Mono-axis vs Bi-axis Tracking for a String of Photovoltaic Modules

N. I. Tatu[1] and C. Alexandru[1]

[1] Department of Renewable Energy Systems and Recycling
Transilvania University of Braşov
B-dul Eroilor, 29, 500036 Braşov (România)
Phone/Fax number: +0040 268 412921, e-mail: nicoleta-irina.tatu@unitbv.ro, calex@unitbv.ro

Abstract. This paper presents a comparative study of motion laws applied to a mono-axis string of photovoltaic modules and to a bi-axis system. This study will reveal which system is more efficient (inclusive economically) in the geographical area of Braşov and under which conditions. There are two types of tracking systems: mono-axis and bi-axis, the last being split into other three types of tracking systems according to their rotation axis. First the solar angles and direct solar radiation are computed and graphically modeled. Further the optimum elevation and daily angles are determined. For each interval both tracking efficiencies are calculated and then compared. Also, the yearly tracking efficiencies of mono-axis and bi-axis systems are compared. Taking into account the technical and economical aspects, beside 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, energetic efficiency, pseudo-equatorial, string.

1. Introduction

The photovoltaic systems occupy an important role in the domain of renewable energies by converting solar energy into electric energy. Tracking mechanisms used to follow the movement of the Sun on the sky dome are added to the photovoltaic (PV) systems in order to capture a maximum amount of solar radiation, thus increasing the energetic efficiency [1], [2].

The tracking mechanisms are actuated by motor sources (linear or rotative) controlled on the basis of various control strategies. Some of these strategies involve the use of photo-sensors to track the Sun or mathematical algorithms to determine the Sun position on the sky dome relative to Earth rotations (daily - around its own axis, seasonal - around the Sun) [3]-[5].

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 bi-axis system was chosen to be a pseudo-equatorial system where the daily rotation axis varies by changing the elevation angle (around which the seasonal rotation is performed) [6]-[8].

The motion laws were developed for a string of PV modules designed to supply the load for small house [9], [10]. The number of modules was determined in accordance with the specific climatic parameters of the geographical area Braşov. The resulted tracking system consists of five PV modules with an active surface of 1.26 m^2 and 15% conversion efficiency each.

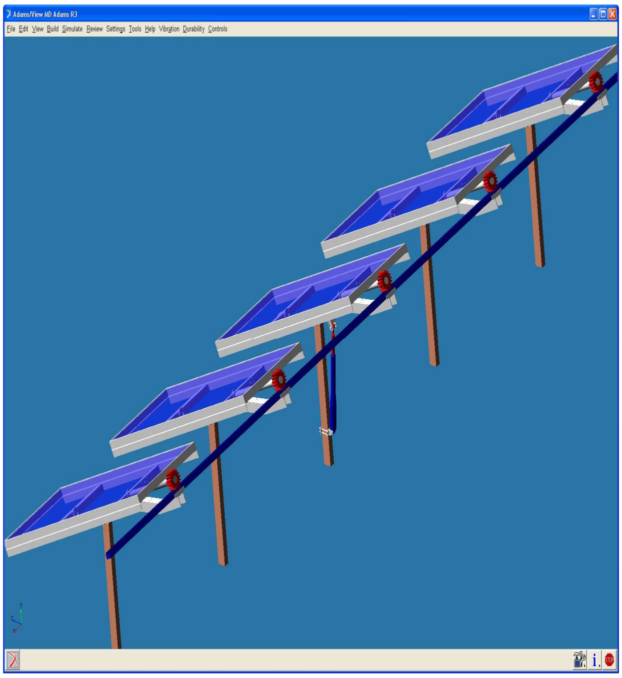


Fig. 1. The five PV modules bi-axis string

The bi-axis tracking system is represented by a five modules string actuated simultaneously with one motor source for each rotation axis. The daily motion is performed through a rotative motor and the seasonal motion through a linear actuator, both positioned on the module situated at the middle of the PV string (fig. 2). The motor`s rotor transmits the motion to the middle module, then to its gear shifting the rack horizontally, which moves all other gears fixed on the other four modules, tracking the whole string. The linear actuator drives the support found on the back of the middle photovoltaic module, moving all other four modules through the rack bar, simultaneously executing the elevation motion [11].

