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DYNAMIC ANALYSIS & SIMULATION OF THE PHOTOVOLTAIC TRACKING SYSTEMS

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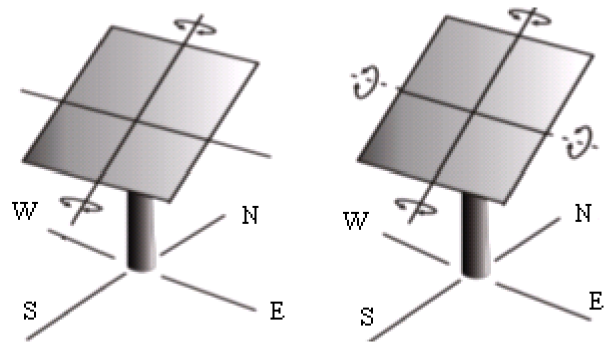
ABSTRACT
The paper presents researches in the field of increasing the efficiency of the solar energy conversion by using tracking systems whose aim is to change the position of the solar panel correlated to the sun position for maximizing the radiation degree of use. The solar trackers are modeled in mechatronic concept, by integrating the control system in the mechanical model at the virtual prototype level. For evaluating the dynamic behavior of the solar 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.
Keywords: tracking system, mechatronics, virtual prototype, dynamic analysis.

1. INTRODUCTION
The efficiency of the photovoltaic systems, which transform the solar radiation in electric energy, depends on the degree of use and conversion of the solar radiation. When performing the energy balance on the solar panel, reference is done to the surface that absorbs the incoming radiation and to the balance between energy inflow and energy outflow. There are two ways for maximizing the rate of useful energy: optimizing the conversion to the absorber level, and decreasing the losses by properly choosing the absorber materials; increasing the incident radiation rate (the maximum degree of collecting is obtained when the incident radiation is perpendicular on the active surface).
In these terms, the paper presents researches in the field of increasing the efficiency of the solar energy conversion by using tracking systems whose aim is to change the position of the solar panel correlated to the sun position for maximizing the radiation degree of use. Basically, the tracking systems are mechanical devices (i.e. mechanisms), driven by rotary motors or linear actuators, which orient the panel in order to follow the sun path on the sky. The orientation of the solar panels may increase the efficiency of the conversion system up to 50% [1, 9].
Determining the real behavior of the tracking systems 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, having as main goal the reducing of the processing time in order to make possible real-time simulation [4, 7]. In the last decade, a new type of studies was defined through the utilization of the MBS software: Virtual Prototyping. This technology consists mainly in conceiving a detailed model and using it in a virtual experiment, in a similar way with the real case. No longer is it necessary to wait months to build a hardware prototype, instrument it, run tests on it, and make a small number of expensive modifications to it in order to assess proposed design changes. 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 (motion, force etc.). 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.

2. ANALYZING THE TRACKING SYSTEMS

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 positions of the Sun on its path along the year represent an input data in designing the solar trackers. Consequently, for the design process of the tracking systems, there are taken into consideration two rotational motions: the daily motion, and the yearly precession motion.



a. b.
Figure 1. Basic tracking systems.

In these terms, there are two fundamental ways to track the sun: by one axis, or by two axes (fig. 1). The single-axis tracking systems (a) pivot on their 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 tracking systems is necessary a seasonal tilt angle adjustment. The two-axis trackers (b) combine two rotational motions (i.e. the daily motion, and the seasonal motion), so that they are able to follow very precisely the sun path along the period of one year. That's why the dual-axis tracking systems are more efficient than the single-axis trackers, but also more expensive because they are using electrical and mechanical components (parts).

The modern design process [5, 8], applied to the tracking systems, involves conceptual and functional design, command & control, digital mock-up, virtual prototyping and testing. The conceptual design has as main objective to establish the best product concept (in the given conditions, by performing an efficient management of information picked by the science, technology, economy, market, culture, legislation, policy). The functional design involves identifying, modeling and evaluating the operational performances of the tracking systems, and the deviations from the imposed characteristics, with other words the mode in which the tracking systems responses to the design requirements.

