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COMPARISON BETWEEN MONO-AXIS AND BI-AXIS TRACKING FOR A PLATFORM OF PHOTOVOLTAIC MODULES

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Abstract: *The paper presents a comparative study of tracking efficiency applied to a mono-axis platform of photovoltaic modules and to a bi-axis system. This study will reveal which system is more efficient in the geographical area of Braşov an under which conditions. Taking into account the technical aspects and the energy gain of the dual-axis tracking system, it was concluded that a mono-axis system is preferred for the studied geographical area.*

Key words: *photovoltaic, tracking system, efficiency, pseudo-azimuthal.*

1. Introduction

The research in the domain of renewable energies represents a priority at world level, because these systems provide viable alternatives to a series of major problems: the limitative and pollutant character of the fossil fuels, global warming or the greenhouse effect. In the domain of producing electric energy, the fossil fuels can be replaced with renewable energies. The solar energy can be converted into electric or thermal energy (photovoltaic systems). The method of converting the solar radiation into electricity is well known: the photovoltaic effect.

The photoelectric effect was first noted by a French physicist Edmund Bequerel in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954.

Devices that operate on the basis of this phenomenon are called photovoltaic cells, which can be made from several semiconductor materials as: wafer-based crystalline silicon cells, thin-film cell based on cadmium telluride or silicon etc., but over 95% are made of silicon. The solar cells convert the available solar radiation directly into electricity. The efficiency of this conversion depends on the quality and the type of the solar cells, their temperature, on amount of solar radiation that falls on the solar cells and quality inverters used to convert DC. To increase the rate of incident solar radiation tracking systems are used.

A photovoltaic module with tracking is efficient if the quantity of electric energy produced by system is substantially greater

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than the sum of the energy produced by the same module without tracking (fixed) and the energy consumption for tracking. For achieving the energetic efficiency condition, all the components of the tracking system (the mechanical device, the actuators, the control system & the controller) are important, as well as their integration. No less important, there are the economical aspects, concerning the cost of the product (which includes the design cost), the reliability, and the pay-back period.

The orientation of photovoltaic modules may increase the efficiency of the conversion system up from 20% to 50% [1-3], [5]. The efficiency of this conversion depends on the quality and the type of the solar cells, their temperature, on amount of solar radiation that falls on the solar cells and quality inverters used to convert DC. To increase the rate of incident solar radiation tracking systems are used. These are mechatronic systems that integrate mechanics, electronics and information technology. These mechanisms are driven by linear actuators or rotary motors which achieve the optimal position of the module relatively to the sun position on the sky.

In these circumstances, the present paper presents a tracking program designed to increase the energetic efficiency of a PV platform.

2. About Solar Radiation

The sun is an enormous nuclear fusion reactor, although most commonly used fossil fuels and radioactive substances are found in limited quantities and in different parts of the globe. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m and, is on the average 1.5×10^{11} m from the earth [9].

As seen from the earth, the sun rotates on its axis about once every four weeks. Because the sun is such a long way from the earth, only a tiny proportion of the sun’s radiation reaches the earth’s surface, but without which life on earth could not exist. The energy is generated in the sun’s core through the fusion of hydrogen atoms into helium. Part of the mass of the hydrogen is converted into energy.

Earth rotates around the sun with an inclination of polar axis mattered 23.45° from the normal to the plane of its trajectory, performing a complete revolution around the sun in 365.25 days land. The main input data in the design process of solar energy conversion systems is the solar radiation, which is not evenly distributed, ranging in intensity from one geographical location to another, depending on latitude, season and time of day. Its measurement can be done using traditional tools or can be digitally recorded with a data acquisition system. Solar radiation incident on the earth's surface is composed of direct and diffuse radiation. Direct solar radiation is known and felt most directly by the people because it goes directly to the soil surface without spreading.

A common size in the literature is the solar constant has a value of 1367 W/m^2, and represents the value of direct radiation that reaches the outskirts of Earth's atmosphere. For the modeling of solar radiation can be used both methods (models) and empirical test. The literature presents several models for estimating solar radiation available in clear sky conditions: Kasten model [6], Bugler model (used as a model for describing the diffuse solar component), ESRA model (expressing the amount of solar radiation at ground level by processing satellite images collected), Hotel model (for the direct component of the radiation), Haurwitz model, Spyce estimation system. In 1922, Linke turbidity factor (T_L) describes the clarity of the sky. This index is the subject of many works of literature. Kleemann and

Meliss have developed a simplified calculation model for rapid estimation of the amount of solar radiation available in a particular place on Earth, using the notation T_R atmospheric turbidity factor and considering the air mass equal to 2.

3. Developing the Tracking Programs

For the design process of the tracking systems two rotational motions can be considered: the daily motion, and the yearly precession motion. To ensure the highest possible conversion efficiency of solar energy into electricity is necessary that the sun's rays to fall perpendicularly on the surface of the module.