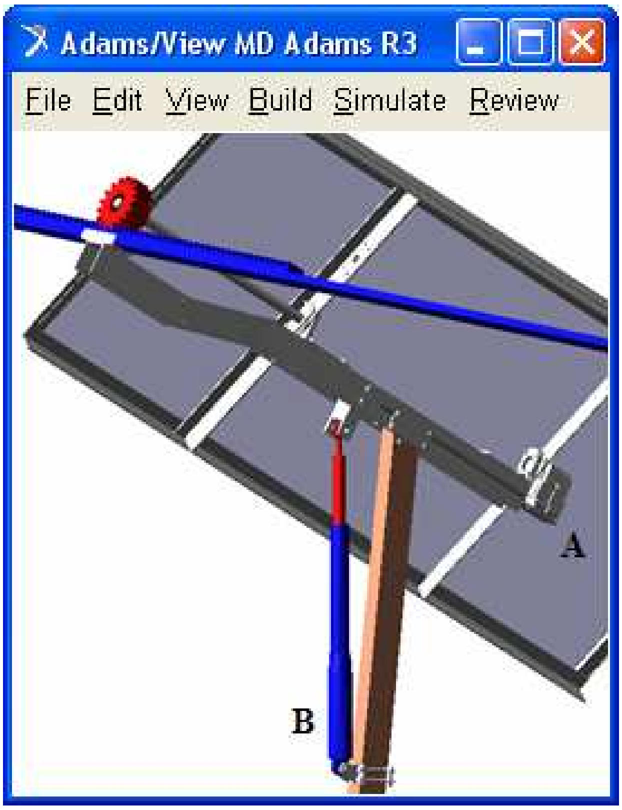


Fig. 2. The PV string motor sources: A – rotative motor, B – linear actuator.

The mono-axis tracking system results from the previous system by annulling the elevation motion. The linear actuator is removed along with the rotation joints which link it to the basis and to the support.

2. Developing the tracking programs

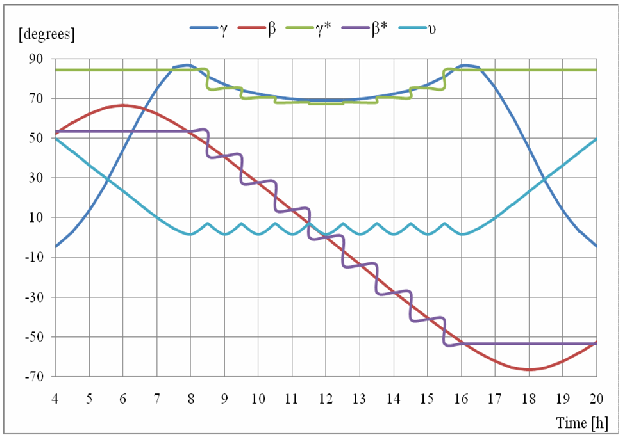
The algorithms used as input for the control system are based on the relations between solar angles with which the position of the Sun is established: latitude φ, declination δ, hour angle ω, altitude α, the angles which give the sunray orientation determined from the previous set (elevation γ, daily β), and the angles which give the position of the tracking system (γ* and β*), resulted from all of the above.

First, for a higher precision, the year was divided into eight intervals (seasons) according to the declination angle δ. The numerical simulations and graphical representations were performed for 24 days, 3 important days per season (first, middle and last day).

