Computer Applications in Electrical Engineering
Vol. 13 *2015*

Single – axis sun tracking unit with sensor control

Artur Bugała, Grażyna Frydrychowicz-Jastrzębska
Poznań University of Technology
60-965 Poznań, Piotrowo 3a, e-mail: {Grazyna.Jastrzebska; Artur.Bugala}@put.poznan.pl

The results of experimental verification of considerations conducted in [3] are presented, in terms of application single – axis tracking units, to increase the efficiency of the photovoltaic conversion, in comparison with fixed systems optimally oriented. The design and physical realization of a measurement stand is presented. A photovoltaic module inclination angle correlation algorithm, for a selected location and a measurement period, is described. The measurements were conducted in natural lighting conditions for different weather conditions. The current – voltage and power – voltage characteristics were compared for a fixed and vertically variable configuration. The value of the electric energy generated by tested photovoltaic modules in both cases was determined.

KEYWORDS: tracking system, spatial orientation, photovoltaics, inclination angle, microprocessor control

1. Introduction

Coefficient of performance in photovoltaic systems is characterized by comparing the energy gain with the maximum possible to achieve value in this system, in the analyzed period of time.

In addition, the parameter indicating the potential electric energy gain is the availability of power density of solar radiation. It is a function of many variables, both the intensity of solar radiation and atmosphere transparency factor and the angle of incidence of the solar rays on the surface of the photovoltaic receiver, resulting from the movement of the Sun.

The angle of incidence of the solar radiation due to the electric energy gain can be adjusted by changing the spatial orientation of the PV receiver (inclination angle β to the ground and azimuth angle γ according to south direction). Good results are obtained in case of single – axis tracking.

It is concluded that the use of uniaxial positioning systems in photovoltaics leads to 25 % - 30 % increase in electricity production during the year, depending on the latitude of the location [2].

The problem of a single – axis tracking was analyzed in publications [1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14], where the authors presented the projects and physical realizations of the follow - up systems, mostly with short – term analysis of electric energy generated by the photovoltaic modules.

The project of uniaxial electromechanical tracking system equipped with auxiliary photovoltaic cells for direct powering the DC permanent magnet motor was presented in [9]. The use of double – sided PV cell in combination with a module manufactured in the same technology allowed to change the position of the photovoltaic receiver in full angular range comparing to solution using standard single – sided PV cell, presented two years earlier in [10].

2. Project and realisation of measurement stand

The receiver positioning in the east – west axis allows to follow the daily movement of the Sun across the sky (azimuth angle γ = var). The mechanical system uses a turntable with a DC motor to change the position of the photovoltaic module in the range of 0 - 170°. The solar detector consists of four photodiodes in parallel configuration, where two elements connected series are differentially summarized with other photodiodes. In order to detect the evening hours a photoresistor is implemented. Figure 1 shows the analyzed photovoltaic system. Built - in socket F allows to transmit the signal from the light sensor to a microprocessor unit.

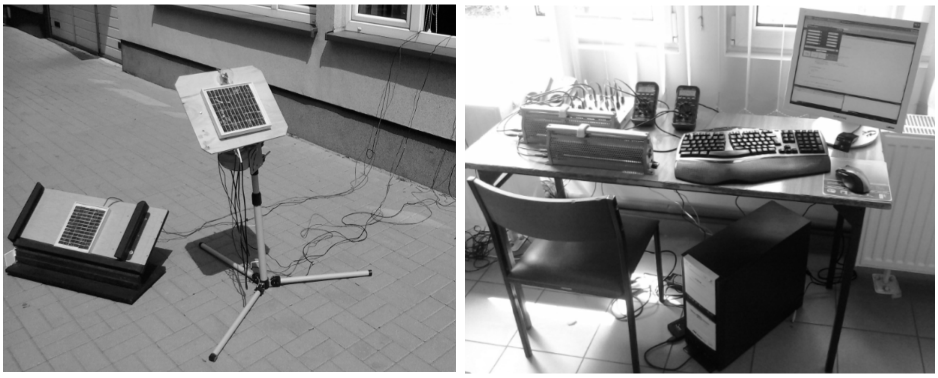

Fig. 1. A measurement stand consisting of a single – axis follow – up and fixed system for a photovoltaic modules

A sensor wiring diagram with optical partition and its physical realization are shown in Figure 2. A differential sensor generates voltage signals to a microprocessor unit about current position of a solar radiation source.

