Multi-body system simulation of the sun trackers used for PV panels

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Abstract. The article approaches the design algorithm of the sun trackers used to improve the energy conversion performance of the photovoltaic systems. In this regard, three specific types of mechanical models are developed in an integrated concept, in the following sequence: kinematics - inverse dynamics - dynamics. The application is carried out by considering a dual-axis sun tracker that uses two linear actuators as driving sources for the diurnal and elevation movements. The MBS package ADAMS is used to model and simulate the behaviour of the sun tracker in virtual prototyping environment.

1. Introduction

The renewable energy is a very good alternative for avoiding the major problems that arise from the use of traditional energy sources, such as the limited resources of fossil fuels, the pollution, or the green-house effect. Improving the efficiency of the conversion devices of the renewable sources (e.g. sun, wind, or water) is a constant concern and challenge for the research, development and innovation (RDI) in the field. In the case of photovoltaic systems (PV), one of the viable solutions for this purpose is the implementation of sun tracking systems, which allow the capture of as much incident solar radiation as possible [1-4]. Most of the tracking systems are based on different structures of mechanical systems (more or less complex), whose drive is made by actuators (motors) that are commanded so that to allow a more accurate tracking of the sun [5-8]. Estimating the behavior of the tracking systems is crucial for their optimal design in accordance with the specific implementation area [9-12].

The literature reveals a variety of ways for evaluating the behaviour of the mechanical/mechatronic systems. The analytical methods are frequently used, being based on the determination of motion laws in the form of analytical functions. Although seemingly more difficult, the analytical approach offers a high accuracy of the results obtained, it can apply to all types of systems (planar, spatial and spherical), and is suitable for computer programming. The analysis can be accomplished with both in-house specialized programs, based on a programming language platform, as well as with MBS (Multi-Body Systems) commercial programs.

An important advantage of MBS programs is that the movement equations are formulated and then automatically resolved. Among the commonly used formalizing algorithms used by the commercial MBS software solutions, the following can be mentioned: Lagrange, Euler, Kane, or d'Alembert. From this point of view, there are two major MBS software groups: programs that form numerically the motion equations for each integration step; programs that symbolically formulate the motion equations, the user then establishing whether or not to integrate the equations, which can be carried out with symbolic computing programs (such as MATLAB or MAPLE). Complex virtual prototypes can be created with the help of MBS software solutions, in order to obtain products that function in line with the high market demands [13-17]. Thus, it is possible to accurately model both the mechanical or mechatronic system itself and the environment in which it operates. This eliminates much of the experimental testing, which is an expensive and time consuming process. However, the experimental testing will still be necessary, but at a much lower level, for validating the virtual prototype.

In this regard, the work shows the analysis algorithm for PV tracking systems. The application is carried out by considering a bi-axial mechanism, which uses linear actuators as driving sources for the daily and elevation motions. The MBS package ADAMS of MSC.Software is used for conducting the tests in virtual environment.

2. Tracking systems designing algorithm

For the tracking systems design, the following mechanical models can be developed/conceived, in accordance with the flow-chart from Figure 1:

a. kinematic model - contains the bodies (parts), connected by geometric constraints; the actuating is modeled by motion restrictions that are applied in the rotational or translational joints of the driving elements (rotary or linear actuators), thus controlling their linear or angular position;

b. inverse dynamic model - includes the external and internal forces that act in the tracking mechanism (e.g. mass and inertia forces), the actuating being performed in a similar way with the kinematic model (by motion restrictions); the model is used to determine the motor torques or forces (depending on the type of actuating element - rotary or linear actuator) that generate the kinematically prescribed behavior of the mechanism;

c. dynamic model - its structure is similar to that of the inverse dynamic model, the distinction consisting in the way in which the action is modeled (by motor torque/force instead of movement restrictions); the dynamic model is useful for evaluationg the tracking system behavior under the action of external and interal forces/torques.

In this paper, for implementing the design algorithm, a bi-axial tracking mechanism is proposed, the two degrees of freedom of the system, namely the daily and elevation movements, being generated/conducted by linear actuators. Sun tracking for the both movements is realized in steps, the motion functions of the photovoltaic panel being designed with the purpose to enssure an optimal number of steps, with a minimal energy demand to carry out the movements, what will be found in increasing the system efficiency.

