Modelling and simulation of a single-motor bi-axial sun tracking mechanism

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Abstract. This work deals with the modelling and simulation in a virtual environment of an innovative bi-axial solar tracker, with two degrees of freedom (DOF), at which the both movements (diurnal and elevation/altitudinal) are driven by a single motor (which is a linear actuator). The tracking mechanism is used for increasing the energetic efficiency of a photovoltaic (PV) platform. The proposed solution allows to reduce the cost of the PV system by minimizing the number of motors, but still preserving the tracking accuracy of the platform. The tracking system in study is one of azimuthal type, at which the main revolute axis, that of the diurnal movement, is positioned vertically. The linear actuator used as motor source directly drives the diurnal movement, and also generates the elevation movement by intercalating a mechanical transmission that contains a bevel gear planetary mechanism and a planar rotary cam-follower mechanism. The virtual prototyping package ADAMS of MSC.Software was used for modeling and simulating the proposed tracking mechanism.

1. Introduction

One of the directions for increasing the efficiency of photovoltaic (PV) systems (which allow the conversion of solar energy in electricity) is the use of tracking mechanisms (also called solar trackers), so that the PV module is able to capture as much as possible of incident solar radiation [1-3]. Tracking systems are frequently operated with linear or rotary motors/actuators, which are controlled by open-loop (based on predefined tracking programs), closed-loop (based on sun-light sensors) or hybrid strategies [4-6].

Depending on the number of movements (degrees of freedom – DOF) that the PV system performs, the tracking mechanisms can be mono-axial (DOF=1) and bi-axial (DOF=2), respectively. The mono-axial systems allow a single movement, diurnal (East-West) or elevation/altitudinal (North-South), as the case may be. The bi-axial solar trackers are able to perform both movements, thus ensuring a much more precise sun tracking (therefore a higher energy efficiency) but obviously the cost of such systems is higher than in the case of mono-axial ones (there are necessary two motor sources, one for each movement, the motor being a generally quite expensive component).

A possible solution to reduce the cost of a PV system with a bi-axial tracking mechanism, but without significantly affecting its energy efficiency, is to use a single motor source for both movements. The idea is that the motor used to control one of the basic movements (e.g. diurnal) to be able to convey the motion to the second axis (e.g. elevation). Various types of mechanisms can be used for this purpose (e.g. linkages, gears or cams).

The present work deals with the modelling and simulation of an innovative bi-axial tracking mechanism equipped with a single motor source, which directly drives the diurnal movement of the system and from which the movement for the elevation axis is taken over by a mechanical transmission that includes a bevel gear mechanism connected with a planar rotary cam mechanism. The study is based on the MBS (Multi-Body System) model of the sun tracking system, which was developed by using the virtual prototyping software package ADAMS of MSC.Software. The control system, which is an open-loop one, was also designed in ADAMS, using the features included in the ADAMS/Controls Toolkit module.

2. Tracking system design

Depending on the way in which the two specific movements (diurnal and elevation) are performed and the relative positioning of the revolute axes, there are four basic categories of bi-axial tracking systems (which are schematically shown in Figure 1, in the North-South plane), namely polar (a), pseudo-polar (b), azimuthal (c) and pseudo-azimuthal (d) systems. A detailed presentation of these types of bi-axial systems, including their specific advantages and disadvantages, was made in a previous paper by the author [7]. For the present paper, a bi-axial system of azimuthal type will be considered, which ensures the best conditions of stability considering that the axis of the main movement (the one for the diurnal movement) is positioned vertically. Thus, a good balance of the structure in terms of diurnal movement is ensured, and this is reflected in the energy balance of the system through a low energy consumption to achieve this movement (the driving force is actually reduced).