A photovoltaic module with identical electrical parameters and manufactured in the same technology was installed in a prepared fixed construction. A sleeve with a variable diameter allows blocking the position of the photovoltaic module plane in a selected angular position between 0° - 90°.

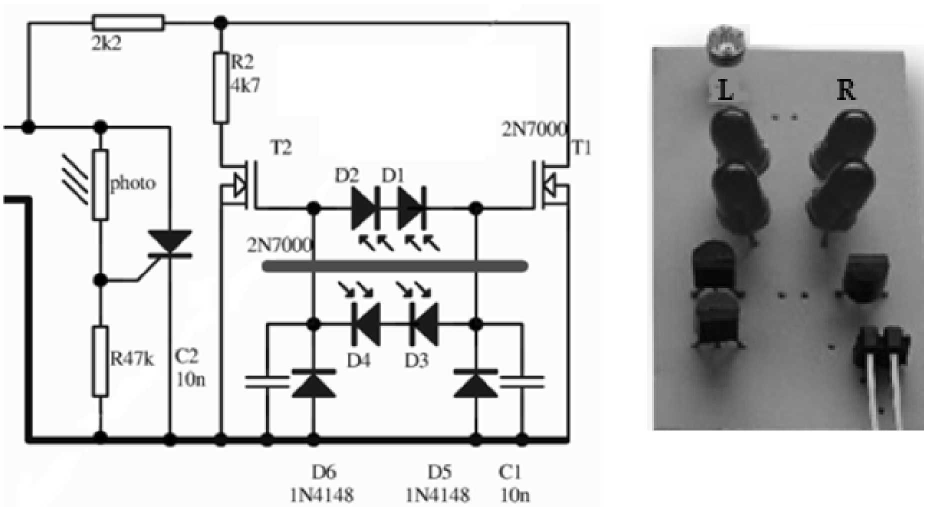

Fig. 2. Wiring diagram of the photodiode solar radiation sensor used with analyzed single – axis Sun tracker

Project of a stationary construction to change the position of a photovoltaic module according to a horizontal axis are shown in Figure 3.

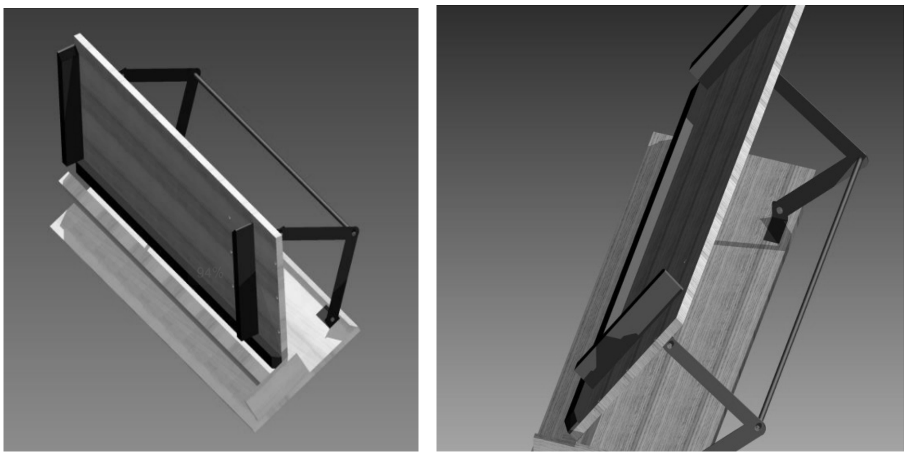

Fig. 3. Project of a stationary construction to change the position of a photovoltaic module according to a horizontal axis

The angle of inclination of the plane of the photovoltaic module to the ground, concerning selected location and the measuring period, as well as meteorological data, was determined by Liu-Jordan model, assuming isotropic solar radiation on any angularly oriented plane , which was shown in Chapter 3.

3. The algorithm for determining the value of inclination angle of the module plane

In accordance with the algorithm presented in Figure 4 an annual inclination angle of the receiver to the ground was calculated and assumed to be equal to 37°.

