SIMULATION AND CONTROL OF THE TRACKING SYSTEMS USED FOR THE PHOTOVOLTAIC PANELS

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ABSTRACT

In this paper, we attempt to carry out some aspects regarding the modeling and simulation of the PV' tracking systems by using virtual prototyping environment ADAMS, as well as the control of these mechanical systems. The objective is to determine the control torque that move the panel in order to generates the cinematically prescribed behaviour. The control system, developed with ADAMS/ Controls and MATLAB, is based on the error between the actual panel position and the desired panel position. For instance, a dual-axis tracking system, with two mobilities, is taken into consideration.

Keywords: photovoltaic panel, tracking system, dynamic model, simulation, control system.

1. INTRODUCTION

Increasing CO_2 emissions and the depletion of the fossil fuel resources require strong and active measures to be taken. The answer is sustainable energy, including energy efficiency, energy saving and renewable energy systems. The sun is an extremely powerful energy source, and solar radiation is by far the largest source of energy received by the Earth. The function of a solar panel is simple; it intercepts incoming insolation and turns it into a usable form of energy that can be applied to meet a specific demand. The photovoltaic panels are products used for conversion of the solar radiation in electric energy. For increasing the efficiency of the photovoltaic panels, tracking systems (also called, solar trackers) are used. Basically, these are mechanical devices for orienting solar systems toward the sun. The aim of a solar tracker is to get the highest possible input of solar radiation for the photovoltaic panels. The evaluation of the existing products shows that the tracking systems may improve the efficiency of a solar energy conversion system from 25% up to 40% [3].

Determining the real behavior of the tracking systems is a priority in the design stage of these mechanical devices since the emergence of the computer graphic simulation. Important publications reveal a growing interest on analysis methods for multi-body systems that may facilitate the self-formulating algorithms, having as main goal the reducing of the processing time in order to make possible real-time simulation. These methods were used to develop powerful modeling and simulation environments - MBS programs (also called, virtual prototyping environments), which allow building and simulating a virtual model of any mechanical system that has moving parts [4, 5].

Virtual prototyping consists mainly in conceiving a detailed model and using it in a virtual experiment, in a similar way with the real case. An important advantage of this kind of analysis consists in the possibility of make virtual measurements in any point or area, and for any parameter (displacements, velocities, forces etc.). Virtual prototyping is used in a lot of industrial applications, including the design, testing and simulation of the mechanical devices used for the renewable energy systems (tracking systems, wind turbines, thin layer deposition installation and so on) [1].

In this paper we attempt to present some aspects regarding the simulation and control of the tracking systems by using the MBS environment ADAMS, connected with a control application – MATLAB. The objective is to determine the control torque that move the panel, in order to generate the cinematically prescribed behaviour.

2. ASPECTS REGARDING THE TRACKING SYSTEMS

For tracking the sun, there are two main types of trackers (fig. 1): single-axis trackers - by one axis (a), and dual-axis trackers - by two axes (b). The single-axis tracker pivots on it axis to track the sun, facing east in the morning and west in the afternoon. The tilt angle of this axis equals the latitude angle of the loco because this axis has to be always parallel with the polar axis. In consequence for this type of single axis tracker is necessary a seasonal tilt angle adjustment. The two-axis tracker follows the sun in both azimuth and elevation, keeping the sun's rays normal to the panel surface. Considering their ability to combine two rotational motions described around perpendicular axis, the two-axis trackers are able to follow very precisely the sun path along the period of one year, and for this reason they are more efficient than the single one.

The panel motions are in according to the relationships exiting between sun and the Earth. The point of interest in sun tracking is to follow the path of the sun on local visible sky. The orientation principle is based on the input data referring to the position of the sun on the sky dome. For the highest conversion efficiency, the sunrays have to fall normal on the receiver so the system must periodically modify its position in order to maintain this relation between the sunrays and the panel. The Earth describes along the year a rotational motion following an elliptical path around the sun. On the other hand, during one day, the Earth also spins around its own axis describing a complete rotation.