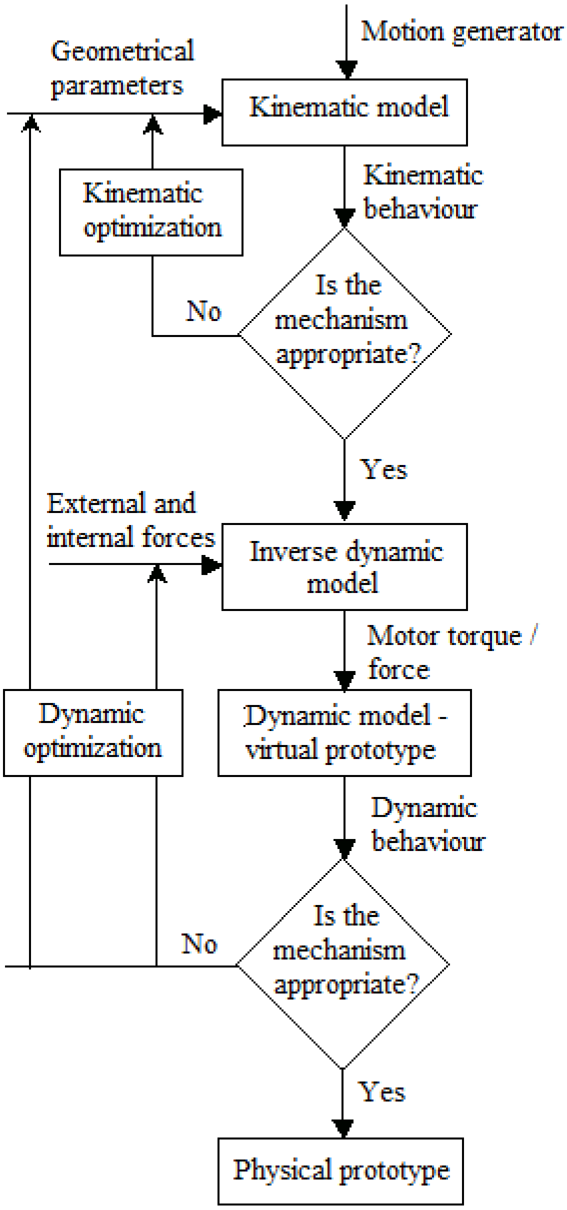


Figure 1. The designing algorithm.

3. Case study

The MBS model of the bi-axial sun tracker (Figure 2) contains two kinematic loops, corresponding to the diurnal (ABCD) and elevation (EFGH) movements. The geometric constraints in A, B, D, E, F, and H have been modeled by rotational joints, whereas the connections C and G (between the two components of the acuators) are translational joints. For the diurnal movement, the panel (1) rotates relative to the intermediary support (2) around the axis A-A'(the joint A' is kinematically passive). The elevation movement is performed by rotating the support relative to the fixed pillar (0), which is rigidly connected to ground.

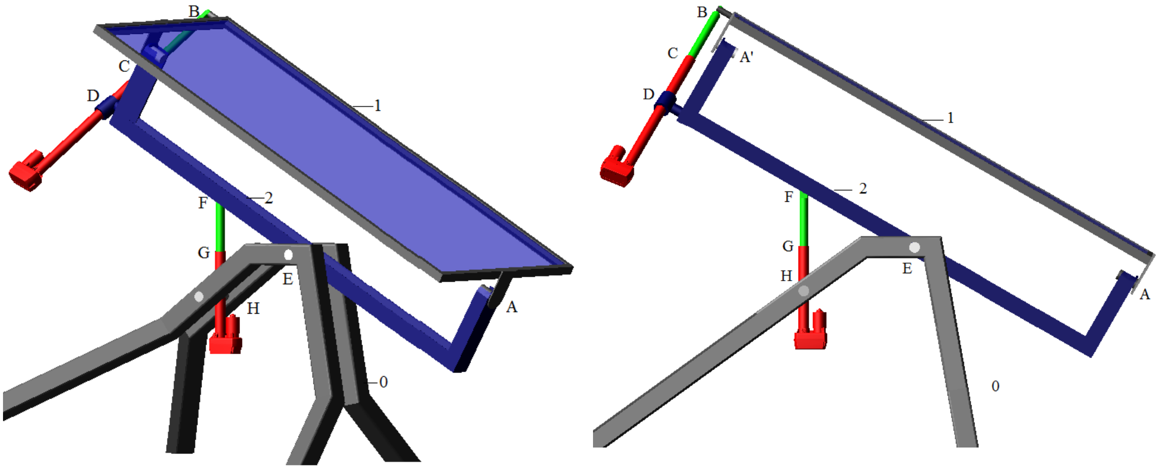


Figure 2. The MBS model of the bi-axial PV system.

