UDC 53.096: 620.97 (045)

[1]M. M. Asanov,
[2]M. Yu. Zaliskyi

# TEMPERATURE MEASUREMENT OF PHOTOVOLTAIC CELLS SURFACE

[1]Energy supply and physics department, National Academy of Environmental Protection
and Resort Development, Simferopol, Ukraine
E-mail: marlen_as@mail.ru
[2]Aviation radio electronic complexes department, National Aviation University, Kyiv, Ukraine
E-mail: maximus2812@ukr.net

***Abstract.*** *In this work a method of measuring the temperature of photocells is considered. A series of works are analyzed in which noted that temperature fluctuations of environment and photocell significantly affect output characteristics of photovoltaic cells. Temperature measurements are used in maximum power point tracking algorithms, for calculating the thermal coefficients of photocells. The described method uses yttrium iron garnet crystal placed in a constant magnetic field and magnetized to saturation as a sensing element of the device. To measure the temperature change the polarization plane rotation angle of transmitted light in the crystal dependence on temperature is used.*

**Keywords:** photovoltaic cells; temperature measurement; ferrites; photopolarimeter.

## I. INTRODUCTION

The sun as an energy source is increasingly attracting researchers and specialists of the energy field. New photovoltaic devices – solar cells are created, allowing converting solar energy into electricity more efficiently. The increasing popularity of solar radiation as a source of energy is explained by the fact that it is absolutely safe, inexhaustible and generally available. Ultimate theoretical efficiency of solar cells taking into account only thermodynamic losses can be 85 %. For real systems the values of efficiency can reach 45 – 55 % [1], [2].

An important factor affecting the efficiency of energy conversion is the temperature of both the solar cell and the environment.

## II. ANALYSIS OF LITERATURE

There are number of works devoted to the maximum power point tracking of the photovoltaic system on the basis of temperature measurements [3] – [5]. Maximum power point is the point on the current-voltage characteristic of a photovoltaic cell, in which maximum power receiving is possible with continuous voltage regulation. To create a tracking algorithm authors of [5] proposed to use the LM35 temperature sensor for measuring the surface temperature of the photovoltaic cell. Based on the received data optimum voltage which is to be applied in this system is calculated. It is noted that the proposed method is not costly, may be implemented in analog or digital form and also involves continuous monitoring of temperature changes. Thus even if a sudden temperature jump occurs, operating voltage is adjusted to achieve the maximum power point.

A large number of studies devoted to the problem of photovoltaic cells efficiency change depending on temperature, in particular, determination of the temperature coefficients [6], [7]. These coefficients contain information about the nature of the change of photoelectric cell various parameters depending on temperature, including voltage, current and power.

Temperature data measured with high accuracy is needed to obtain the temperature coefficients, which in turn make it possible to determine the characteristics of solar cells, regulate their parameters during designing for maximum efficiency in the current operating conditions.

## III. STATEMENT OF THE PROBLEM

Literature analysis showed that to investigate the energy characteristics of photovoltaic cells is important to increase the accuracy of temperature change measurement. For this purpose, in this work is proposed to use the method and device described in [8], [9].

## VI. RESEARCH METHODOLOGY

To measure (fix) the temperature change the authors of [8], [9] are proposed to use yttrium iron garnet crystal ($Y_3Fe_5O_{12}$) placed in a constant magnetic field and magnetized to saturation as a sensitive element. This type of crystals is widely used in radiotechnics as a magnetic material. After discovering of their transparency in the infrared they have found application in radiooptics. For fixing the temperature change the polarization plane rotation angle of the light that passed the crystal dependence on temperature is used [10]. Polarization plane rotation angle is registered by photopolarimeter with Faraday modulator (Fig. 1). The Faraday modulator is a placed in a magnetic field closed magnetic circuit in which additional rotation of the polarization plane takes place when light passes through it.