The analysis algorithm of the tracking systems involves the development of three mechanical models: the kinematic model, the inverse-dynamic model, and the dynamic model, respectively. The kinematic model contains the component parts, which are connected through geometric constraints, and the specific geometric parameters; the input is made using kinematic restrictions (motion generators) that controls the angular or linear position / velocity of the driving elements. The inverse dynamic model includes the kinematic model and, in addition, the external and internal loading; this model is used to determine the turning moment or force applied by the driving element. Finally, the dynamic model includes the inverse dynamic model, but the input is made through the above-determined torque / force; the aim is to evaluate the "real" behaviour of the tracking system.

The traditional design practices focused on a concept referred to as art-to-part, for obtaining higher quality parts [6]. Unfortunately, optimal part design rarely leads to optimal system design. The interaction of form, fit, function, and assembly of all parts in a product is a major contributor to overall product quality. The big opportunity to increase quality and reduce time and cost has now shifted to the system level. Therefore, the growth in simulation-based design tools has now shifted away from traditional CAD/CAM/CAE software and toward these newer system-focused solutions. Specifically, these system-level solutions include Digital Mock-Up (DMU) tools to investigate product form and fit, and Functional Virtual Prototyping (FVP) tools to assess product function and operating performance.

The Digital Mock-Up solutions that make efficient use of tessellated three-dimensional component solid models, while the Functional Virtual Prototyping solutions make efficient use of three-dimensional component solid models and modal representations of component finite element models to accurately predict the operating performance of the product in virtual lab tests and virtual field tests. The combination of these modern techniques provide a means for realizing an effective transition from hardware prototyping practices to software prototyping practices with all of the concomitant benefits.

Typically, the virtual prototyping platform includes CAD, MBS and FEA programs [2]. The CAD environment is used to create the geometric model of the system, which contains information about the mass and the inertia properties of the bodies (rigid parts). The MBS software, which represents the central component of the virtual prototyping platform, is used for analyzing, optimizing and simulating the kinematic and dynamic behavior of the mechanism. The FEA software is used for modeling flexible components (deformable bodies, compliant joints) in mechanism, which allows capturing inertial and compliance effects during simulation, and predict loads with greater accuracy, therefore achieving more realistic results. At the same time, using the FEA software, durability studies can be performed, in order to evaluate the product lifecycle.
In addition, a modern virtual prototyping platform includes a PDM software product, in order to assure the product data management. The PDM technique is the glue that enables the main components of the virtual prototyping platform to be successful by making all of the up-to-date component data readily available and manageable.
The photovoltaic tracking systems are, in fact, controlled systems (i.e. mechatronic systems), which integrates mechanics, electronics and information technology. In this concept, the design of the controlled tracking systems is made in two steps: the synthesis of the fixed part (which contains the electric motor and the mechanical system), and the synthesis of the controller. From the controller synthesis point of view, several possibilities are known, starting by classical PID family controller and ending by robust or adaptive controller [3]. Once again, the important aspect of this problem is to be able to use the electro-mechanical model for controller synthesis, to use the well know controller synthesis algorithms for this models. A possible solution of controller synthesis is the utilization of software products like MATLAB - MathWorks Company or EASY5 – MSC Software, which allow the combination between the mechanical model, the actuator and the generator models and also has several toolboxes for controller design.
In the typical design process of a tracking system with controls, the mechanical designer and the controls designer work from the same concept, but use different sets of software tools. The result is that each designer produces a model for the same problem. Each design is then subject to verification and testing, and the first time the two designs are brought together is during physical prototype testing. If a problem occurs during the interaction between the controls design and the mechanical design, the engineers must refine the control design, the mechanical design, or both, and then go through the entire verification process. Integrating the control system in the mechanical model of the tracking mechanism, the two designers can share the same mechanical model (fig. 2); they can also verify from one database the combined effects of a control system on a nonlinear, non-rigid model. The physical testing process is greatly simplified, and the risk of the control law being poorly matched to the real system is eliminated.

