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DESIGN OF THE PHOTOVOLTAIC TRACKING SYSTEMS BY CONSIDERING THE ENERGY BALANCE

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ABSTRACT
The paper presents researches in the field of increasing the efficiency of the solar energy conversion in electric energy. The idea is to design a dual-axis tracking system, which changes the position of the photovoltaic panel in order to maximize the solar radiation degree of use. The daily motion is driven by a rotary motor, and for the seasonal motion a linear actuator is used. The tracking system is approached in mechatronic concept, by integrating the control system in the mechanical model. The analysis is made using a virtual prototyping platform that includes the following software: CAD - CATIA, MBS - ADAMS/View, Command & Control - ADAMS/Controls and MATLAB/Simulink. The behavior of the tracking system is evaluated from energetic efficiency point of view.
Keywords: tracking mechanism, control system, virtual prototype, energetic efficiency.

1. INTRODUCTION
The efficiency of the photovoltaic (PV) systems can be increased by using tracking systems, whose aim is to change the position of the photovoltaic panel correlated to the sun position, for maximizing the radiation degree of use (the maximum degree of collecting is obtained when the incident radiation is perpendicular on the panel surface). According to the scientific literature, the orientation of the photovoltaic panels may increase the efficiency of the conversion system up to 50% [1, 3, 4].
Determining the real behavior of the tracking systems is a priority in the design stage since the emergence of the computer graphic simulation. In the previous paper [TMT07-164], for analyzing – optimizing the photovoltaic tracking systems, we developed a virtual prototyping platform, which integrates specific software solutions: CAD - solid modeling, MBS – kinematic and dynamic analysis & optimization, FEA - finite element analysis, Command & Control. At the same time, the simulation algorithm has been defined in the following sequence: kinematic analysis – for evaluating the relative motion between components, inverse dynamic analysis – for determining the turning torque or force applied by the driving element, dynamic analysis – for evaluating the real behavior of the PV system.
The active PV tracking systems are mechatronic products, which integrates mechanics, electronics and information technology. For this paper, the tracking systems are approached in the concurrent engineering philosophy, by integrating the electronic control system in the mechanical structure at the virtual prototype level. In this way, two main aspects can be taken into consideration: optimizing the interaction between the mechatronic system components (mechanics, electronics, and informatics); reducing the cost and time for the design process by replacing the traditional tests on hardware models, which are very expensive, with the testing in virtual environment [2].
In order to accomplish the paper goal, we will use a strategy made by two steps:
- designing the optimal tracker - this design intends to minimize the actuating torques / forces that are needed for tracking the sun movements; the optimization problem uses the dynamic model of the mechanical structure and computes the geometrical parameters of the tracking mechanism;
- designing the optimal control low - the idea is to balance the tracking error with the command signal, in order to minimize the energy consumption of the actuators; this compromise solution is

necessary because by increasing the tracking error, the efficiency of the tracking system will decrees, but decreasing the command signal value, the energetically consumption will also decrees.
These design steps are possible by developing the virtual prototype of the mechatronic tracking system, which is a complex dynamical model. In fact, the virtual model is a control loop composed by the multi-body mechanical model connected with the dynamic model of the actuators and with the controller dynamical model.
The behavior of the PV tracking system is evaluated from energetic balance point of view; the keyword of the design is the energetically efficiency. Using the tracking system, the PV panel follows the sun and increase the collected energy, but the driving actuators consume a part of this energy. In order to identify the optimal solution (which minimizes the energy consumption), we compare two specific possibilities for driving the daily motion: continuous motion during the entire day (without brakes), and step-by-step motion (rotating the panel with equal steps at every hour).

