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DESIGNING AND OPTIMIZING THE CONTROL SYSTEM FOR A PSEUDO-AZIMUTHAL SUN TRACKER

Monica Alina IONIŢĂ[1]

Abstract: *Increasing the conversion efficiency of the solar energy into electricity is one of the most addressed topics in the field of renewable energy systems. This study is focused on the optimal design of the control system for a pseudo-azimuthal sun tracker, which is used to move a platform of PV strings. The tracking system is approached in mechatronic concept, by integrating the control system and the mechanical device at the virtual prototype level. The optimization is performed by using parametric design technique, the design variables for optimization being the amplification factors of the controllers. The optimization study leads to the maximization of the incident solar radiation gain by minimizing the tracking errors.*

Key words: *solar tracker, photovoltaic platform, control system, controller, optimization.*

1. Introduction

The researches in the domain of renewable energy systems represent a priority at global level, because these systems provide viable alternatives to a series of major problems: the limitative and pollutant character of the fossil fuels, the global warming, and the greenhouse effect.

The sun is the most important source of renewable energy, the current technique allowing the conversion of solar radiation into thermal and electric energy. The method of converting the solar radiation into electricity is well known: the photovoltaic (PV) effect [13].

The energetic efficiency of the PV system depends on the degree of use of solar radiation, which can be maximized by using tracking mechanisms for the orientation of the photovoltaic modules. The tracking mechanisms can bring a growth of energetic efficiency of the photovoltaic systems from 20% up to 50% [1-3], [9-12].

The key word in designing tracking systems is the energetic efficiency. A photovoltaic system with sun tracker is efficient if the following condition is assured [6]:

$$\varepsilon = E_T - (E_F + E_C) >> 0, \qquad (1)$$

where E_T is the amount of electricity produced by the photovoltaic module with tracking system, E_F - the amount of energy produced by the equivalent PV system without tracking (fixed), E_C - the amount of energy that is consumed in the tracking.

[1] Centre "Renewable Energy Systems and Recycling", *Transilvania* University of Braşov.

In the current conditions, the maximization of the energetic efficiency through the optimal design of the tracking system became an important challenge in the modern research and technology.

The tracking systems are actually mechanisms actuated by electrical motors, commanded/controlled in order to ensure the optimal position of the module relative to the sun position on the sky dome. The earth describes throughout the year an elliptical rotational motion around the sun, and on the other side, during a day, a complete rotation around its own axis.

Considering the two motions (daily and seasonal), there can be systematized two fundamental types of tracking mechanisms: mono-axis, respectively dual-axis. The mono-axis tracking mechanisms are used for performing the daily motion, the elevation angle of the rotation axis, parallel to the polar axis, corresponding to the latitude of the location. Therefore, for these systems it is necessary a seasonal adjustment of the rotational axis tilt [5].

The dual-axis tracking mechanisms combine the two motions (daily and seasonal), so that they ensure a precise orientation of the photovoltaic module without the need of further positioning adjustments. Regarding how the rotational axes are located, there can be distinguished two types of dual-axis systems: equatorial systems, where the daily motion axis is parallel with the polar axis, respectively azimuthal systems, at which the daily motion axis is vertically disposed.

This paper presents the concept of integrated analysis - optimization - simulation of the tracking systems by using a digital software platform for virtual test environment. The tracking mechanism in study is a pseudo-azimuthal system, in the bi-axial variant, which is derived from the azimuthal system, having the main/daily rotational axis positioned on the horizontal (North-South). Its main advantage is the stability of the structure, being the best option for orientating the platforms of photovoltaic modules strings (modules mounted on individual strings, which are arranged on a platform type common frame).

The mechanical device of the pseudo-azimuthal solar tracker was described and optimized in [6]. The mechanical model (Figure 1) was developed in multi-body system concept by using the MBS software environment ADAMS.

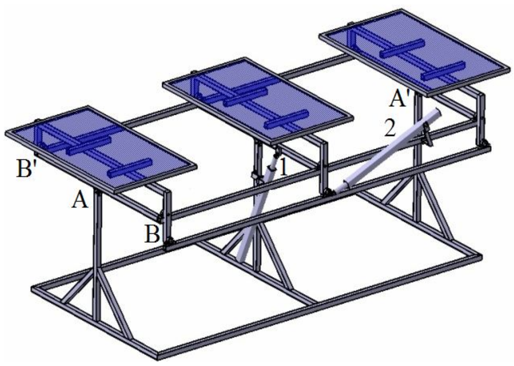


Fig. 1. *The MBS model of the pseudo-azimuthal tracking system (ADAMS)*

The system uses two linear actuators as driving sources: actuator “1” acts directly on the platform frame, thus generating the daily motion (around the axis A-A’), while actuator “2” moves the rod of a multi-parallelogram mechanism, which transmits the elevation motion (around B-B’) between the three photovoltaic strings/ modules.

The purpose of the present paper is to optimize the pseudo-azimuthal tracking mechanism from the control system (controller) point of view. The optimization of the control system is focused on minimizing the tracking errors. The control system of the solar tracker was developed in mechatronic concept, using the DFC (Design for Control) software environment EASY5.