The declination angle (δ) is the angular position of the sun at solar noon with the respect to the plane of the equator, and the hour angle (ω) is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour. In these terms, the driving motions of the photovoltaic panel have the following expressions [3]: $\delta=\arcsin\{0.39795\cdot\cos[0.98563\cdot(N-173)]\}$, $\omega=15°\cdot(t-12)$, where N is the day number (N=1...365), and t represents the time hour (t=1...24).

a.

b.

Figure 1: Basic tracking systems.

For this paper, a dual-axis tracking system, with two degrees of freedom, has been taken into consideration (fig. 2). The daily motion is controlled by a gear mechanism; the input gear wheel (i.e. the rotor) is driven by a stepping motor. The seasonal motion is controlled by a linear actuator. The model is designed so that it has 7 moving parts, which are connected one with other, respectively to ground, using geometric constraints, as follows: rotor (1) to ground - revolute joint; reduction gear (2) to ground - revolute joint; azimuth plate (3) to ground - revolute joint; panel support (4) to plate - fixed joint; panel (5) to support - revolute joint; actuator piston (7) to support – revolute joint; actuator cylinder (6) to panel – revolute joint; actuator cylinder to piston - translational joint. At the same time, a rotor gear couples the revolute joint at the rotor to the revolute joint at the reduction gear, and a gear plate couples the revolute joint at the reduction gear to the revolute joint at the plate.

For the kinematic model of the tracking system, in order to control the two degrees of freedom and to move the panel, there are two motion generators (kinematic constraints), which are applied in the revolute joint between rotor & ground, and in the actuator translational joint, respectively.

For the dynamic model, the motion generators are replaced with external torques that move the panel, which are computed by control systems based on the error between the actual panel position and the desired panel position. This is more realistic than attaching motion generators and driving the motion directly; at the same time, by applying a torque, we can look at issues related to motor size in an actual mechanical system.

For this paper, only the daily motion is taken into consideration, so that we are looking for the azimuth control torque that is applied to the rotor. The steps to create the virtual tracking system mirror the same steps to build the physical model, as follows: build - create parts, constrain the parts, create forces acting on the parts, define controls, perform simulations and review numeric results.
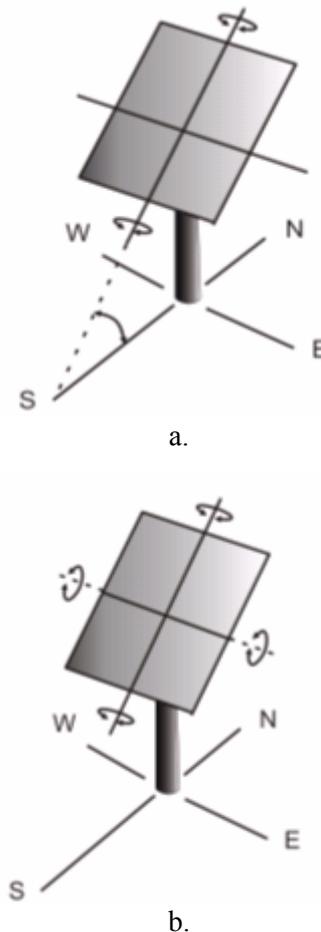
3. CONTROLLING THE PV TRACKER

In order to obtain the torque that moves the panel, a control system is developed using ADAMS/Controls and MATLAB. ADAMS/Control is a plug-in to ADAMS/View that allows integrating motion simulation and controlling system design in the virtual model. ADAMS/Controls allows connecting the ADAMS model to block diagrams that are developed with control applications.

The four-step process of combining controls with a mechanical system involves: build the virtual mechanical model, which includes all necessary geometry, constraints, forces; identify the ADAMS inputs and outputs - the outputs describe the variables that go to the controls application, and the inputs describe the variables that come back into ADAMS; build the block diagram - build the control system block diagram with a control software, and include the ADAMS plant in the block diagram; simulate the combined mechanical model and control system.

In our case, the input in the tracking system model is the control torque. The output, which will be transmitted to the controller, is the azimuth position of the panel (panel support) and the angular velocity of the rotor (fig. 3). ADAMS/Controls and MATLAB communicate by passing state variables back and forth. Therefore, it is necessary to define the model's input and output variables, and the functions that those inputs and outputs reference, with a set of ADAMS state variables.