2. VIRTUAL PROTOTYPE OF THE TRACKING SYSTEM

For evaluating the energetic efficiency, a dual-axis tracking system, with two degrees of freedom, has been taken into consideration. The tracking system is used for following the sun in both polar and seasonal directions, keeping the sun's rays normal to the platform surface. The daily motion is directly driven by a rotary motor that is able to develop an angular displacement up to 180 degrees. The seasonal motion is driven by a hydraulic actuator that changes the panel elevation.
The geometry and the characteristics of the conversion system correspond to a Vitovolt 200 photovoltaic panel, which comprises a total of 72 solar cells. The main specifications of this panel are: active surface – 1.26 m^2, weight – 15.5 Kg, rated output – 165 Wp, voltage & current during the maximum power point – 36 V & 4.46 A, idle voltage in standard test conditions (1000 W/ m^2 irradiation) – 43.3 V [7].
The 3D-solid model of the tracking system was made using the CAD software CATIA V5. The geometry was transferred to ADAMS/View using the STEP file format and the specific ADAMS/Exchange module. The virtual model of the tracking system, shown in figure 1, is designed so that it has five parts, which are connected one with other, respectively to ground, using the following geometric constraints: base (1) fixed on the ground; intermediary element (2) mounted on the base – revolute joint (B); hydraulic cylinder (4) to base – revolute joint (E); hydraulic piston (5) to intermediary element – revolute joint (C); cylinder to piston – translational joint (D); motor fixed on the intermediary element; panel (3) to motor (and on the intermediary element) – revolute joint (A).

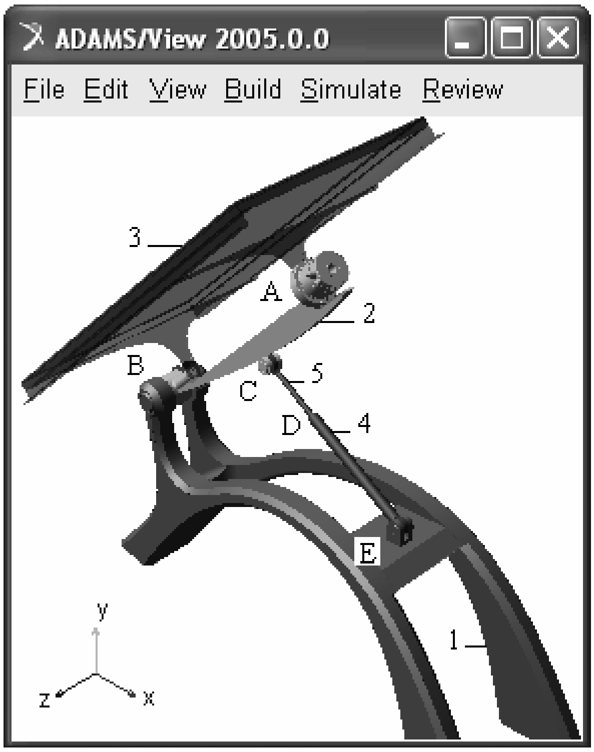

Figure 1. The virtual prototype of the PV system.

For the kinematic model of the tracking system, there are two motion generators, which are applied in the revolute joint between intermediary element and the solar panel, and in the translational joint between the hydraulic piston and cylinder. For the dynamic model, the kinematic constraints are replaced with the polar torque generated by the rotary motor, and the axial force in the linear actuator, respectively. This is more realistic than attaching motion generators and driving the motion directly; at the same time, we can look at issues related to motor size in an actual tracking system.
For this paper, only the daily motion is considered (the elevation position is fixed on 45 degrees – the inclination of the polar axis), so that we are looking for the polar control torque that is applied by the rotary motor. In order to minimize the actuating torque that generates the polar rotation of the panel (for minimizing the energy consumption), we realized the dynamic optimization of the mechanical

structure. As design variables, there was taken into consideration the mounting position of the rotary motor, in fact the global coordinates of the revolute joint A (see fig. 1) between the intermediary element, on which the motor is mounted, and the photovoltaic panel. The revolute axis has to be parallel with the polar axis, and in these terms there is a single independent design variable, for example the horizontal coordinate, $X_A \rightarrow DV\_1$, the vertical coordinate depending on this variable, as well as on the elevation angle, as follows: $Y_A = DV\_1 \cdot tg(45^o)$.

