SOLAR CELL EFFICIENCY

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After the global energy crisis in the 70s of the last century, the development of unconventional and renewable energy began. Currently, the total capacity of operating power plants based on renewable energy sources is about 600 GW, which is almost twice the capacity of all operating nuclear power plants in the world. [1]. On the territory of the Central Asian region, the priority areas of research in the field of solar energy are:

1. Improvement of solar power plants (SPP), allowing to generate electrical and thermal power on an energetically significant scale without negative impact on the ecological environment [2];
2. Experimental research and practical application of solar parabolic cylindrical power plants [3];
3. Developments for the widespread use of heat pipes as a heat sink for solar parabolic cylindrical installations [4];
4. Research to improve the efficiency of photoelectric conversion (solar flux, ambient temperature, wind speed, optimal system load matching) [5];
5. Development and improvement of existing hybrid structures for air, water cooling, heat removal from panels, with forced cooling [6].

In the automated systems for measuring the energy indicators of the above solar systems, certain structures and algorithms are formed, which consist of the following main parts:
object of research - solar energy system;
sensor;
secondary, microprocessor device;
actuating mechanism;
experimental data logger.

The measuring system of experimental data consists of functionally combined measures, measuring instruments, measuring transducers, computers, other hardware and software modules installed to measure one or more energy quantities. The main task of measuring systems is to generate measuring information signals in a form most convenient for automatic processing and control, transmission and use in registration systems [7, 8].

The efficiency of a solar cell is directly related to the current-voltage characteristic (CVC) of the solar cell. Two characteristic parameters are distinguished for it – no-load voltage ($V_{o.c.}$), at which the current is zero and short-circuit current ($I_{s.c.}$), at which the voltage is zero. These are the CVC values at which the power of the solar cell is equal to zero. I_{max} and V_{max} are the maximum current and voltage values that determine the maximum power. Figure 1.1 shows an example of the CVC of a solar cell.

Solar cell open circuit voltage $V_{o.c.}$ (see figure 1.1) corresponds to the voltage at the open terminals of the photocell ($R = \infty$). It can be found by taking $I = 0$.

$$V_{o.c.} = \frac{kT}{e}\ln\left(\left(\frac{I_{ph}}{I_s}\right)+1\right) \quad (1.1)$$

$$V_{o.c.} = \frac{kT}{e}\ln\left(1+\frac{e\gamma\beta S I_r}{h\nu I_s}\right) \quad (1.2)$$

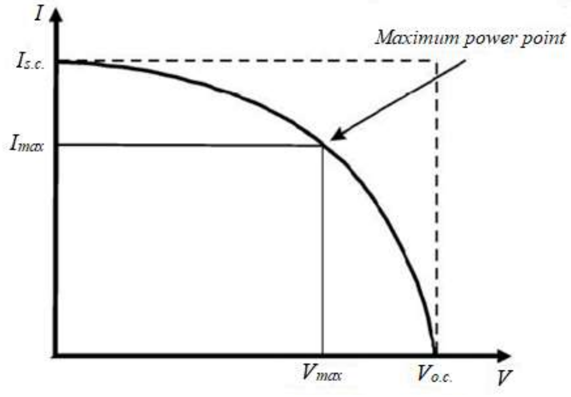

Figure 1.1 – Current-voltage characteristic of the solar cell

From expressions (1.1) and (1.2) it follows that the open-circuit voltage can be increased by increasing the ratio of photocurrent to saturation current (dark saturation current) $\frac{I_{ph}}{I_s}$, this can be achieved by reducing the dark current, either by increasing the doping level of the substrate, or by increasing lifetime of nonequilibrium charge carriers [9].

It also follows from (1.2) that the open-circuit voltage depends on the level of illumination. At a high level of illumination $\frac{I_{ph}}{I_s} \gg 1$, we have:

$$V_{o.c.} = \frac{kT}{e}\ln\left(\frac{e\gamma\beta SI_r}{h\nu I_s}\right) \qquad (1.3)$$

At a low level of illumination, when $\frac{I_{ph}}{I_s} \ll 1$, using expansions in a Taylor series, we get:

$$V_{o.c.} = kT\left(\frac{e\gamma\beta SI_r}{h\nu I_s}\right) \qquad (1.4)$$

Thus, at a low level of illumination, the open-circuit voltage is proportional to the light intensity.

The maximum output power generated by the solar cell is indicated in Figure 1.1 by the dot $P_m = I_m V_m$. Where I_m, V_m corresponding to the maximum generated power values of current and voltage. The output power is:

$$P = IV = I_s V\left(\exp\left(\frac{qV}{kT}\right) - 1\right) - I_{ph}V \qquad (1.5)$$

Differentiating $\frac{dP}{dV} = 0$, we obtain the maximum power condition.

$$V_m \approx V_{o.c.} - \frac{kT}{q} \qquad (1.6)$$

$$I_m \approx \frac{eI_sV_m}{kT}\exp\left(\frac{qV_m}{kT}\right) \approx I_{ph}\left(1 - \frac{kT}{eV_m}\right) \qquad (1.7)$$

The values of V_m and I_m are in the ranges $I_m = (0.85 - 0.95)\, I_{s.c.}$, $V_m = (0.75 - 0.9)\, V_{o.c.}$.