2. Designing and Optimizing the Control System

The pseudo-azimuthal tracking system for the PV platform is a mechatronic system, which integrates the mechanical device and the actuating & control device. The control system is developed in the concept of the concurrent engineering, through the integration with the MBS model (shown in Figure 1) at the level of the virtual prototype. In this respect, the virtual prototyping platform integrates a software solution of DFC type (Design for Control), which exchanges information (export - import) with the MBS software (output from MBS means input in DFC and vice-versa).

The simulation algorithm implies, besides conceiving the MBS model of the mechanical device, the following stages: identifying the input and output plants (the output describe the variables transmitted by the DFC application, while the input describes the variables returned in the MBS application); importing and configuring the MBS interface block in the DFC software, designing the block diagram of the control system; synthesizing the controller, and co-simulating the mechatronic system [4].

For the present paper, a single-loop control system has been selected, the monitored/controlled parameter being the daily/elevation angle of the PV platform (modules).

To ensure the communication between the mechanical device (MBS ADAMS) and the control system (DFC EASY5), the input and output plants have been defined. For the input variable, representing the motor force in the actuator, the time function has the value 0.0, because the variable follows to receive its value from the control application. For the output variable, the function returns the daily/ elevation position angle of the platform, which was modeled by using the "Angle about Axis" function. For example, Figure 2 shows the communication scheme between the mechanical device and the control system for the daily motion of the PV platform.

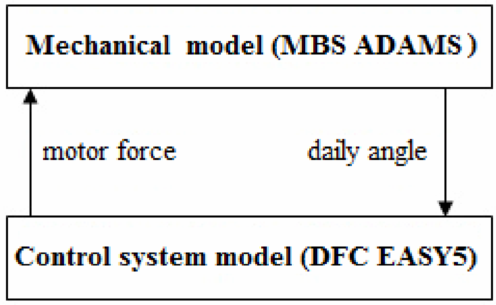


Fig. 2. *The input & output plants*

The information about the input & output plants are saved in a file with the extension "inf" (specific for EASY5). Also, there is generated a command file "cmd" (for ADAMS/View) and a database file "adm" (for ADAMS/Solver), which will be used during the simulation. The configuration of the ADAMS interface block (which is an extension library in EASY5) involves selecting the "inf" file and setting the execution mode (in this case, co-simulation).

From the controller point of view, several variants from the PID (Proportional-Integral-Derivative) family have been investigated, in order to identify the simplest controller that ensures appropriate behavior of the system (in terms of stability and robustness).

The PID family contains controllers with fixed structure, which can achieve the objectives imposed by changing the parameters of the transfer function. The following advantages of this family can be mentioned: easy practical realization, which leads to a low price; facile tuning; solving various targets on the specific performance indexes (e.g. stationary error, overshoot).

The controller tuning (intending to determine the optimal values of the specific factors: *KP* - proportional, *KI* - Integral, *KD* - derivative) can be achieved through various methods from the control system theory, including root locus, frequency method and others [8]. In this paper, the controller tuning is approached as a parametric optimal design, the optimization procedure being similar to that used in [7] for optimizing of the MBS mechanical model of the tracking system.

There are the following specific data for the optimization process:

- design variables - the tuning factors of the controller;
- design objective - the tracking error (the difference between the imposed daily/elevation angle and the current measured value - see Figure 3);
- monitored value of the design objective - the root mean square (RMS);
- optimization purpose - minimizing the monitored value of the design objective.

In what follows, the optimization algorithm of the control system with PID controller (shown in Figure 3) will be described, the procedure for the other types of controllers (PD, PI, P) being similar. The study is developed for the daily motion of the system, considering a step of 30°, which is performed in 60 seconds.

For accessing the parametric optimization capabilities, which are integrated in the MBS software package ADAMS, the control system model has been transferred in ADAMS through the ESL (External System Library) format. Once imported in ADAMS, in the form of a general state equation, the parameterized model of the control system, coupled with the MBS model of the mechanical device, becomes available for optimization.

As a result of the parametric optimization, the optimal values of the PID controller factors have been obtained, as follows: $KP = 4.73 \cdot 10^8$, $KI = 1$, $KD = 5.23 \cdot 10^8$. With these values, the time-history variation of the tracking error is shown in Figure 4a. The root mean square value is very small, $RMS = 1.48 \cdot 10^{-6}$, and this demonstrates the viability of the adopted optimization technique.

Afterwards, the optimization algorithm has been applied to the other types of controllers from the PID family (PI, PD, and P), obtaining the following results:

- controller PI (Figure 4b): $KP = 4.8 \cdot 10^8$, $KI = 1$; $RMS = 1.44 \cdot 10^{-6}$;
- controller PD (Figure 4c): $KP = 6.7 \cdot 10^8$, $KD = 5.01 \cdot 10^5$; $RMS = 1.69 \cdot 10^{-6}$;
- controller P (Figure 4d): $KP = 6.71 \cdot 10^8$; $RMS = 1.69 \cdot 10^{-6}$.