For the input state variable, representing the control torque, the run-time function is 0.0 during each step of the simulation, because the control torque will get its value from the control application - MATLAB. The run-time function for the input variable is VARVAL(control_torque) [5], where VARVAL (variable value) is an ADAMS function that returns the value of the given variable. In other words, the control torque gets its value from the input variable.

Figure 2: Two-axis tracking system.

Figure 3. Combining ADAMS with MATLAB.

The run-time functions for the output variables are: AZ(MAR_support, MAR_plate) – for the azimuth position (the function returns the angle about the z-axis, the vertical axis about which the panel rotates), and WZ(MAR_rotor, MAR_ground) – for the rotor velocity (the function measures the rotational velocity of the rotor relative to ground).

The next step is for exporting the ADAMS plant files for the control application. The Plant Input refers the input state variable, and the Plant Output refers the output state variable. ADAMS/Controls save the input and output information in an "*.m" file. It also generates a command file (*.cmd) and a dataset file (*.adm), which will be used during the simulation. With these files, the control system is created in MATLAB, in order to complete the link between the controls and mechanical systems (fig. 4).

4. RESULTS AND CONCLUSIONS

The control system is designed in order to rotate the photovoltaic panel with 30 degrees, around the vertical axis, and then to stop the motor. ADAMS accepts the control torque from MATLAB and integrates the mechanical model in response to them. At the same time, ADAMS provides the panel position and the rotor velocity for MATLAB to integrate the Simulink model. This simulation process
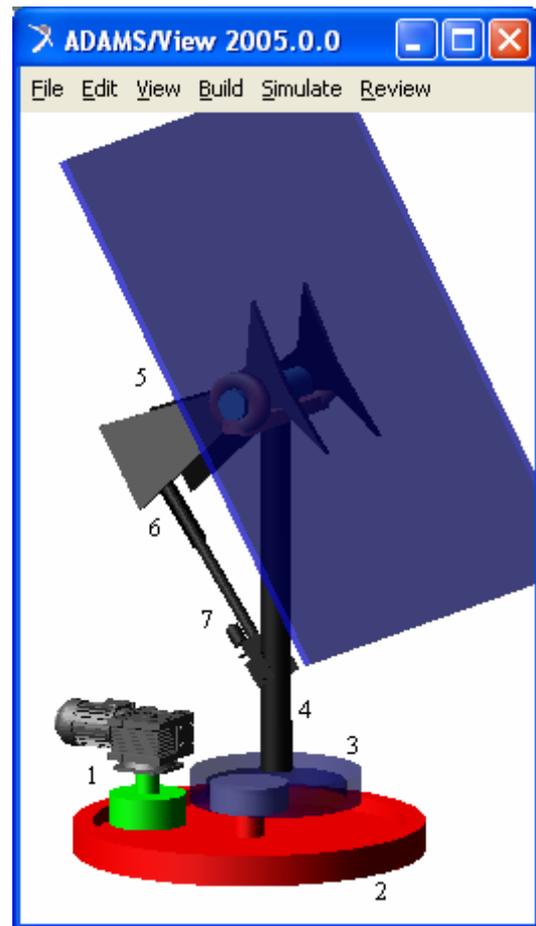
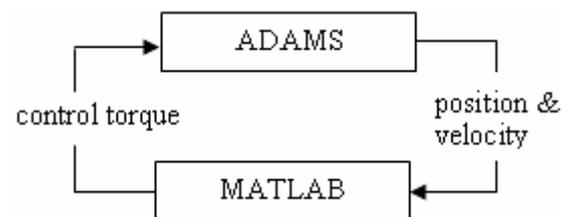creates a closed loop in which the control input from MATLAB affect the ADAMS simulation, and the ADAMS outputs affect the control input level. Connecting the mechanical model (fig. 2) with the control system (fig. 4), specific results are obtained in order to evaluate the dynamic behaviour of the tracking system. For example, in figure 5, there are presented the time - history variations of the rotor velocity, panel position and control torque.
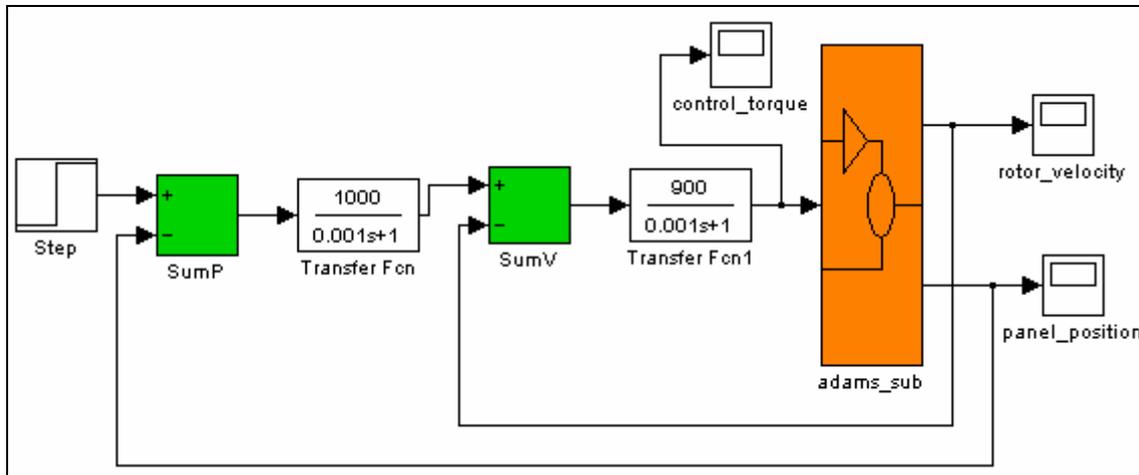