According to these two rotations, PV tracking systems can be mono-axis and bi-axis. In the first only the daily rotation is performed, the last involves both rotations. For comparison, the mono-axis system was chosen to be a pseudo-azimuthal system, designed to supply the load for small house [7], [9]. The pseudo-azimuthal system is derived from the azimuthal system, having the main/daily rotational axis positioned on the horizontal (North-South). Its main advantage is the structures stability, being the best option for orientating the platforms of photovoltaic modules strings (modules mounted on individual strings, which in turn are arranged on a platform type common frame).

The number of modules was determined in accordance with the specific climatic parameters of the geographical area Brașov. The resulted tracking system consists of four PV modules with an active surface of 5.04 m^2 and 15% conversion efficiency each.

The motion law was designed to ensure the optimum positioning of the PV system relative to the Sun's position on the sky, so that the received solar radiation is very close to the ideal case. The PV system is orientated according to two angles: module tilt angle, ρ^* which is kept at a fixed value throughout the duration of a season or the entire year, and the daily angle, ε^* around which the daily motion is performed. In turn, these depend on the following: the angles determining Sun`s position on the sky dome: latitude, declination, hour angle, altitude [8]. From these, the angles used for the sunray orientation were determined: elevation angle - ρ and daily angle - ε (Figure 1):

$$\varepsilon = \cos^{-1}\frac{(\cos\delta\cdot\cos\omega\cdot\cos\varphi+\sin\delta\cdot\sin\varphi)}{\cos\rho}, \tag{1}$$

$$\rho = \sin^{-1}(\cos\delta\cdot\cos\omega\cdot\sin\varphi-\sin\delta\cdot\cos\varphi). \tag{2}$$

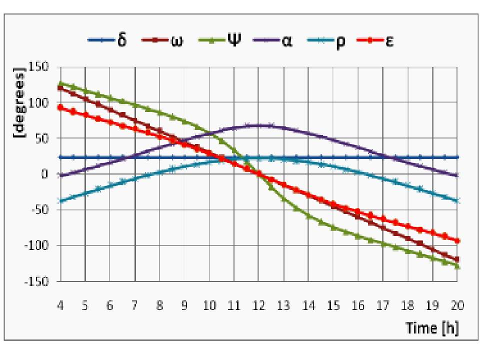

Fig. 1. *Variation of solar angles for summer solstice*

To find the suitable step-by-step tracking program in the premise of the previously specified criterion, the optimum angles must be found through a series of combinatorial calculations of ρ^* and ε^*. The optimum values for this pair of angles are found at the point where the tracking efficiency is highest, but with a minimum angular field of the daily angle in order to keep the energy consumption during tracking at minimum. The tracking efficiency is computed in percents as the radiation captured effectively from the maximum amount to be captured.

The solar radiation is influenced by a series of parameters specific for each geographical area, climatic conditions and parameters (turbidity factor - T_R [4], clouds, rain) and degree of pollution. In order to estimate the direct solar radiation (G_D) for Braşov region following mathematical model was used the, where N represents the day of the year:

$$G_D = G_0 \cdot (1 + 0.0334 \cdot \cos x) \exp\left(-\frac{T_r}{0.9 + 9.4 \cdot \sin \alpha}\right), \quad \text{where:} \tag{3}$$

$$x = 0.9856^\circ \cdot N - 2.72^\circ, \quad \omega = 15^\circ \cdot (12 - T), \tag{4}$$

$$\alpha = \sin^{-1}(\sin\delta \cdot \sin\varphi + \cos\delta \cdot \cos\varphi \cdot \cos\omega), \tag{5}$$

in which G_0 is the medium solar constant (1367 W/m^2); N - the number of the day in the year; T_r - the turbidity factor (atmosphere clarity); α - altitudinal solar angle; φ - location latitude; ω - hour angle; δ - solar declination; T - local time.

The incidence angle for the pseudo-azimuthal system, defined as the angle between the sunray and the normal on the photovoltaic module, was determined with the relation (Figure 2):

$$i = \cos^{-1}(\cos\rho \cdot \cos\rho^* \cdot \cos(\varepsilon - \varepsilon^*) + \sin\rho \cdot \sin\rho^*). \tag{6}$$

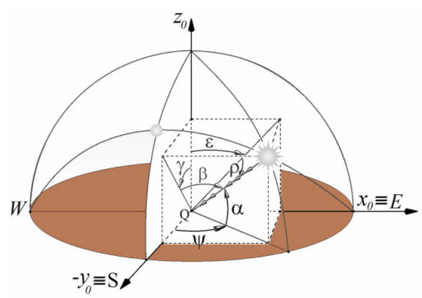

Fig. 2. *The angles of the pseudo-azimuthal system*

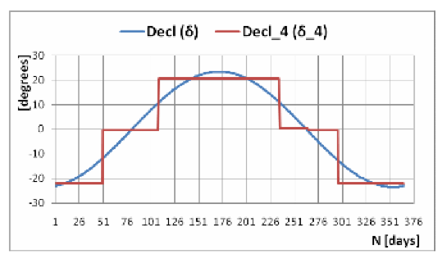

Fig. 3. *The 4 seasons of the year based on the solar declination angle*

Seasons Table 1

Season	First day	Middle day	Last day
I	297	355	50
II	51	79	108
III	109	172	235
IV	236	266	296

To increase the precision of the motion law, the year was split into 4 seasons depending on the declination angle, δ (Figure 3).