Analyzing these results, it was found that all types of controllers (PID, PI, PD, and P) ensure appropriate behavior of the tracking system (very small tracking errors, with the root mean squares around 10^{-6}). Under these circumstances, the optimal variant retains the simplest/ cheapest controller type, namely the proportional controller (P).

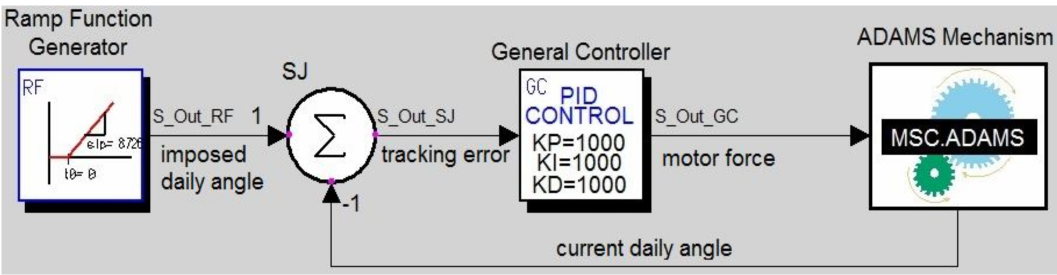
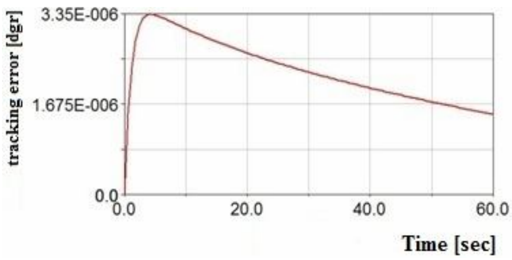
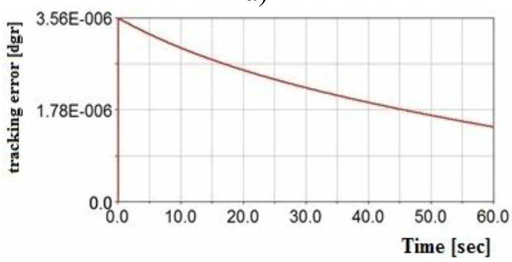


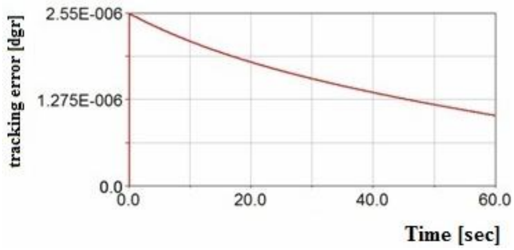
Fig. 3. *The control system with PID controller (EASY5)*



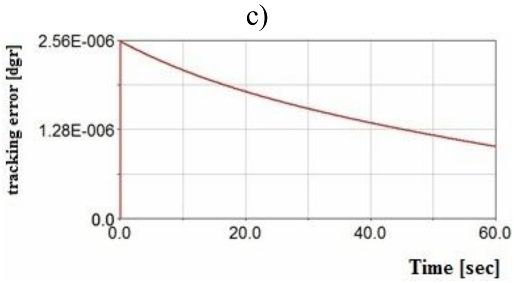
a)



b)



c)



d)

Fig. 4. *The tracking error for the daily motion*

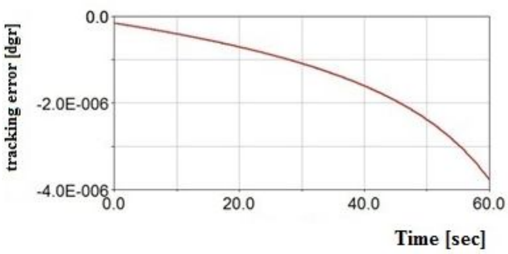


Fig. 5. *The tracking error for the elevation motion (controller P)*

This type of controller has also been implemented for the elevation motion, with the proportional term *KP* = $6.71 \cdot 10^8$. For the same simulation conditions (30 degrees, in 60 seconds), the time-history variation of the tracking error is shown in Figure 5, the root mean square during simulation being *RMS* = $1.64 \cdot 10^{-6}$. Therefore, the proportional controller operates very well for the both motions (daily and elevation).

3. Final Conclusions

By integrating the mechanical device of the tracking mechanism and the control system at the virtual prototype level (modelling in the concurrent engineering concept), the risk that the mechanical model does not follow the control law can be minimized. The virtual prototype allows the evaluation of several tracking strategies (regarding the angular motion field, the number of tracking steps, the operating/ actuating time), in order to increase the energetic efficiency of the PV system, by maximizing the incident solar radiation, and minimizing the energy consumption during tracking.

The future researches in the domain will target mainly the following aspects: evaluating some more complex control strategies (for instance, with three loops/ contours, for the control in position, velocity and current); physically implementing the tracking system in the solar park from the Research Institute of the Transilvania University of Braşov.

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