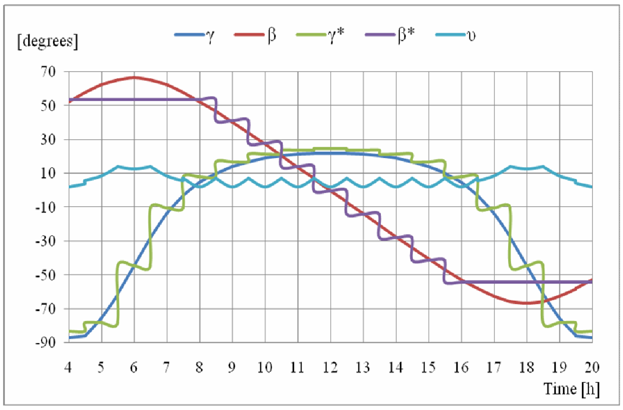
The motion law was performed step-by-step, so that it generates an incident solar radiation curve close to that of the ideal case (continuous). The captured solar radiation is determined by the product of the direct solar radiation and the angle between the sunray and normal to the module (incidence angle, υ).

For the bi-axis system the motion law steps, both daily and seasonal, are chosen accordingly to the angles curves (γ and β) of each seasons` middle days (this is called seasonal orientation program). In case of the mono-axis system, steps are taken only for the daily motion, γ* being kept fixed at an optimum value throughout the year [12].

When the steps are chosen in correspondence to spring or autumn equinox, the motion law is performed according to an annual orientation program. The time interval between steps is an hour and they are performed during one minute, statement available for both orientation programs (annual and seasonal). For example, in figure 3 is presented the motion law for the bi-axis system in seasons 1 and 5.



a)



b)

Fig. 3. Motion law for: a) season 1 (winter solstice); b) season 5 (summer solstice).

The tracking efficiency (η) represents the ratio between the generated and available energy, determined by integrating the incident solar radiation curves and, respectively, the direct solar radiation curves. The best η gives the optimum module angles γ* and β*.

During the numerical simulations the following was considered: for the mono-axis system γ^* has a single value (being fixed) and β^* has the minimum possible angular stroke without significantly altering the tracking efficiency; for dual-axis case both γ^* and β^* have the minimum angular fields with the best η. All simulations were performed in the premise of a cloudless sky.

For the bi-axis system the angles optimum values/angular domains were determined following the next stages:

- numerical simulations and graphical representations of the solar and PV system angles γ, β, γ^*, β^* and υ;
- calculating the direct and incident solar radiation with corresponding diagrams;
- computing the available and generated energies;
- computing the average available and generated energies for a medium day for every season;
- computing the tracking efficiencies;
- identifying the highest efficiencies, thus establishing the optimum angles (fig. 4 for the seasonal orientation program and 5 – annual orientation program).

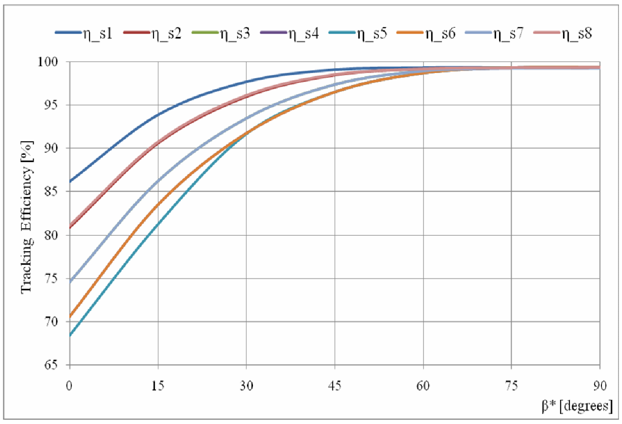


Fig. 4. Identifying the β^* optimum angular domain for all seasons in the seasonal orientation program.