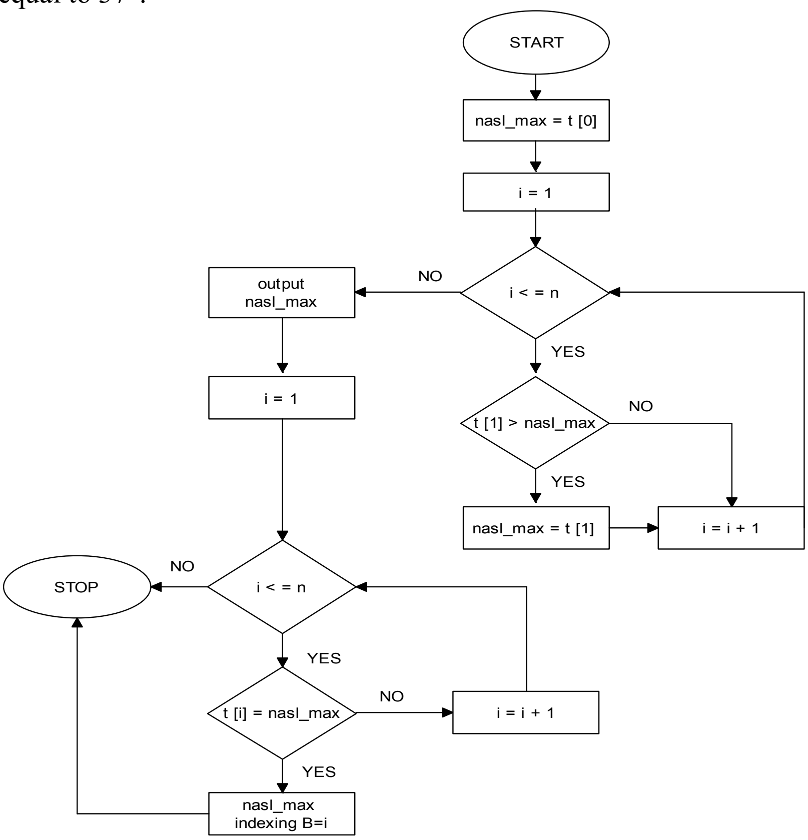

Fig. 4. The algorithm for determining the value of inclination angle of the photovoltaic module plane for a given measurement period

As source data for the analysis and to determine the annual inclination angle for a fixed photovoltaic construction data provided by the Ministry of Infrastructure and Development was used. A typical meteorological year, generated on the basis of 30 - year (1971 – 2000) for the analyzed location (Poznań, 52° 25' N, 16° 51' E), one - hour or three - hour (eight times a day) measurement sequences made available by the Institute of Meteorology and Water Management, Poznań Hydrological and Meteorological Station [1, 8]. A typical meteorological year is an hour set of 8760 lines, including solar power radiation for various spatial settings and different solar radiation components in the total radiation.

$$G_\beta = G_b \cdot \frac{\sin\delta(t)\cdot[\sin\varphi\cdot\cos\beta - \cos\varphi\cdot\sin\beta\cdot\cos\gamma]}{\sin\delta(t)\cdot\sin\varphi + \cos\delta(t)\cdot\cos\varphi\cdot\cos\omega(t)} + \frac{\cos\delta(t)\cdot[\cos\varphi\cdot\cos\beta\cdot\cos\omega(t) + \sin\varphi\cdot\sin\beta\cdot\cos\gamma\cdot\cos\omega(t) + \sin\beta\cdot\sin\gamma\cdot\sin\omega(t)}{\sin\delta(t)\cdot\sin\varphi + \cos\delta(t)\cdot\cos\varphi\cdot\cos\omega(t)} + G_d\cdot(\frac{1+\cos\beta}{2}) + (G_b + G_d)\cdot\rho_o\cdot(\frac{1-\cos\beta}{2}) \quad (1)$$

where: G_b, G_d – direct and diffuse solar radiation for a horizontal surface; G_β - total solar radiation for a plane tilted at β angle; φ - latitude angle; $\delta(t)$ - declination angle; $\omega(t)$ - hour angle; ρ_o - reflectance factor.