The control system of the optimized mechanical model was developed using ADAMS/Controls and MATLAB/Simulink. ADAMS/Controls is a plug-in to ADAMS/View that allows integrating motion simulation and controlling system design in the virtual model.

For generating the daily motion of the panel, a DC rotary motor is used, the actuating torque depending on the mechanical model of the tracking system, on which acts the external environment. The motor torque represents the input parameter in the mechanical model; the output, which will be transmitted to the controller, is the polar position (angle) of the PV panel (fig. 2). ADAMS/Controls and MATLAB/Simulink communicate by passing state variables back and forth. Therefore, it is necessary to define the input and output variables of the model, and the functions that those inputs and outputs reference, with a set of ADAMS state variables.

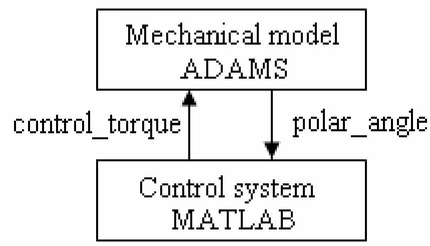

Figure 2. Input & output parameters in the control process.

Therefore, it is necessary to define the input and output variables of the model, and the functions that those inputs and outputs reference, with a set of ADAMS state variables [5]. For the input state variable, the run-time function is 0.0 during each step of the simulation, because the torque will get its value from the control application. The run-time function for the input variable is VARVAL(control_torque), where VARVAL is an ADAMS function that returns the value of the given variable. For the output state variable, the run-time function returns the angle about the polar axis (about which the panel rotates).

The next step is for exporting the ADAMS plant files for the control application. The Plant Input refers the input state variable (control_torque), and the Plant Output refers the output state variable (polar_angle). The input and output information are saved in a specific file for MATLAB (*.m). ADAMS also generates a command file (*.cmd) and a dataset file (*.adm) that will be used during the simulation [5, 6]. With these files, the control system block was created in Simulink, in order to complete the link between the control and mechanical systems (fig. 3). ADAMS accepts the control torque from MATLAB and integrates the mechanical model in response to them; at the same time, ADAMS provides the current polar angle for MATLAB to integrate the control system model.