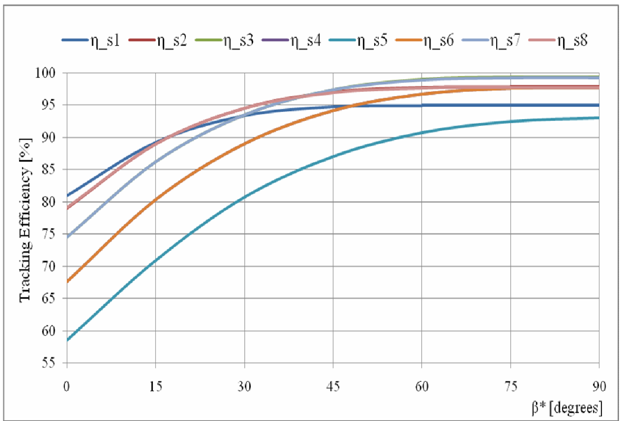


Fig. 5. Identifying the β^* optimum angular domain for all seasons in the annual orientation program.

3. Results and conclusions

For both cases, mono-axis and bi-axis systems, it was determined the optimum pair of angles, elevation γ^* and daily β^*. Further, there were drawn the curves of the incident and direct solar radiations for a specific day of each time interval. For example, in fig. 6 are shown in comparison the curves obtained for the summer and winter solstices.

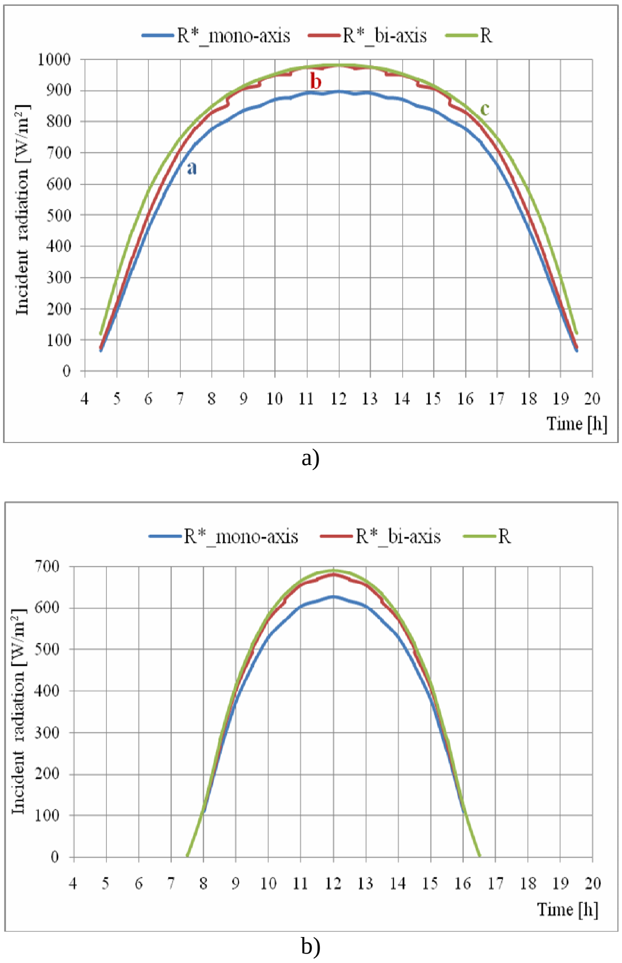


Fig. 6. The incident solar radiation a – mono-axis, b – bi-axis, c – direct solar radiation (ideal case) for: a) summer solstice (season 5); b) winter solstice (season 1)

In the case of a seasonal orientation program, it can be noticed that the bi-axis system has an increased tracking efficiency with 0.37-0.88 % and an increased generated energy with 0.52-1.08 % (fig. 7).

