023
Published: 18/07/2023

ABSTRACT

The world's most important source of energy is the sun. The solar heating energy is the main energy source that affects the physical formations in the earth and atmosphere system. Matter and energy flows in the world are possible thanks to solar energy. Wind, sea wave, temperature difference in the ocean and biomass energies are modified forms of solar energy. Solar energy also plays a role in the realization of the water cycle in nature and creates the power of the stream. Solar energy, which is the origin of most of the natural energy sources, is directly used for purposes such as heating and electricity generation.

One of the strategic goals of developed and developing countries is expanding the use of energy resources. Solar energy is almost the most widely used of alternative energy sources.

In the presented article, the factors influencing the efficiency of the photovoltaic system have been determined in order to achieve effective results in the construction of the photovoltaic system. Based on the obtained indicators, it is aimed to build a photovoltaic system based on a GaAs photocell with 75% efficiency in the educational building.

Aims: The goal is to use solar panels to ensure continuity of energy supply in educational buildings. Initially, it was considered to determine the parameters that will affect the efficiency of the solar panel system used.

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Keywords: Energy; photovoltaic systems; photovoltaic elements; solar pane; photovoltaic cell.

1. INTRODUCTION

Energy has become one of the most important problems of the whole world in our time. In recent times, high energy consumption and depletion of fuel sources have increased interest in renewable (solar) energy. Photovoltaic power is a technology that has seen tremendous growth in its use over the past 10 years. The use of solar energy is more suitable for countries with many sunny hours [1-3].

The ongoing wars and occupations are the reflection of the global energy problem on people. Energy is not only a means to satisfy people's demands, but has already become a form of power that directs politicians on the international platform [4-7].

From the point of view of ecological stability, it is extremely important to use alternative energy sources to ensure human living, especially in cities where demographic growth is at its peak. The use of solar energy is at the top of the list of energy sources that residential facilities can benefit from. Solar energy is a clean and inexhaustible source of energy for our world [8-12].

1.1 Photovoltaic Systems

Photovoltaic cells (photocells) are electronic systems that convert sunlight directly into electrical energy without moving mechanical parts, are very easy to maintain and have a long service life. The French physicist Becquerel observed for the first time in 1839 that the voltage between the electrodes placed inside the electrolyte depends on the light falling on the electrolyte. Becquerel explained the photoelectric effect in this way: "Light, which is a form of energy, enters the photovoltaic element and produces the energy that will move the electrons. This energy creates a voltage capable of generating an electric current of electrons." Photovoltaic cells have been improved in parallel with the development of semiconductor technology. Here, depending on the properties of the semiconductor material, solar radiation is converted into electrical energy with high efficiency [13,14].

Initially, photovoltaic cells were used, which worked like semiconductor diodes. In these photovoltaic elements, the energy carried by the sun's rays is directly converted into electrical energy with the help of the photoelectric phenomenon. Depending on the structural characteristics of the photovoltaic cells, solar energy performed energy conversion with an efficiency of between 5% and 20%.

The surfaces of photovoltaic elements are mostly made with quadratic, rectangular and circular structures. Areas of photovoltaic elements are 60-160 cm2, and their thickness varies from 0.2 to 0.4 mm. In order to increase the output power, a large number of photocells are connected in series and parallel and assembled in the form of a module.

Photovoltaic modules are mainly obtained by combining 48, 60 or 72 photocells and placed between two layers (ethylene vinyl acetate layer) that are not affected by solar rays (Fig. 1). High optical transmittance glass is placed on the upper surface of the module. They are surrounded by an aluminum frame in order to protect the glass material and increase the stability of the system.

