Dynamic optimization of a 2-DOF pseudo-equatorial tracking system in virtual prototyping concept

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Abstract. The key word for the design process of the photovoltaic tracking systems is the energetic efficiency. Using the tracking system, the photovoltaic panel follows the sun and increase the collected energy, but the driving motors & actuators consume a part of this energy. In these terms, the optimization of the tracking system became an important provocation in the modern research and technology. In our paper, we evaluate a strategy for the dynamic optimization of the photovoltaic tracking systems. The main task in optimization is to maximize the energetic gain by increasing the incoming solar radiation, and minimizing the energy consumption for tracking. This study is performed by developing the virtual prototype of the tracking system, which is a control loop composed by the multibody mechanical model connected with the dynamic model of the actuators, and with the controller model.

Key words

Photovoltaic panel, optimization, tracking mechanism, control system, virtual prototype, energy balance.

1. Problem Statement

Solar energy conversion is one of the most addressed topics in the field of renewable energy systems. The technical solution for converting the solar energy in electricity is well-known: the photovoltaic systems. The energetic efficiency of the photovoltaic systems depends on the degree of use and conversion of the solar radiation. There are two ways for maximizing the rate of useful energy: optimizing the conversion to the absorber level, and increasing the incident radiation rate by using mechanical tracking systems.

The key word for the design process of the tracking systems is the energetic efficiency; using the tracking system, the photovoltaic panel follows the sun and increase the collected energy, but the driving motors & actuators consume a part of this energy. The tracking system is efficient if the difference among the energy produced by the photovoltaic panel with tracking system and the same panel without tracking system (fixed) is larger than the energy consumption for orientation.

Determining the real behaviour of the tracking system is a priority in the design stage since the emergence of the computer graphic simulation. Important publications reveal a growing interest on analysis methods for multi-body systems (MBS) that may facilitate the self-formulating algorithms. In the last decade, a new type of studies was defined through the utilization of these programs: virtual prototyping. This simulation technique consists in conceiving a detailed model and using it in a virtual experiment, in a similar way with the real case.

In the above-presented conditions, our contributions can be structured in the following directions: developing a general method, based on the MBS theory, for the structural synthesis of the tracking systems; developing a mathematic model for establishing the incident solar radiation; developing the analysis & optimization flow-chart; developing the virtual prototyping platform for simulating the tracking systems in real operating conditions; developing the control system and integrating the control in the mechanical model of the tracking system at the virtual prototype level; evaluating the energetic efficiency of the tracking systems.

2. Optimization Strategy

The main task in optimization is to maximize the energy gained through the step-by-step orientation, for absorbing a quantity of solar energy closed by the ideal case (continuous orientation), and to minimize the energy consumption for tracking. The optimization is made by reducing the angular field of the axes and the number of steps (in fact, the operating time of the motors), without significantly affecting the incoming solar radiation.

The optimization study is performed by developing the virtual prototype of the tracking system, which is a control loop composed by the multi-body mechanical model connected with the dynamic model of the motors and with the controller dynamical model. The virtual prototyping platform includes CAD (CATIA), MBS (ADAMS/View), and C&C (MATLAB/Simulink & ADAMS/Controls) software solutions.

The application is made for a pseudo-equatorial tracking system, with two degrees of freedom, which is able to follow very precisely the sun path along the period of one year. The two independent motions (i.e. the daily motion and the elevation motion) are performed using linear actuators (fig. 1). The panel is mounted on a support, which rotates around a horizontal axis for generating the elevation. The daily motion is made by rotating the panel relative to the support.