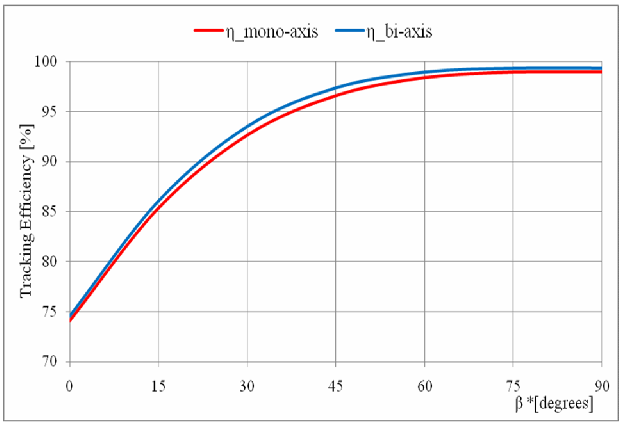


Fig. 7. Comparison of seasonal orientation programs.

In the case of an annual orientation program, as it can be observed in figure 8, the tracking efficiencies are almost the same.

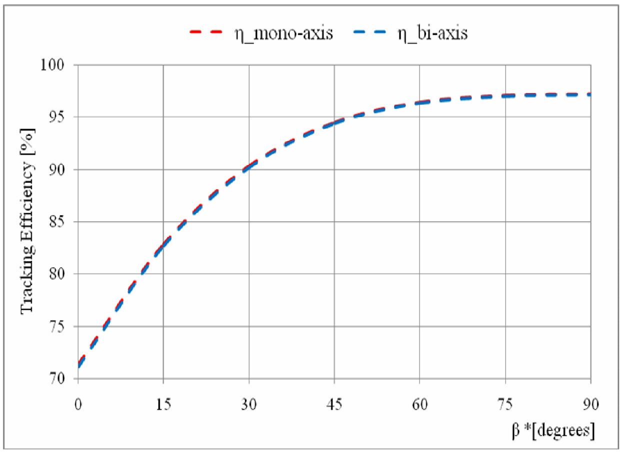


Fig. 8. Comparison of annual orientation programs.

Considering the active surface for a module (1.26 m^2), the number of modules (5) and the modules efficiency (15%), the curves are integrated resulting the generated energy of the entire PV system of each time interval for both cases. The results are shown in Table 1, where γ*_m and γ*_b are the elevation angles for mono-axis, respectively, bi-axis tracking systems, β* is the daily angle used for both cases, E_m and E_b are the energies generated in a day for mono-axis and bi-axis cases.

Table 1. The generated energy

Season	γ*_m	γ*_b	β*	E_m [Wh/day]	E_b [Wh/day]
I	44^0	65^0	[$+60^0$; -60^0]	4550,01	4737,46
II		58^0		5958,81	6089,92
III		46^0		7669,44	7671,52
IV		34^0		8805,46	8890,75
V		20^0		9470,07	9925,22
VI		34^0		8694,96	8780,09
VII		46^0		7527,72	7530,32
VIII		58^0		5836,93	5972,63

With N being the day of the year and N = 1 representing 1 January 2010, the seasons are split as follows: I – first day 310, middle – 355 and last day 35; II – first 36, middle – 51 and last 67; III – first 68, middle - 81 and last 93; IV – first 94, middle – 106 and last 118; V – first 119, middle – 172 and last 226; VI – first 227, middle – 238 and last 250; VII – first 251, middle – 265 and last 278; VIII – first 279, middle – 294 and last 309. The seasons were determined in another paper participating at the International Conference on Renewable Energies and Power Quality, ICREPQ 2011 ("A Step-By-Step Tracking Program for a String of Photovoltaic Modules").

Observing the small energy difference between a bi-axis and a mono-axis tracking system (even more, the bi-axis system consumes a part of the generated energy to accomplish the elevation motion), along with first`s economical aspect (more components and an extra motor source) plus its technical complexity, it can be concluded that a mono-axis tracking system is best suited for the geographical area of Braşov.

In the future, the authors intend to extend the research for variable atmospheric conditions, as well as for other types of tracking systems (ex. azimuthal).

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