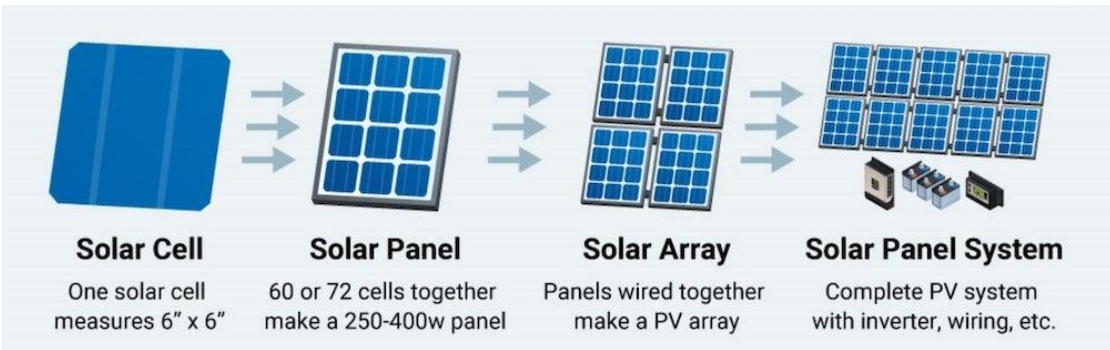

Fig. 1. Photovoltaic elements, modules and arrays

2. MATERIALS AND METHODS

The circuit shown in Fig. 2 is used to calculate the operating parameters of photovoltaic elements. When the photocell is included as an element in the circuit, the electric charges flowing from the elements outside the circuit are the source of the photocurrent obtained directly from the solar energy. When the photovoltaic element is inserted into the circuit, the electric current begins to circulate (Fig. 2) [15].

In Fig. 2, I_{PH} is the current flowing under the influence of photons, R_S is the resistor connected in series, R_{SH} is the resistor connected in parallel, I is the output current of the photovoltaic element, and V is the voltage generated at the output of the photovoltaic element. In a photovoltaic cell, the photon current is at its highest value in sunny outdoor conditions. In cloudy and dark weather, depending on the incoming rays from the sun, the amount of photons also decreases. In addition to these, a decrease in short-circuit current is observed in cloudy weather. As a result of the analysis of the electrical circuit model given in Fig. 2, the current flowing from the output of the photovoltaic cell

$$I = I_{ph} - I_0\left(e^{-\frac{q(V+IR_S)}{nkT_S}} - 1\right) - \left(\frac{V+IR_S}{R_{sh}}\right) \quad (1)$$

is determined by the expression [15-20].

Here you need to pay attention to one parameter. This parameter is one of the main parameters affecting the productivity of the photovoltaic element. The part of the rays entering the photovoltaic element that is not converted into energy is removed from the photoelement as heat energy. T_{nom} photocell temperature is 20^0C room environment (T_{room}), exposed to 800 $W/m2$ radiation for 1 $^m/_{san}$. Then T_C we can determine the temperature of the photocell with the following expression.

$$T_C = T_{room} + \frac{T_{nom}-20}{0.8} \cdot G \quad (2)$$

The approach of high efficiency of photovoltaic elements at high temperature is wrong. Photovoltaic cells are more efficient at low temperatures and high irradiance. It is possible to determine the relationship between solar radiation and temperature using simple empirical expressions. The influence of the temperature effect on the productivity of photovoltaic sources in cloudy weather can be determined based on these expressions. It was determined that the increase in temperature leads to a decrease in the productivity of photovoltaic elements. It can be concluded that by reducing the temperature, we can increase the efficiency of photovoltaic elements.

We can use this method to determine the main characteristics of photovoltaic elements, just as the volt-ampere characteristic is determined to investigate the main characteristics of other electronic devices and the effects they create in the circuit. Various methods are used to establish the volt-ampere characteristic of photovoltaic cells.

1. By switching the variable resistor exposed to constant light intensity between open circuit and short circuit modes, measuring the current flowing in proportion to the voltage across the photocell terminals;
2. Photocells in a dark environment with the help of a constant current source, as if operating it as a diode;
3. By connecting the light source that varies the intensity to the work and measuring the V_{OC} and I_{SC} parameters.