The maximum output power is given by:

$$P_m = I_m V_m \approx I_{ph}\left(V_{o.c.} - \frac{kT}{e}\ln\left(1+\frac{eV_m}{kT}\right) - \frac{kT}{e}\right) = I_{ph}\left(\frac{E_m}{e}\right) \qquad (1.8)$$

where,

$$E_m = e\left(V_{o.c.} - \frac{kT}{e}\ln\left(1+\frac{eV_m}{kT}\right) - \frac{kT}{e}\right) \qquad (1.9)$$

The value E_m corresponds to the maximum energy released in the load when one photon is absorbed with the condition of optimal matching of the photocell with the external circuit. Since the value of E_m depends on I_s, it depends on the parameters of the material (for example, τ, D, doping level). The ideal conversion efficiency is realized with the optimal choice of material parameters, when the value of I_s is minimal [9].

An important parameter characterizing the quality of solar cells is the fill factor of the current-voltage characteristic ξ:

$$\xi = \frac{I_m V_m}{I_{s.c.} V_{o.c.}} \qquad (1.10)$$

From (1.10) it follows

$$P_m = \xi I_{s.c.} V_{o.c.} \qquad (1.11)$$

The CVC fill factor shows how the real CVC of a solar cell differs from the CVC with voltage $V_{o.c.}$

The fill factor for silicon solar modules with a *p-n*-junction is in the range of 0.75 ... 0.85, for modules based on *GaAs* – in the range of 0.79…0.87 [9].

The efficiency is equal to the ratio of the maximum power to the power of the incident radiation:

$$\eta = \frac{P_m}{P_r} = \frac{I_m V_m}{P_r} = \frac{\xi I_{s.c.} V_{o.c.}}{P_r} \qquad (1.12)$$

The main task of solar energy is to increase the maximum efficiency of photovoltaic converters, but all types of solar cells have a limitation in efficiency. There are several ways to determine the maximum theoretical efficiency [10-11]. The Shockley-Queisser limit [11] is mainly used. More than 60 % of photons of solar radiation have energy unsuitable for the excitation of free charge carriers in a photocell. The energy that could not be converted into electricity is used to heat the solar module. It is possible to overcome the Shockley-Queisser limit with the help of serial and parallel division of the solar spectrum into subranges. At the moment, the production of such solar cells is much more expensive and more complicated in terms of technology.

Factors affecting the decrease in efficiency:

1. Reflection of solar radiation incident on the surface of the solar module.
2. Shading of the light-sensitive surface of the photoconverter with a contact grid.
3. Overheating of the solar cell leads to a decrease in voltage.

Literature

1. Нигматов, У. Ж., & Наимов, Ш. Б. (2020). Анализ потенциала использования энергии солнечного излучения на территории республики Таджикистан. In *International scientific review of the technical sciences, mathematics and computer science* (pp. 59-71).
2. Эргашев, С. Ф., Нигматов, У. Ж., Абдуганиев, Н. Н., & Юнусов, Б. С. А. (2018). Солнечные параболоцилиндрические электростанции-современное состояние работ и перспективы использования их в народном хозяйстве Узбекистана. *Достижения науки и образования*, (5 (27)), 6-8.

3. Эргашев, С. Ф., & Нигматов, У. Ж. (2020). Солнечные параболоцилиндрические установки, конструктивные особенности и расчёт отдельных параметров. *Universum: технические науки*, (11-5 (80)), 51-56.
4. Ергашев, С. Ф., & Нигматов, У. Ж. (2021). Солнечные параболоцилиндрические установки, конструктивные особенности и расчет отдельных параметров. *Журнал Сибирского федерального университета. Техника и технологии*, *14*(1).
5. Эргашев, С. Ф., Нигматов, У. Ж., & Пулатов, Э. У. У. (2018). Анализ перепадов температур, возникающих в тепловых трубах солнечных параболоцилиндрических установок. *Проблемы науки*, (5 (29)), 18-21.
6. Эргашев, С. Ф., Нигматов, У. Ж., Орипов, А., & Ощепкова, Э. А. (2019). Энергоэффективный трекер без использования светозависимых датчиков (Фоторезисторов, фотодиодов и тд). *Известия Ошского технологического университета*, (3), 234-236.
7. Нигматов, У. Ж. (2020). Анализ конструктивных элементов охлаждения гибридных солнечных коллекторов. *Вестник науки и образования*, (2-3 (80)).
8. Рахимов, Р. Х., Эргашев, С. Ф., Абдурахмонов, С. М., & Нигматов, У. Ж. (2017). Автоматизированная компьютерная система измерения производительности солнечных водонагревателей с порционной подготовкой горячей воды. *Computational nanotechnology*, (1), 23-26.
9. Rakhimov, R. K., Irgashev, S. F., Abdurakhmanov, S. M., & Nigmatov, U. J. (2017). The automated computer system of measurement of productivity of solar water heaters from portion preparation of hot water. *Computational nanotechnology*, (1), 23-26.
10. Афанасьев, В. П., Теруков, Е. И., & Шерченков, А. А. (2011). Тонкопленочные солнечные элементы на основе кремния. 2-е изд. *СПб.: Изд-во СПбГЭТУ «ЛЭТИ*, 41.
11. Андреев, В. М. (1989). *Фотоэлектрическое преобразование концентрированного солнечного излучения*. Наука, Ленингр. отд-ние.
12. Shockley W., Queisser, H. J. / Appl. Phys. // 1961. V. 32/ 510 с.