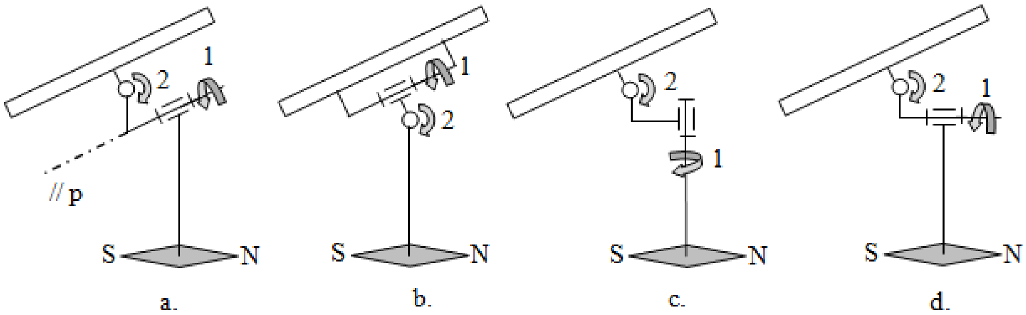

Figure 1. Bi-axial tracking systems setups (1 - diurnal motion, 2 - elevation motion) [7].

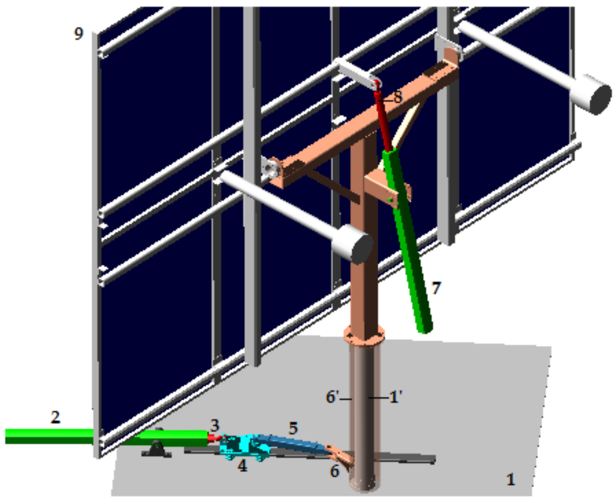

Figure 2. The virtual prototype of the bi-axial azimuthal solar tracker [8].

In the classic version of the bi-axial azimuthal tracking system (the one with two motor sources, one for each of the two movements), which was approached in [8] for a platform of PV modules, the diurnal and elevation movements are driven by linear actuators, the virtual prototype of the tracking system being shown in Figure 2. Considering that for the diurnal movement the orientation field of the

PV platform is higher than in the case of the elevation movement, in order not to be necessary to use an actuator with a very large stroke (therefore size), it was opted to use the same type of actuator as for the elevation movement (so one with a reasonable stroke/size), which was connected with a stroke amplification mechanism (slider-rocker type), thus managing to go through the required orientation field without the risk of self-blocking. For the diurnal movement, the moving part of the vertical pole (noted by 6' in Figure 2) rotates around the fixed part of the pillar (1'), while the elevation movement is ensured by rotating the platform frame (9) relative to the rotating pillar (6'). The notations used to mark the bodies in Figure 2 are those used in [8].

Starting from this type of bi-axial tracking system (with two actuating/motor sources), through the solution proposed in this paper it is possible to eliminate the linear actuator used for the elevation movement and replace it with a mechanical transmission (whose cost is lower than that of an actuator) that is also operated from the actuating source of the diurnal movement. The design of tracking mechanism for the elevation movement was based on the following requirements: (i) the system must allow the changing of the revolute axis, from vertical (diurnal movement axis) to horizontal (elevation axis); (ii) the system must allow the modification of the angular range for orientation, which is smaller than in the case of diurnal movement; (iii) the system must allow the intermittent orientation of the PV platform, the sun tracking along the elevation axis being performed less often and with fewer tracking steps than in the case of diurnal movement.

The three design requirements have been met by designing a mechanical transmission that was interleaved between the driving system of the diurnal movement and the platform frame. This transmission is composed of two types of mechanisms, one with bevel gears (to meet the first two design requirements) and the other with a rotary cam (to meet the third design requirement).

The gear mechanism is of planetary type with bevel gears (so as to ensure the change of the revolute axis), whose transmission ratio is so defined as to ensure the necessary reduction in the revolution angle compared to the diurnal movement angle. The schematic model of the planetary bevel gearbox is shown in Figure 3. The satellite of the planetary mechanism (i.e. the bevel gear II) rotates around the satellite carrier arm, which is a common part with the rotating pillar (6'). The central bevel gear (I) is rigidly connected to the fixed part of the vertical pillar (1').