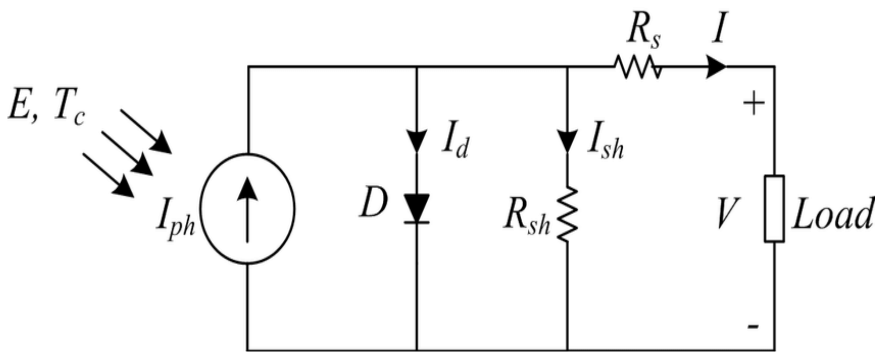

Fig. 2. Electric circuit model of a photovoltaic cell

Open circuit voltage (V_{OC}); The open circuit voltage of any photocell is the voltage that can be measured across the cell's terminals when the current flowing through the photocell is zero [19,20,21].

Short circuit current (I_{SC}); the short-circuit current of any photocell is the current flowing through the photocell at zero voltage and under illumination. In ideal cases where parallel resistor effects are not taken into account, the current is equal to the intensity and depends on the intensity of the light [19,20,21].

The productivity of photovoltaic elements and modules has a completely separate meaning. The efficiency of an individual photovoltaic cell is higher than the efficiency of a photovoltaic module. The conversion of solar energy takes place with an efficiency varying from 5% to 20%, depending on the structure of the solar cell. The yield of semiconductor elements varies from 10% to 30% in laboratory conditions, and from 5% to 20% in an experimental environment. In experimental applications, the selection of a photovoltaic cell with an efficiency of 15% is considered quite good.

As a result of general empirical studies, the factors affecting the productivity of the photovoltaic system were determined as follows [22,23,24]:

- Structural material of photovoltaic element;
- VAX of photovoltaic element;
- Characteristics of food control circuit;
- Productivity of the converter and the accumulator;
- Thickness of current carrying wire used.

As we mentioned, the efficiency of the photocell and the efficiency of the module are different. For example, the efficiency of a monocrystalline silicon photocell is 24%, while the efficiency of a module varies between 13% and 17%. The efficiency of the polycrystalline silicon photocell is 24%, while the efficiency of the module varies between 11% and 15%. This is due to the presence of non-conductive surfaces between the photocell arrays. These surfaces are considered as yield-reducing effects in the yield calculation. Table 1 provides a comparison of photovoltaic elements with different structures based on data collected from various literatures.

The power generated in a photovoltaic system depends on many parameters. Factors such as the characteristics of the elements that make up the photovoltaic system, the geographical location of the system, the existing objects in the place of installation of the system, the area of the module, the cost of the rays falling on the surface of the module, the angle of inclination of the module, the temperature of the module and the environment, and the wind speed can be cited as examples. If we generalize, we will get the following diagram according to the degree of influence on the productivity of the system (Fig. 3).

2.1 Factors Affecting Energy Conversion

William Shockley and Hans Queisser conducted the first research work devoted to determining the factors affecting energy conversion in 1961. In physics, the Shockley-Queisser limit, stability limit, or Shockley Queisser effective limit defines the highest theoretical efficiency of a photovoltaic cell consisting of a p-n junction to harvest power from a photovoltaic cell. This calculation was first performed by William Shockley and Hans-Joachim Queisser. The Shockley-Queisser boundary is calculated as a function of the amount of electrical energy produced proportional to each photon of incoming solar radiation. The limit is one of the most important criteria in electricity production based on the photoelectric effect from solar energy [25-28].

Table 1. Comparison of different types of photovoltaic cells

Photovoltaic technology		Photocell efficiency (%)	Module efficiency (%)
Crystalline Silica	Monocrystalline silicon	25	14-15
	Polycrystalline silicon	21,3	14-16
Thin film	Amorphous silicon	13,6	6-9
	Cadmium tellurium	22,1	9-12
	CIS/CIGS	22,3	8-14