Parameters of the photopolarimeter were calculated using Stokes vector and Mueller matrices method [11]. Intensity of a light beam at the output of the analyzer is determined by the equation:

$$I=(1-R)^2 e^{-\gamma z}\frac{I_0}{4}(k_1+k_2)^2\left[1-P\cos 2\theta+2\Delta P\sin 2\theta\right],$$

where $R$ and $\gamma$ are the coefficients of light reflection and absorption of the modulator, respectively; $z$ is the modulator thickness; $I_0$ is the intensity of light at the polarizer input; $k_1$ and $k_2$ are the principal transmittance values of polarization prisms; $P$ is the polarization degree of the light which passed the photopolarimeter; $\Delta$ is the unbalancing angle of the photopolarimeter (the sensitivity); $\theta$ is the angular amplitude of the polarization plane oscillations, changing according to the periodic law: $\theta=\theta_0\Phi(t)$; where $\Phi(t)$ is an arbitrary periodic function, which changes in time with the frequency $\omega$.

Measurement error of the polarization plane rotation angle determined by the sensitivity of photopolarimeter which in turn is connected with a signal-to-noise ratio at the output of the photodetector:

$$\frac{S}{N}=\frac{U_S^2}{U_T^2+U_{SH}^2}=A(k_1+k_2)^2\Delta^2\frac{4P^2\sin^2 2\theta}{\dfrac{U_T^2}{A'(k_1+k_2)^2}+1-P\cos 2\theta},$$

where $U_S$, $U_T$ and $U_{SH}$ are the voltages created by the signal, the thermal and shot noises, respectively; $A$ and $A'$ are the constants depending on the properties of the photodetector.

Rectangular shaped control signals are supplied to modulator, because in this case the polarization degree of light $P$ in modulator is maximal during period of modulation [13].

Angular amplitude of the polarization plane oscillations is selected optimum, i.e. at which the signal-to-noise ratio at the output of the photodetector is maximal [13].

More detailed operation of the photopolarimeter is described in [11 – 13].

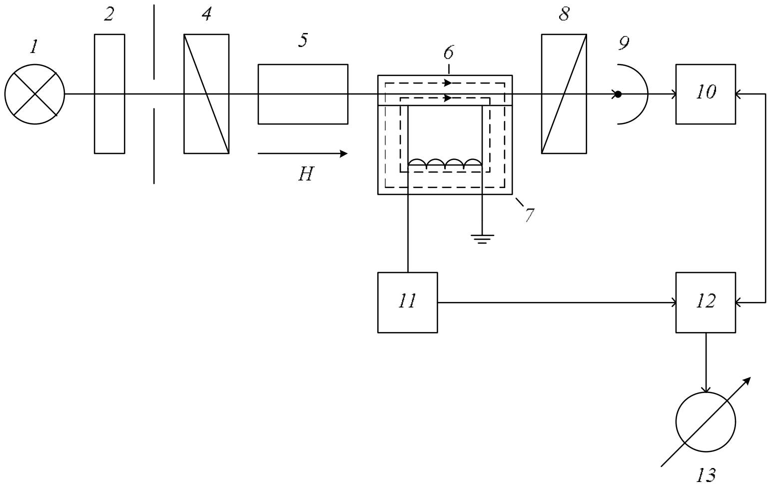

Fig. 1. A block diagram of the device for temperature change measurement:
*1* is source of light; *2* is filter; *3* is diaphragm; *4* is polarizer; *5* is sensing element; *6*, *7* are Faraday modulator; *8* is analyzer; *9* is photodetector; *10* is amplifier; *11* is sound generator; *12* is synchronous detector; *13* is ammeter (indicator)

Operation of the described device is following. Light from the light source *1* passes successively filter *2*, diaphragm *3*, polarizer *4*, the sensing element *5*, the Faraday modulator *6* and the analyzer *8*, enters the photodetector *9*, wherein the optical radiation is converted into an electric signal. This signal is amplified by narrow band amplifier *10*, passes the synchronous detector *12* to increase the sensitivity and enters the indicator *13*. Optical system is pre-configured to the moment when the signal at the output of the photodetector disappears. Under the influence of temperature on the sensing element *5* system balance brakes and at the photodetector *9* output the signal begins to register. This signal is the result of polarization plane rotation of optical radiation to an angle which value is associated with the value of the temperature change [14]. The temperature change is found by equation:

$$\Delta T=\frac{\Delta\varphi}{\dfrac{2\pi\sqrt{\varepsilon}}{c}\gamma\dfrac{dI_S}{dT}},$$

where $\Delta\varphi$ is the polarization plane rotation angle; $\varepsilon$ is the dielectric permittivity; $\gamma$ here, is the gyromagnetic ratio; $I_S$ is the saturation magnetization.