In order to ensure the intermittent transmission of the elevation movement to the platform, a mechanism with planar rotary cam and oscillating follower is used, as schematically shown in Figure 4. The cam (II') is mounted on the same shaft (A-A') as the satellite bevel gear (II), while the follower (IV) is fixed connected to the platform frame (9). For a better transmission of the movement/forces between cam and follower, the roller (III) is used. The cam profile (shape) is designed to ensure the desired tracking law for the elevation movement, through the lifting and lowering areas of the cam. In this sense, the cam can be interchangeable to adapt to the tracking program for the four seasons during the year.

In the two structural schemes shown in Figures 3 and 4 (as well as in the above paragraphs), the same notations for bodies were used as in Figure 2, where it was the case.

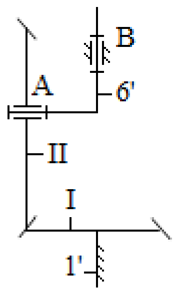

Figure 3. Structural scheme of the planetary bevel gearbox.

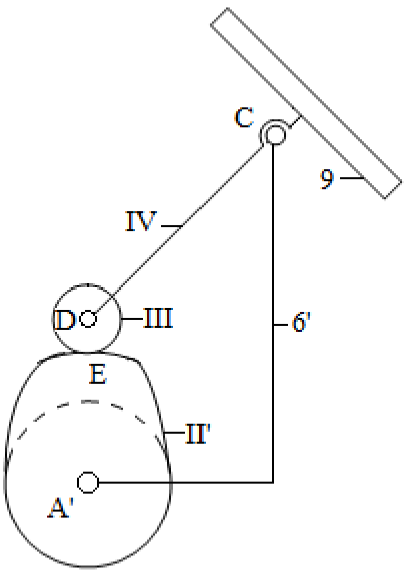

Figure 4. Structural scheme of the cam - follower mechanism.

3. Virtual model of the proposed tracking system

Based on the above, the virtual model of the single-motor bi-axial azimuthal tracking system (which is shown in Figure 5) was further developed by using the MBS (Multi-Body Systems) software package ADAMS. In fact, it started from the initial prototype (with two motors) shown in Figure 2, the actuator for the elevation movement was removed, and the mechanical transmission formed by the two mechanisms from Figures 3 and 4 was designed/modeled. As mentioned, the cam profile was designed so that to ensure the tracking law for the elevation movement corresponding to the specific period (season) of the year. The effective design of the cam profile was achieved by using a graphical synthesis method based on the inversion of the motion [9], which was implemented / transposed in ADAMS. The contact between the roller and the cam (which is a solid to solid type) is maintained by practicing a channel in the cam (similar in shape to the cam profile), in which the roller is inserted.

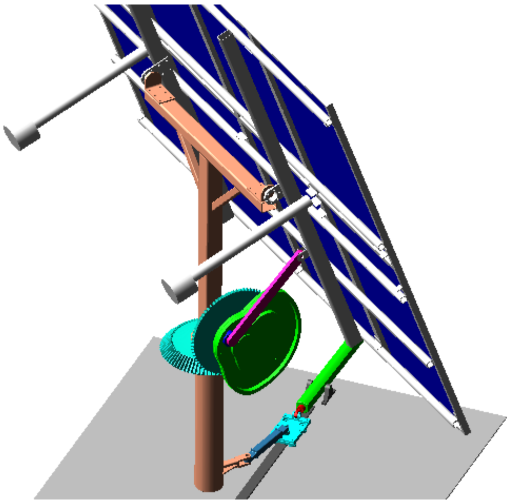

Figure 5. The virtual prototype of the single-motor bi-axial tracking mechanism.

Regarding the tracking mode of the PV platform, in practice it is frequently used the orientation in steps (step-by-step) with constant speed, and less the continuous orientation with variable speed (even if the continuous orientation would ensure a better efficiency, the disadvantages that this tracking mode implies make it avoidable) [7, 8]. The numerical simulations in this paper correspond to one of the representative days of the year, namely the spring/vernal equinox day (March 20), the bi-axial tracking program being defined by the following data (where ψ is the diurnal angle of the PV platform, and α - the elevation angle): $\psi \in [55°, -55°]$, $\alpha \in [14°, 40°]$; diurnal movement timetable (in actuation time – revolute angle pair): 9.26 – $\Delta\psi$=29°, 11.36 – $\Delta\psi$=26°, 12.56 – $\Delta\psi$=26°, 14.76 – $\Delta\psi$=29°, 18.50 – $\Delta\psi$= -110°; elevation movement timetable: 9.26 – $\Delta\alpha$=26°, 14.76 – $\Delta\alpha$= -26°.