Simulations performed for this work correspond to summer solstice day, and Braşov implementation area (sunrise at 4.26, sunset at 19.74, in solar time), which actually determines the orientation of the PV panel according to the sun position. In case of the daily motion, the angular domain of the panel is 120°, in the interval [+60°, -60°], relative to the zero position at solar noon. At sunset, the panel returns to the initial position. The adjustment of the elevation angle of the panel is performed with two motion steps (passing from 11° to 22.05°, and then back to 11°, the angle being measured relative to the horizontal axis). In the virtual model developed in ADAMS, the motion laws of the panel have been modeled by summing a series of STEP time functions, by using ADAMS/Function Builder. In these terms, the variation diagrams of the diurnal and elevation angles are shown in Figure 3. Afterwards, the inverse kinematic analysis was carried out with the aim to determine the corresponding linear displacements (strokes) in the two actuators (Figure 4).

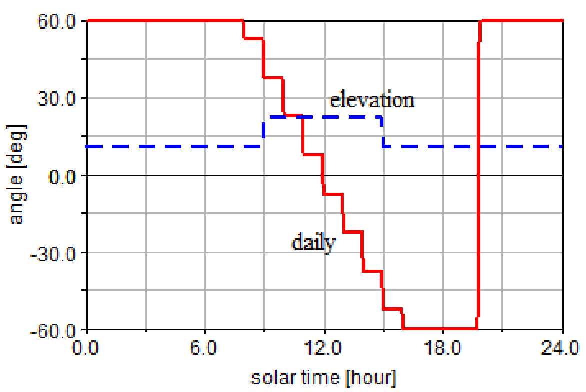


Figure 3. The angular motion functions.

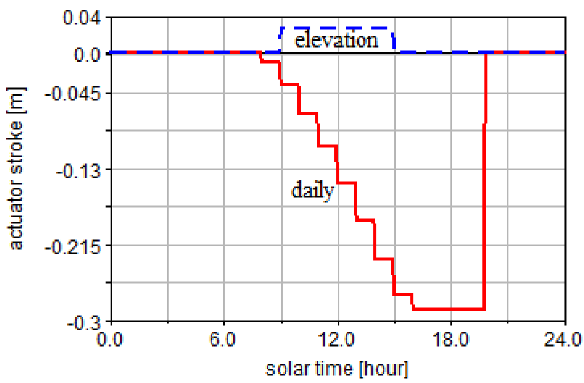
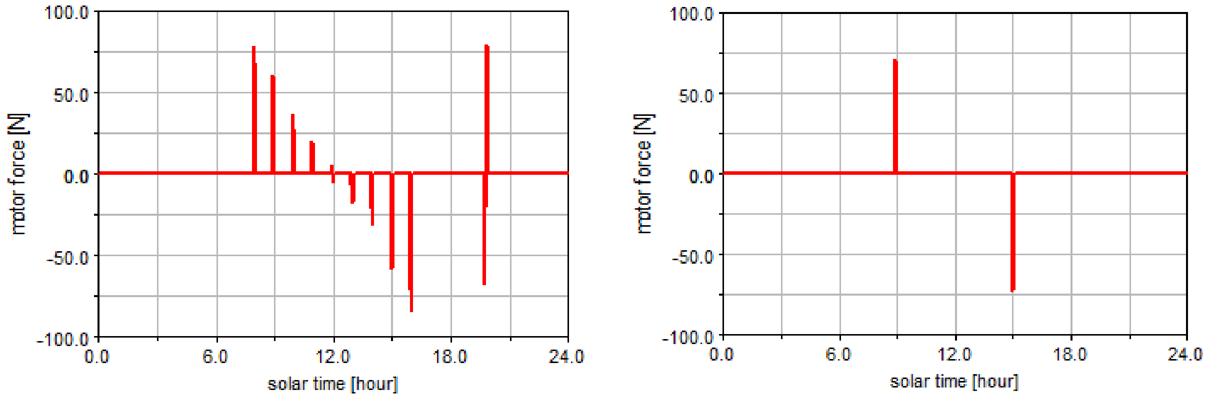
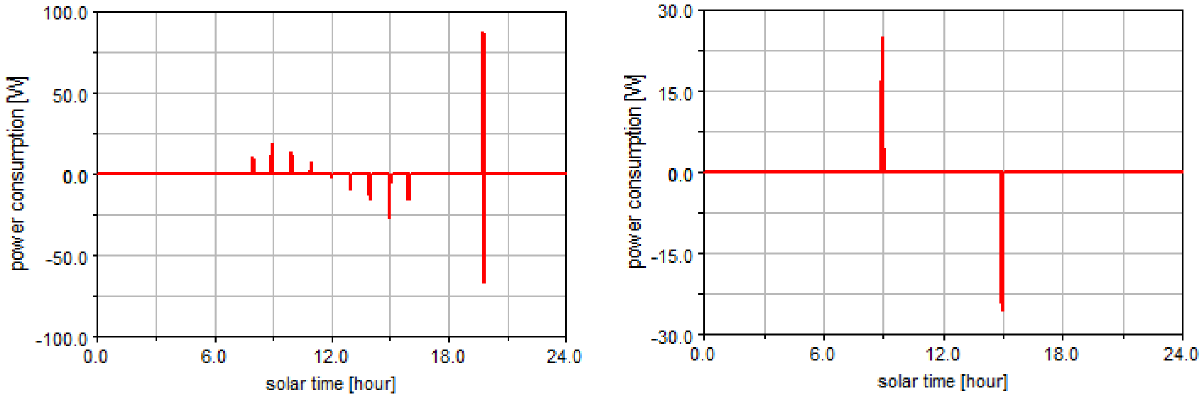