The calculations involved verifying the total value of solar radiation power density in a one - degree step. For each new value of the β angle, an insolation value was determined for particular hours and was added on a daily and yearly basis. The calculations were repeated until the highest value corresponding to the amount of electricity was obtained.

4. Results of measurements

The measurements conducted in real conditions were carried out from June 2013 to July 2014. Based on the obtained values of current, voltage and DC power, for two polycrystalline modules SL005 - 12 with the maximum power 5 Wp, the current – voltage and power – voltage characteristics were determined for different weather conditions like clear sky, medium cloud cover and heavy clouds. Results of measurements are shown in Figures 5-10.

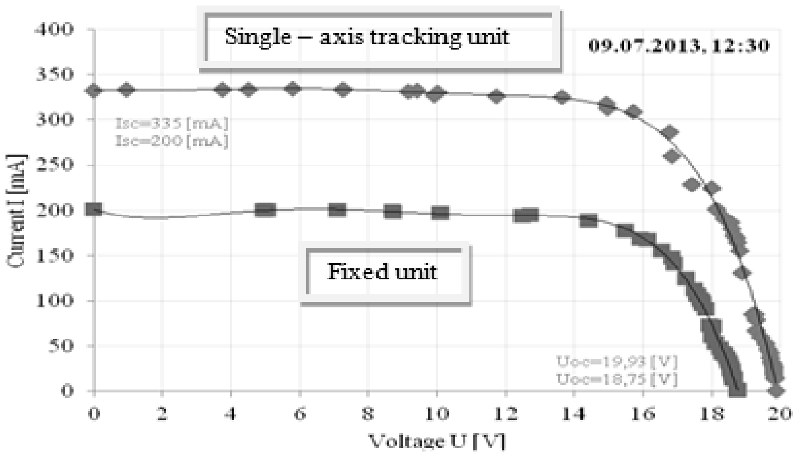

Fig. 5. Comparison of the current – voltage characteristics for a polycrystalline photovoltaic module with a maximum power 5 Wp installed stationary and in a follow – up unit in case of clear sky

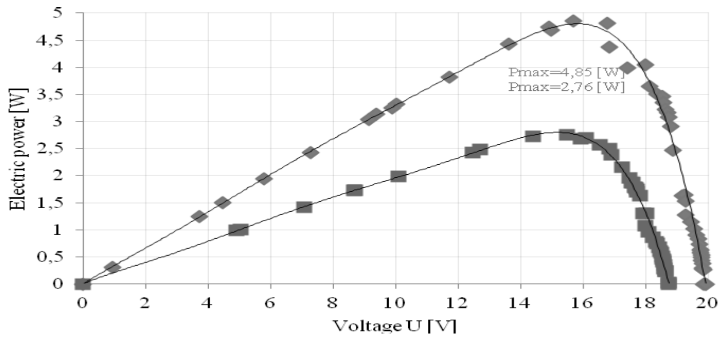

Fig. 6. Comparison of the power – voltage characteristics for a polycrystalline photovoltaic module with a maximum power 5 Wp installed stationary and in a follow – up unit in case of clear sky

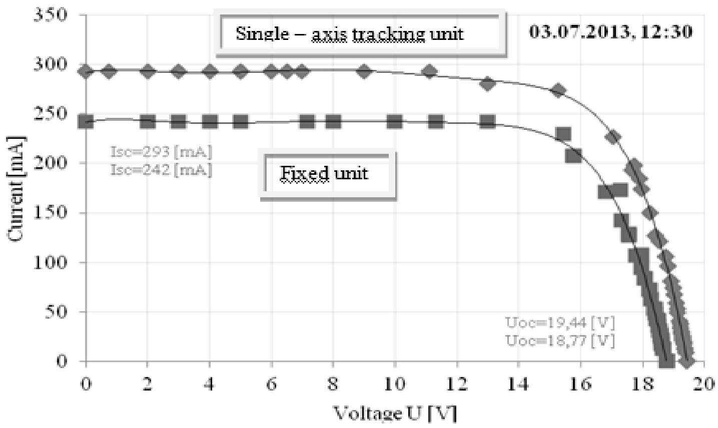

Fig. 7. Comparison of the current – voltage characteristics for a polycrystalline photovoltaic module with a maximum power 5 Wp installed stationary and in a follow – up unit in case of medium cloud cover