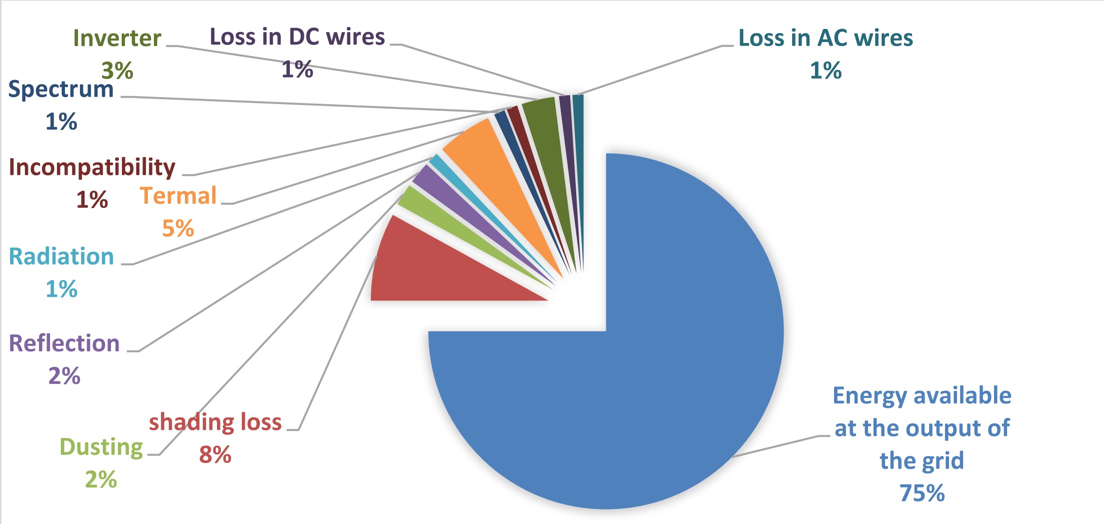

Fig. 3. Percentage distribution of losses in the photovoltaic system

A p-n junction with a cut-off energy band of 1.34 eV is determined to have the highest efficiency of about 33.7% in converting solar energy into electrical energy under the AM-1.5 solar spectrum condition. In other words, when an ideal photovoltaic cell is exposed to 1000 W/m² of solar radiation, only 33.7% of the solar energy, i.e. 337 W/m^2, is converted into radiation electricity in the photocell exposed to this radiation. Semiconductor silicon, which is widely used as a photovoltaic cell material, has an energy of 1.1 eV and the highest efficiency is 32%. The energy conversion efficiency of modern monocrystalline photovoltaic cells is about 24%. Losses in energy conversion are caused by front surface scattering and light "absorption" in very small diameter wires placed on the surface.

3. RESULTS AND DISCUSSION

The energy conversion efficiency of photovoltaic cells has been the object of research by various researchers for many years. For polycrystalline silicon photovoltaic cells used in practical applications, the energy conversion efficiency ranges from 14% to 19%. At the same time, in order to increase solar energy, it is necessary to increase the intensity of the sun's rays by focusing them. If the light intensity is increased, the energy carriers produced by the light increase and the productivity increases up to 15%. As a result of the development of GaAs elements with high productivity, these systems, which are called intensifying systems, have started the stage of economic competition. The intensification process is typically accomplished using intensifying optical lenses. A typical intensifier system has the ability to increase the light intensity by 6-400 times that of the sun. Note that as a result, the yield of GaAs elements increased from 31% to 35%.

The surfaces of photovoltaic elements absorb a small part of the energy of the sun's rays and convert it into galvanic energy. Another part of the radiation is reflected by photovoltaic elements. To reduce the proportion of reflected rays, attention is paid to the type of material covering the surface of the photocell. Various photovoltaic elements are used to increase the absorption of radiation. In environments where the temperature is high to a large extent, photovoltaic elements made of single crystal are more productive than elements made of polycrystal.

4. CONCLUSION

The intensity of radiation and the inclination angles of photovoltaic modules directly affect the output power of the photovoltaic system. A decrease in the intensity of the sun's rays or entering the photocell at a certain angle reduces the output power of the photovoltaic system. Contrary to what is thought, the productivity of the photovoltaic system does not increase with the increase in temperature. As a result of the heating of photovoltaic elements, the value of the current increases, while the voltage decreases. Since this drop in voltage is greater than the current, it also causes a noticeable drop in output power. As a result, we can say that the amount of energy produced in the photovoltaic system decreases due to high ambient temperature values.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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