Figure 4. Control block of the tracking system (controlling the daily motion).
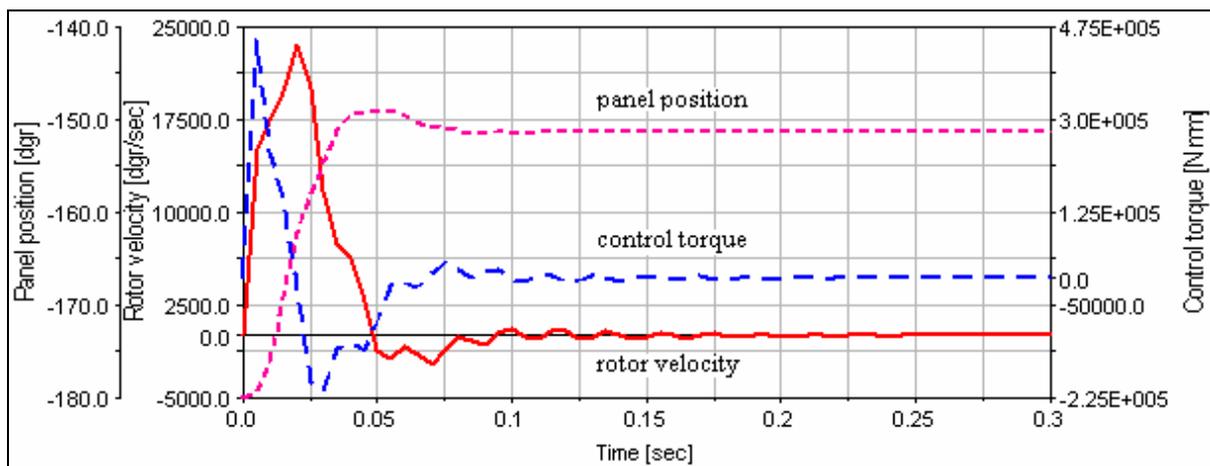

Figure 5. Postprocessing results.

One of the most important advantages of this kind of analysis - simulation is the possibility to perform, fast and easy, virtual measurements in any point and/or area of the system and for any parameter. This is not always possible in the real cases due to the lack of space for transducers placement or lack of appropriate transducers. This helps designers to make quick decisions on any design changes without going through expensive prototype building and testing.

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