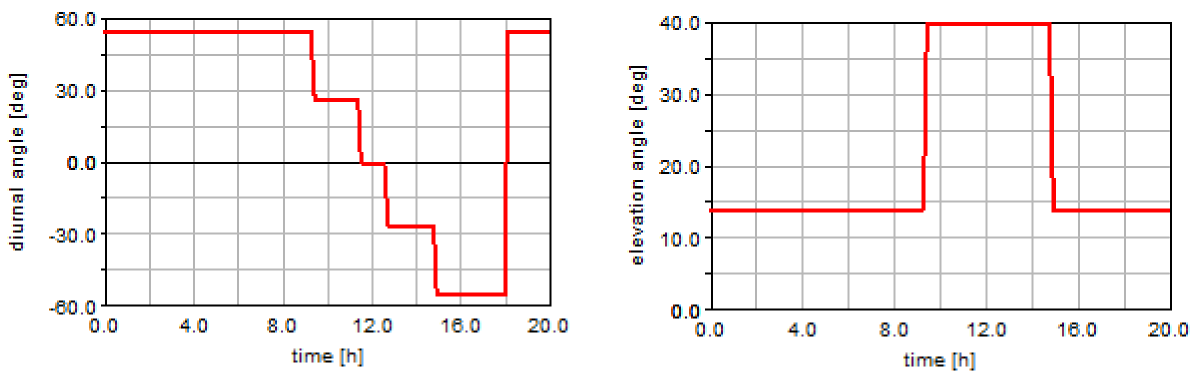

Figure 6. The diurnal and elevation angles of the PV platform.

The movements laws for this tracking program are presented in Figure 6, the corresponding incident radiation captured by the PV platform being that shown in Figure 7 (curve a). The available direct radiation is also presented (b), as well as the incident radiation in case the platform would be fixed in the noon position, tilted at an elevation angle of 45° (c). As can be seen, with the proposed tracking system, there is an amount of incident solar radiation very close to the maximum available, and respectively significantly higher than in the case of the fixed PV system.

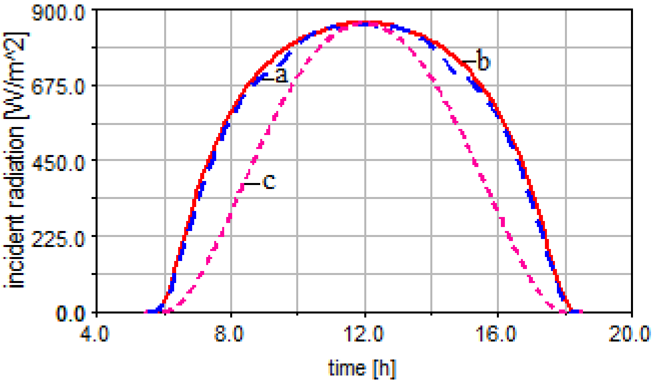

Figure 7. The incident solar radiation curves.

4. Conclusions

By minimizing the number of motors for the bi-axial tracking mechanism, although the accuracy of the orientation program for the elevation movement is lower than in the case of the two-motor system, a decrease in the system cost is ensured (the motor being the most expensive component of such system), so an increase in economic efficiency. The way in which the cam profile was designed allows the intermittent transmission of the elevation movement from the actuator that directly drives the diurnal movement to the PV platform (fixedly connected with the oscillating follower), correlated with the diurnal tracking program. The cam is interchangeable, so the system can be adapted for all seasons of the year. No less important is the design of the planetary mechanism with bevel gears, which ensures the change of the axis of rotation (from vertical to horizontal), but also influences (through its transmission ratio) the angular velocity of the cam, and thus its shape (given the need to obtain constructively rational cam profiles).

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