In each season the most important three days were chosen: first, middle and last day as seen in Table 1 (for example, 297 represents 24 October 2011). For each day the direct and incident solar radiation were computed.

The steps of the motion law are chosen according to the angle ε curve of each season's middle day (Figure 4).

The number of steps varies according to season from 14 steps in season 3 (summer season) to 8 in season 1 (winter season), plus the step taken to return the system to its previous position. Because in the morning the amount of solar radiation is small, the number of steps was reduced to 8 for each season.

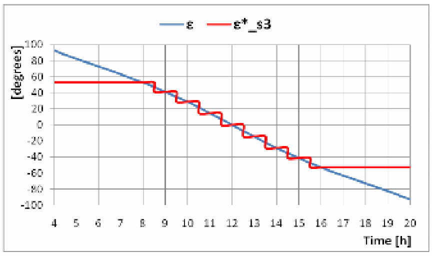

Fig. 4. *The motion law for summer solstice*

For the combinatorial calculations, various values were attributed to the daily and elevation angles as follows: ε^* varies in the intervals [+15°; –15°], [+30°; –30°], [+45°; –45°], [+60°; –60°], [+75°; –75°], [+90°; –90°] and the value 0°; ρ* takes fixed values within the interval [–35°; 40°]. All simulations were performed in the premises of clear sky.

Afterwards values of the elevation angle ρ^* were determined the fixed values of the elevation angle ρ^*, for each season, simultaneous with the correspondent angular domain of the daily angle ε^*. For each pair of angles the quantity of the incident solar radiation is almost to the ideal case (continuous).

Because the energetic intake from angular domains cases: $\varepsilon^* \in$ [+75°; –75°] and $\varepsilon^* \in$ [+90°; –90°] is very small comparative with $\varepsilon^* \in$ [+60°; –60°], the last was chosen as optimum for the daily angle ε^* in all seasons (Figure 5 - tracking efficiency season 3 with $\rho^* = 6°$).

To determine the annual optimum pair of angles, the same steps were followed in performing the calculations for all 12 days in the year with the specification that the motion law of ε^* is the same throughout the year. So, the final values are presented in Table 2.

Values of the angles ρ^* Table 2

Seasons	ρ^*_season	ρ^*_annual
I	28°	28°
II	34°	
III	6°	
IV	34°	

Further, there were drawn the curves of the incident and direct solar radiations for a specific day of each time interval. For example, in Figure 6 are shown in comparison the curves obtained for the summer solstice.

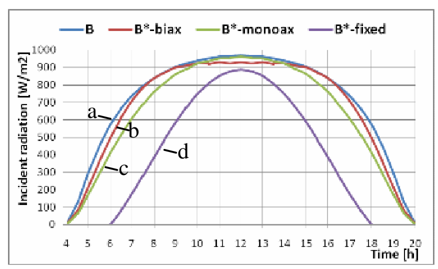

Fig. 6. *The incident solar radiation: a) direct solar radiation; b) bi-axis; c) mono-axis; d) fixed, for summer solstice1*

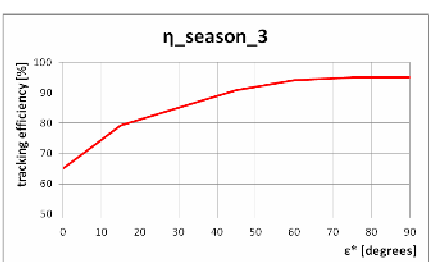

Fig. 5. *Determination of* ε^* *angular domain in season 3*

In the case of a seasonal orientation program, it can be noticed that the bi-axis system has an increased tracking efficiency with 0.66% (Figure 7).

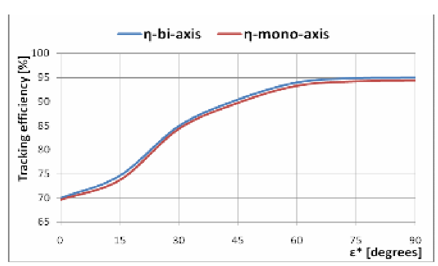

Fig. 7. *Comparison of annual orientation programs*

4. Conclusions

Observing the small energy difference between a mono-axis and a bi-axis tracking system, along with first`s economical aspect plus its technical complexity, it can be concluded that a mono-axis tracking system is best suited for the geographical area of Braşov. Compared to the fixed module, the tracked system collects a far greater amount of solar energy.

Regarding the future research in the field, the study will continue with modeling the diffuse component of the solar radiation and developing the control system of the tracking mechanism, following the mechatronic concept.

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