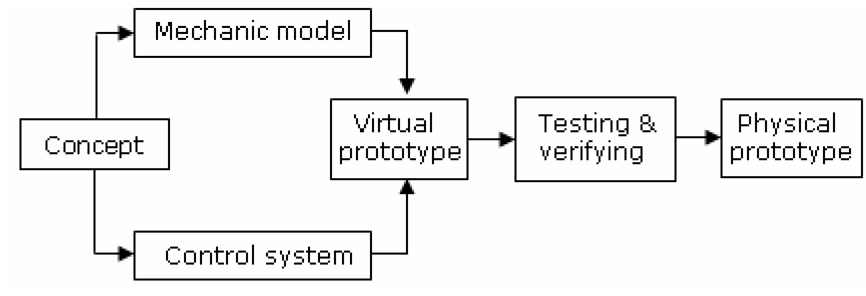


Figure 2. The concurrent engineering model.

In these conditions, the virtual prototyping platform has to include a control software product, which directly exchanges information (import – export) with the MBS automatic analysis software; the output from the MBS model is input for the control system and vice-versa [2]. In the concurrent engineering concept, the analysis algorithm of the mechatronic tracking systems is made in two steps:

- regarding the MBS software: designing – realizing the mechanical model (including bodies, joints, elastic and damping elements, external forces and torques); analyzing the dynamic model; identifying the inputs and outputs, which complete a closed loop between the MBS model and the control application; exporting the obtained model;

▪ regarding the control application: importing the mechanical model block; explaining the mechatronic system trajectory in the task space and defining the input block diagram (the synthesis of the reference signals); designing the control system block diagram; designing the controller and the interface electric circuits; simulating the mechatronic system.

The simulation process creates a closed loop in which the control inputs from the control application affect the MBS simulation, and the MBS outputs affect the control input levels. Generally, in literature, as reference parameters, there are taken into consideration the positioning angles of the photovoltaic panel (or panel support), namely the polar and the declination angles, respectively the azimuth and elevation angles, depending on the orientation scheme (rotation around the polar or azimuth axis); at the same time, the angular velocity of the rotor is considered as reference signal. As output parameter from the control system (input parameter for the MBS model), there is usually taken into consideration the motor torque or force applied to the driving element [1, 9].

In addition, by integrating in the virtual prototyping platform a specific software for designing and simulating solar systems (ex. VALENTIN PV-SOL), the functionality of the photovoltaic tracking system can be evaluated from energetic balance point of view (the contribution of energy that is obtained by tracking versus the material and energetic cost prices, including the energy consumed by the driving motors & actuators).

Having in view these aspects, the structure of a complete virtual prototyping platform used for analyzing the photovoltaic tracking systems, is shown in figure 3. Such platform is used in our next paper [TMT07-165], by integrating licensed software products from the Centre Product Design for Sustainable Development in the "Transilvania" University of Braşov. A dual-axis tracking system is taken into account, the functionality of the photovoltaic system being evaluated from kinematic and dynamic point of view (i.e. motions, forces), as well as from energetic efficiency point of view.

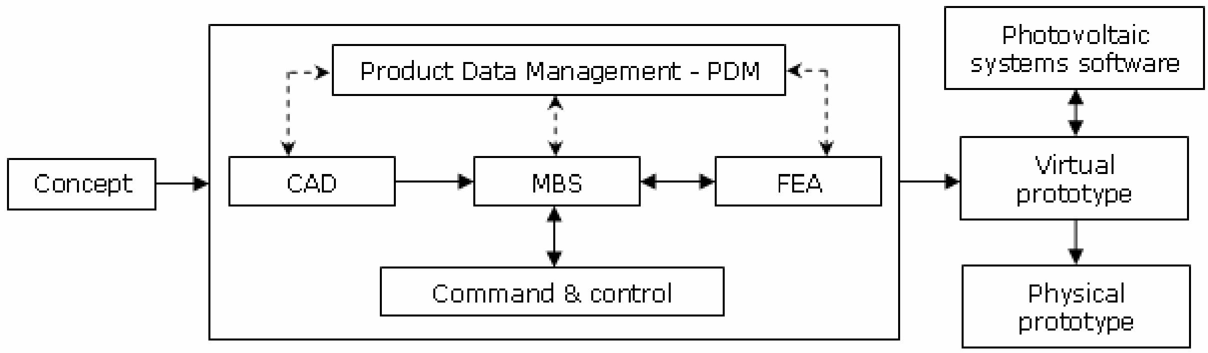


Figure 3. The virtual prototyping platform.

3. ACKNOWLEDGEMENT

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