From the work [12] follows that the measurement accuracy of the polarization plane rotation angle of light by used photopolarimeter is 0.0005 angular degrees. Based on this, in [8] potential accuracy of the described temperature change fixing method was calculated, which amounted to a few thousandths of a degree Celsius. The authors noted that the actual accuracy of temperature change fixing will be several orders lower due to fluctuations in the ambient temperature.

## V. CONCLUSION

The described method allows fixing temperature changes with high accuracy. Its usage will increase the efficiency of maximum power point tracking algorithms and will also promote to a more accurate determination of the temperature coefficients. In general, the use of this method of temperature change fixing would increase the efficiency of solar photovoltaic cells.

Another advantage of this method is that the output electrical signal of the measuring device, which carries information about the temperature change may be amplified, converted, can be used in digital processing. It will allow to automate the process of temperature change fixing and, consequently, the calculation of the photocells temperature coefficients.

## REFERENCES

[1] Alferov Zh. I.; Andreev V. M.; Rumyantsev V. D. “Trends and development prospects of solar photovoltaic.” *Physics and Semiconductor Technology.* vol. 38. no. 8. 2004. pp. 937–948. (in Russian).

[2] Parashchuk D. Y.; Kokorin A. I. “Modern photoelectric and photochemical solar energy converters.” *Russian chemical journal.* vol. 52. no. 6. 2008. pp. 107–117. (in Russian).

[3] Mutoh N.; Matuo T.; Okata K.; Sakai M. “Prediction-Data-Based Maximum-Power-Point-Tracking Method for Photovoltaic Power Generation Systems.” *Works of the IEEE 33rd Annual Power Electronics Specialists Conference*. Cairns. vol. 3. 2002. pp. 1489–1894.

[4] Park M.; Yu I. “A Study on the Optimal Voltage for MPPT obtained by Surface Temperature Solar Cell.” *Works of the IEEE Conference on Industrial Electronics Society*. Busan. vol. 3. 2004. pp. 2040–2045.

[5] Roberto R. F.; Concer F. M.; Martins D. C. “A MPPT Approach Based on Temperature Measurements Applied in PV Systems.” *Works of the IEEE International Conference on Sustainable Energy Technologies*. Kandy. 2010. pp. 1–6.

[6] King D. L.; Kratochvil J. A.; Boyson W. E. “Temperature coefficients for PV modules and arrays: measurement methods, difficulties, and results.” *Works of the IEEE Photovoltaic Specialists Conference*. Anaheim. 1997. pp. 1183–1186.

[7] Krauter S.; Preiss A. “Comparison of module temperature measurement methods.” *Works of the 34th IEEE Photovoltaic Specialists Conference*. Philadelphia. 2009. pp. 333–338.

[8] Skrypets A. V.; Tronko V. D.; Slobodyan O. P.; Asanov M. M. et al. “Precision device for temperature change fixing using ferrimagnetic crystal.” *Avtoshlyahovyk of Ukraine*, Journal of TAU. no. 13. 2010. pp. 106–108. (in Ukrainian).

[9] Skrypets A. V.; Tronko V. D.; Asanov M. M. “Method of temperature changes fixing and device for its implementation.” *Patent of Ukraine*. 2010. no. 96861. (in Ukrainian).

[10] Smit J.; Wijn H. P. J. Ferrites. Physical properties of ferrimagnetic oxides in relation to their technical applications. Eindhoven. Philips’ Technical Library. 1959. 504 p.

[11] Skrypets A. V.; Tronko V. D.; Asanov M. M. “Registration of the rotation angle of light-beam polarization plane with the use of optically transparent ferrimagnetic crystals.” *Ukrainian journal of physics*. vol. 57. no. 10. 2012. pp. 993–998.

[12] Derjugin I. A.; Kuznetsov Yu. A.; Tronko V. D. “Infrared Photoelectric polarimeter.” *Optics and Spectroscopy*. vol. 28. no. 2. 1970. pp. 415–418. (in Russian).