Figure 4. The linear displacements in actuators.



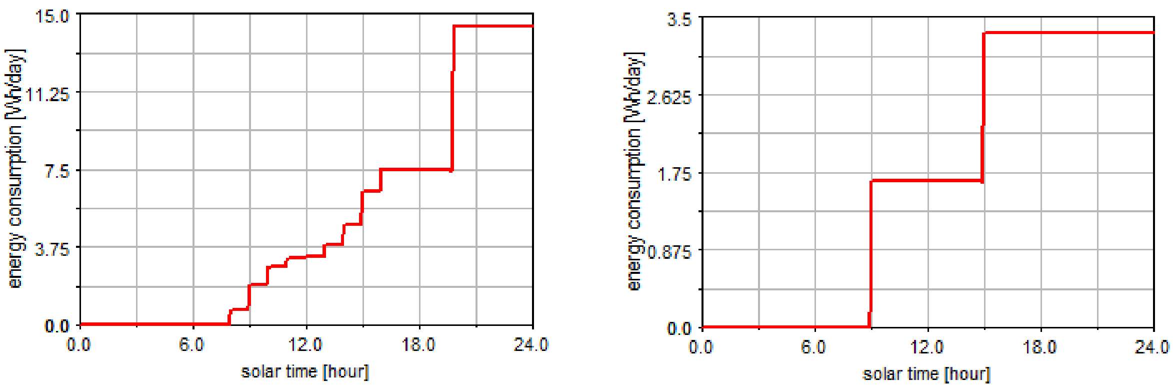
a. b.

Figure 5. The motor forces generated by the linear actuators (a - daily motion, b - elevation).



a. b.

Figure 6. The power consumptions for performing the tracking (a - daily motion, b - elevation).



a. b.

Figure 7. The energy consumptions for performing the tracking (a - daily motion, b - elevation).

The actuating forces generated by the motors for assuring the sun tracking in compliance with the imposed motion laws have been obtained by the inverse dynamic analysis (Figure 5). Then, these forces have been applied as input parameters in the dynamic analysis. Among the specific dynamic parameters, Figure 6 shows the power consumptions required to carry out the two movements, through whose integration the corresponding energy consumptions have resulted (Figure 7). It is noticeable that low consumption is obtained, which influences positively the PV system efficiency.

4. Conclusions

This work aims to highlight the importance of the testing in virtual prototyping environment, given that the alternative for identifying the optimal solution would have been the development and testing of experimental models, which is an expensive and time consuming process. An important advantage of the testing in virtual prototyping environment consists in the ability to make measurements that are actually very difficult to be performed on physical prototypes. The paper was focused on the analysis process, following that in a forthcoming work to accomplish the optimization of the proposed sun tracker, thus addressing the whole design flow-chart in the manner in which it is shown in Figure 1.

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