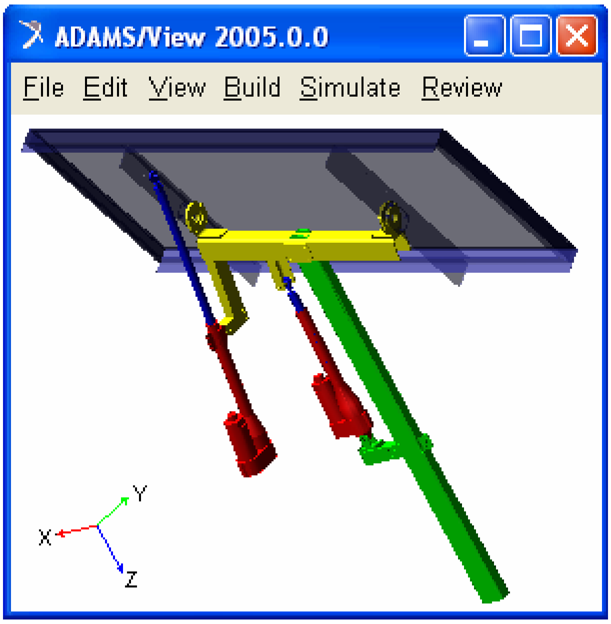

Fig. 1. The virtual prototype of the tracking system.

The solution for the system was selected from the multitude of the structural solution by using of the Multi Criteria Analysis. The evaluation criteria of the solutions were referring to the tracking precision, the amplitude of the motion, the complexity of the system, design and easy manufacturing and implementation. The structural synthesis is made using a method based on the Multi-Body Systems (MBS) theory.

For obtaining more realistic results, we have developed the control system of the tracking system in concurrent engineering concept. For realizing the connection between the MBS mechanical model and the control system, we defined the input & output parameters of the controlled process. The motor torques for the daily & elevation motion represent the input parameters in the mechanical model. The outputs, which are transmitted to the controller, are the daily & elevation angles of the panel. For controlling the system we used two PID controllers; the phase and gain margins were established for obtaining a robust controller for the entire interval.

The mathematic model for estimating the solar radiation takes into consideration the extraterrestrial radiation, the solar constant, the day number during a year, the distortion factor, the solar altitude angle, the solar declination, the location latitude, the solar hour, the local solar time, the diurnal and seasonal angles of the sun's rays, the daily and elevation angles of the panel, and the azimuth angle. With this mathematic algorithm, we are able to estimate the incident radiation in every day during a year, for different locations and tracking strategies. In this paper, the numeric simulations were performed for the Braşov area, in the summer solstice day.

Intending to minimize the energy consumption, we have adopted a solution in which the orientation is made in steps. The tracking strategy uses optimal algorithms based on the number of steps necessary for orientation. The algorithms are developed considering the correlation between the maximum amplitudes of the motion and the number of the tracking steps. In this way, we obtained the optimal variations of the daily & elevation angles. With these motions, we have obtained the variation of the incident radiation, and the energy (mechanical work) produced by the panel.

On the other hand, using the mechatronic model of the tracking system, we have obtained the energy consumption for realizing the imposed tracking law, which depends on the control torques generated by the driving motors, as well as the angular velocities of the input elements. For the step by step tracking, the energy consumption curves are shown in figure 2 (a - daily motion, b - elevation, c - total consumption). In these conditions, we have obtained an energy contribution of 39.5% by tracking the sun relative to the fixed panel case.

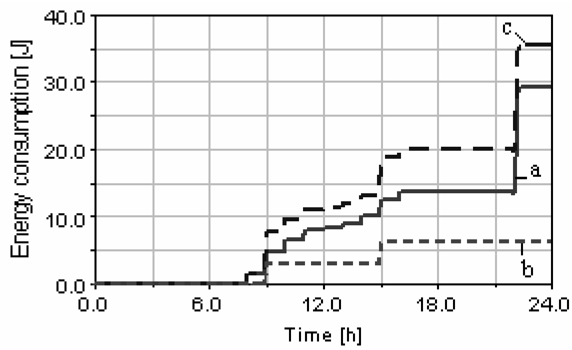

Fig. 2. The energy consumption for orientation.

One of the most important advantages of this kind of simulation is the possibility to perform virtual measurements in any point and/or area of the system and for any parameter. This helps us to make quick decisions on any design changes without going through expensive prototype building and testing.

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