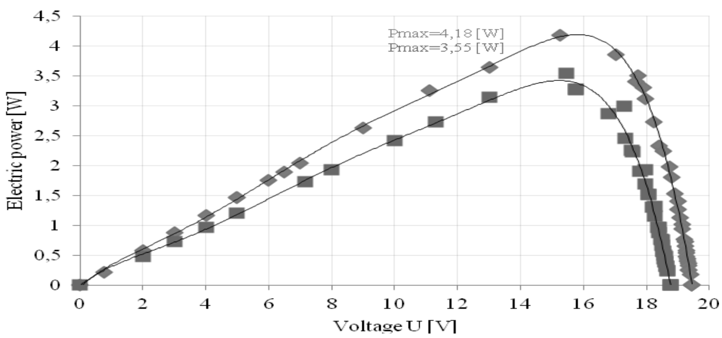

Fig. 8. Comparison of the power – voltage characteristics for a polycrystalline photovoltaic module with a maximum power 5 Wp installed stationary and in a follow – up unit in case of medium cloud cover

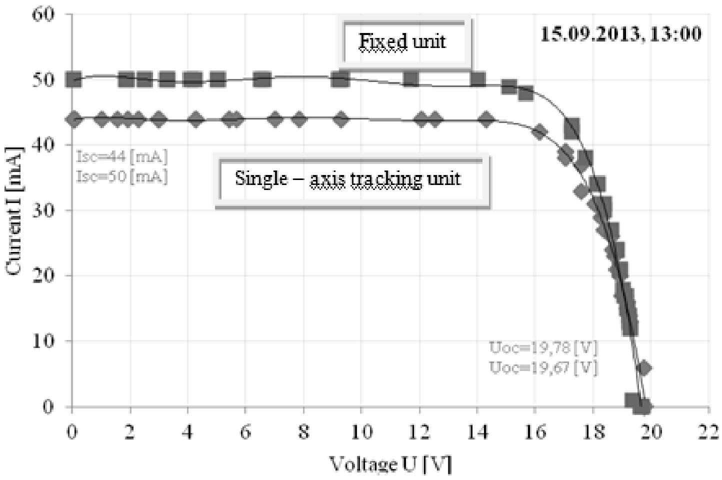

Fig. 9. Comparison of the current – voltage characteristics for a polycrystalline photovoltaic module with a maximum power 5 Wp installed stationary and in a follow – up unit in case of heavy clouds

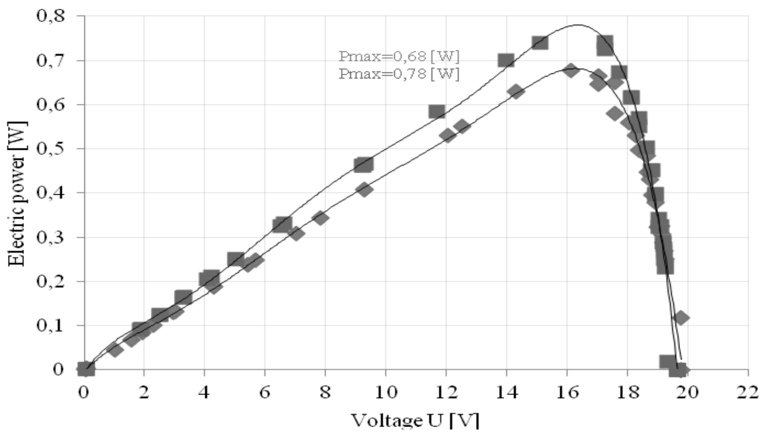

Fig. 10. Comparison of the power – voltage characteristics for a polycrystalline photovoltaic module with a maximum power 5 Wp installed stationary and in a follow – up unit in case of heavy clouds

5. Conclusions

Basing on the conducted measurements and obtained results the following conclusions can be drawn from this study:

- The effectiveness of spatially oriented photovoltaic systems depends on the type of positioning, method of solar detecting, the frequency of position changes and the angular range of operation.