[13] Vanyurihin A. I.; Kuznetsov Yu. A.; Maystrenko V. F.; Tronko V. D. “Registration the oscillation plane angle of linearly polarized infrared radiation.” *Optomechanical industry.* no. 8. 1970. pp. 30–33. (in Russian).

[14] Krinchik G. S.; Gushina S. A. “Effect of magnetic field on the Faraday effect in ferrite-garnet.” *Journal of Experimental and Theoretical Physics*. vol. 55. no. 2 (8). pp. 490–495. (in Russian).

Received 08 November 2013

**Marlen Asanov**. PhD.
Energy supply and physics department, National Academy of Environmental Protection and Resort Development, Simferopol, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2007).
Research area: polarized radiation, alternative sources of energy.
Publications: 24.
E-mail: marlen_as@mail.ru

**Maksym Zaliskyi**. PhD.
Aviation radio electronic complexes department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2007).
Research area: maintenance, data processing, radio engineering.
Publications: 41.
E-mail: maximus2812@ukr.net

**М. М. Асанов, М. Ю Заліський. Вимірювання температури поверхні фотоелектричних елементів**
Розглянуто спосіб вимірювання температури фотоелементів. Розглянуто ряд робіт, в яких зазначено, що коливання температури, як навколишнього середовища, так і самих фотоелементів суттєво впливають на їх вихідні характеристики. Температурні вимірювання використовуються в алгоритмах пошуку точки максимальної потужності, для отримання, так званих, температурних коефіцієнтів. Описаний метод передбачає застосування кристала фериту-граната ітрію, поміщеного у постійне магнітне поле і намагніченого до насичення у якості чутливого елемента пристрою. Для вимірювання зміни температури використовується залежність кута повороту площини поляризації світла, що проходить крізь кристал, від температури.
**Ключові слова:** фотоелектричні елементи; вимірювання температури; ферити; фотополяриметр.

**Асанов Марлен Мустафаєвич.** Кандидат фізико-математичних наук.
Кафедра енергопостачання та фізики, Національна академія природоохоронного та курортного будівництва, Сімферополь, Україна.
Освіта: Національний авіаційний університет, Київ, Україна (2007).
Напрям наукової діяльності: поляризаційне випромінювання, альтернативні джерела енергії.
Кількість публікацій: 24.
E-mail: marlen_as@mail.ru

**Заліський Максим Юрійович**. Кандидат технічних наук.
Кафедра авіаційних радіоелектронних комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна (2007).
Напрям наукової діяльності: системи експлуатації, обробка даних, радіоелектронне обладнання.
Кількість публікацій: 41.
E-mail: maximus2812@ukr.net

**М. М. Асанов, М. Ю. Залисский. Измерение температуры поверхности фотоэлектрических элементов**
Рассмотрен способ измерения температуры фотоэлементов. Рассмотрено ряд работ, в которых отмечено, что колебания температуры, как окружающей среды, так и самих фотоэлементов существенно влияют на их выходные характеристики. Температурные измерения используются в алгоритмах поиска точки максимальной мощности, для получения, так называемых, температурных коэффициентов. Описанный метод предполагает применение кристалла феррита-граната иттрия, помещенного в постоянное магнитное поле и намагниченного до насыщения в качестве чувствительного элемента устройства. Для измерения изменения температуры используется зависимость угла поворота плоскости поляризации проходящего света в кристалле от температуры.
**Ключевые слова:** фотоэлектрические элементы; измерение температуры; ферриты; фотополяриметр.

**Асанов Марлен Мустафаевич.** Кандидат физико-математических наук.
Кафедра энергоснабжения и физики, Национальная академия природоохранного и курортного строительства, Симферополь, Украина
Образование: Национальный авиационный университет, Киев, Украина (2007).
Направление научной деятельности: поляризованное излучение, альтернативные источники энергии.
Количество публикаций: 24.
E-mail: marlen_as@mail.ru

**Залисский Максим Юрьевич**. Кандидат технических наук.
Кафедра авиационных радиоэлектронных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина (2007).
Направление научной деятельности: системы эксплуатации, обработка данных, радиоэлектронное оборудование.
Количество публикаций: 41.
E-mail: maximus2812@ukr.net