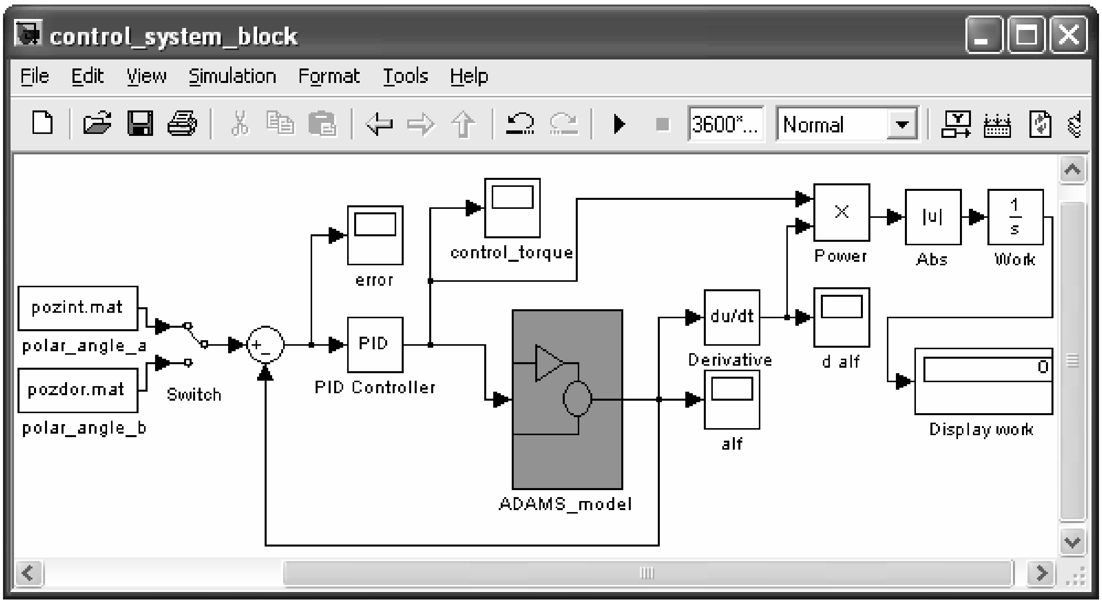

Figure 3. The control system block.

3. RESULTS AND CONCLUSIONS

For identifying the optimum energetic consumption, we compared two specific variants for driving the daily motion, as follows (see fig. 3, 4): step by step motion, rotating the panel with equal steps at every hour - 15º (a, polar_angle_a), and continuous motion during the entire day, without brakes (b, polar_angle_b). In the control system block, there is a switch for commutating between these variants.

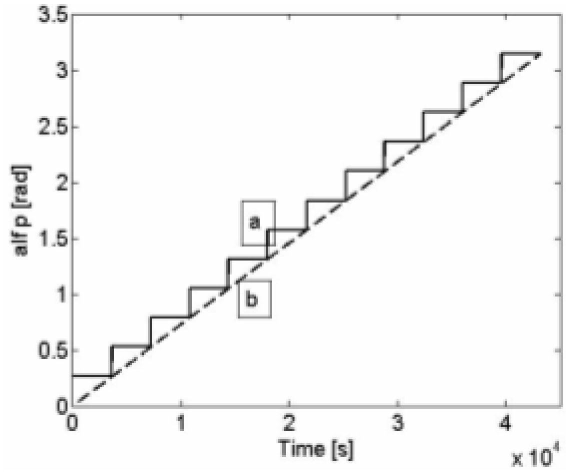

Figure 4. The desired trajectories (a – step by step, b - continuous).

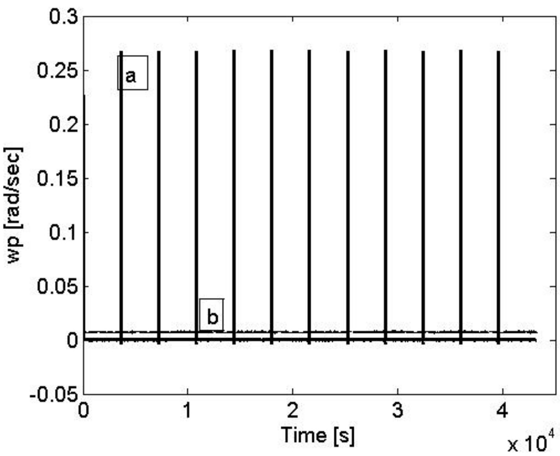

Figure 5. The angular velocities of the controlled tracker.

As evaluation parameter for the energetic efficiency, we have chosen the mechanical work consumed for the panel rotation around the polar axis; the simulation was made for 12 hours. In the first case (a), the obtained mechanical work is 0.06308 J, respectively 1.853e-6 J for the second case (b). This difference is because of the over-shootings that can be observed in figure 5. More precisely, each time when the panel performs a step, there is maximum energy consumption, so that the optimal actuating mode corresponds to the continuous motion (without brakes). In the future work, we intend to optimize the control strategy in order to obtain a maximum energetically balance, considering the supplement of energy obtained by tracking (the balance between energy inflow and energy outflow).

One of the most important advantages of this kind of simulation, based on virtual prototyping tools, is the possibility to perform virtual measurements in any point and/or area of the PV system and for any parameter (motion, force, energy). 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 us to make quick decisions on any design changes without going through expensive prototype building and testing. With virtual prototyping, behavioral performance predictions are obtained much earlier in the design cycle, thereby allowing more effective and cost efficient design changes.

4. ACKNOWLEDGEMENT

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