- Photovoltaic systems in tracking configurations allow to obtain electric energy gain, reducing negative factors like losses resulting from incidence of solar radiation on a photovoltaic module plane at inclination angle $\beta \neq 90°$, deposition of dirt and dust leading to shading effect, temperature increase providing additional ventilation.
- The increase in the electrical power generated by the photovoltaic modules results in higher efficiency of DC/AC inverters, which operate more effectively in the upper load range.
- The use of light dependent elements as sensors to detect the direction of solar radiation allows accurate tracking the Sun position on the sky, but following problems should be considered: the total amount of the contribution of diffuse radiation reaches even 75 % during winter months, light reflected from the surrounding objects falling on the sensor surface instead of photovoltaic module plane, medium and heavy clouds may cause additional movement of the DC motor and unjustified electric energy consumption.
- In case of heavy clouds an application of the analyzed tracking construction leads to the effect of "wandering" behind the Sun limiting the instantaneous electric power, which is presented in Figure 9 – 10 where the maximum power generated by the stationary photovoltaic module is about 15 % higher.
- The use of single – axis follow – up systems based on the sensor control may increase the instantaneous electric power, especially on cloudless days, up to 70 % (Figure 5 – 6). The energy consumed for the system's powering purposes should be taken into account.

References

[1] Bugała A., Frydrychowicz-Jastrzębska G.: Pozycjonowanie modułu fotowoltaicznego w jednoosiowym układzie nadążnym, Poznań University of TechnologyAcademic Journal, 81, 2015, pp.153-160.

[2] Dhanabal R., Bharathi V., Ranjitha R., Ponni A., Deepthi S., Mageshkannan P.: Comparison of efficiencies of solar tracker systems with static panel single - axis tracking system and dual - axis tracking system with fixed mount, International Journal of Engineering and Technology (IJET), Vol. 5, No. 2, 2013, 1925 – 1932.

[3] Frydrychowicz-Jastrzębska G, Bugała A.: Sun tracking in PV systems aspects, Monograph Computer Applicationsin Electrical Engineering, Poznań University of Technology, 2012, 333-346.

[4] Kais A.: A low cost single - axis sun tracker system using PIC microcontroller, Diyala Journal of Engineering Sciences, 5, 2012, 65 – 78.

[5] Khatib T., Mohamed A., Khan R., Amin N.: A Novel Active Sun Tracking Controller for Photovoltaic Panels, Journal of Applied Sciences, 9, 2009, 4050 – 4055.

[6] Lorenzo E., Perez M., Ezpeleta A., Acedo J.: Design of tracking photovoltaic system with a single vertical axis, Progress in Photovoltaics: Research in Applications, 10, 2002, pp. 533-543.
[7] Mohammed H., Al-Najjar T.: Experimental evaluation of the performance of one - axis daily tracking and fixed PV module in Bagdad , Iraq. Journal of Engineering , vol. 19, 9, 2013, 1145-1157.
[8] Ministry of Infrastructure and Development. Available online: https://cms.transport.gov.pl (accessed on 20 April 2014).
[9] Poulek V., Libra M.: A very simple solar tracker for space and terrestrial applications, Solar Energy Materials & Solar Cells, 60, 2000, 99 – 103.
[10] Poulek V., et al.: New Solar Tracker, Solar Energy Materials & Solar Cells, 51, 1998, 113 – 120.
[11] Rokunuzzaman M., Islam M., Hossain M.: A stand-alone single axis offline PV tracker using low cost CMOS circuitry, Proceedings of the 3rd BSME - ASME International Conference on Thermal Engineering, 2006, 20 – 22.
[12] Sefa I., Demirtas M., Colak I.: Application of one - axis tracking system, Energy Conversion and Management, 50, 2009, 2709 – 2718.
[13] Tatu N., Alexandru C.: Mono - axis vs bi - axis tracking for a string of photovoltaic modules, Department of Renewable Energy Systems and Recycling, International Conference of Renewable Energy and Power Quality, 2011.
[14] Tudorache T., Kreindler L.: Design of a solar tracker system for PV power plants, Acta Polytechnica Hungarica, Vol. 7, No. 1, 23 – 29.

(Received: 5. 10. 2015, revised: 2. 12. 2015)