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Dynamic optimization of a dual-axis solar tracker for PV modules

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Abstract. This paper deals with the dynamic optimization of the dual-axis tracking mechanism, which is used for increasing the energetic efficiency of a photovoltaic module, by maximizing the rate of incident solar radiation. The study is based on the optimal design algorithm included in the commercial MBS (Multi-Body Systems) software solution ADAMS, through the parameterization of the virtual model, which offers the possibility to perform a series of studies aiming at identifying the design parameters that decisively influence the dynamic behavior of the tracking systems. The global coordinates of the design points (i.e. the mounting points of the actuating sources) are defined as design variables for the optimization process, while the design objectives refer to the power consumptions of the actuating sources.

1. Introduction

The continuous diminution of fossil fuel resources has led the energy market to turn to the renewable resource systems industry, which can obtain electricity and heat through environmentally-friendly and non-polluting methods. So, the sun, water, wind, geothermal energy and biomass are increasingly used to generate energy. Solar energy is the most important source of renewable energy and offers enormous potential to generate green energy without emissions of pollutant gases into the atmosphere. A viable solution for increasing the efficiency of solar energy conversion systems (photovoltaic or thermal panels) is the use of tracking mechanisms that change the position of the panel to maximize the amount of incident solar radiation.

Depending on the two axes of motion of the earth, the tracking systems may be bi-axial and mono-axial. The dual-axis tracking systems provide precise positioning by performing the diurnal and seasonal movements [1-5]. The mono-axis tracking systems are frequently used for the diurnal motion of the panel, the seasonal position being fixed at an optimal angle predefined to the location (i.e. the elevation angle) [6-9]. The mono-axis systems have the advantage of low cost due to lower number of elements and drive with a single motor, but have the disadvantage of lower energy efficiency relative to the dual-axis systems.

Given the working principle, two basic types of tracking systems can be identified: passive and active. The operation of passive orientation systems is usually based on the thermal expansion of a Freon-based fluid from one corner of the system to the other because of the heat sensitivity of the working fluid. The active tracking systems are mechatronic systems based on electrically driven positioning devices, including motors (rotary or linear actuators), speed reducers, linkages, couplings, etc. The orientation of solar panels by active tracking systems can increase the efficiency of the conversion system with values between 20% and 50% relative to the fixed panel situation [10-16].



By using MBS commercial software (such as ADAMS - Automatic Dynamic Analysis of the Mechanical Systems), given the computing power and the facilities they provide, as pointed out in [17-23], true virtual prototypes for the tracking systems can be designed, with a view to obtaining products that function properly to meet the high market demands. This means that faithful modeling of both the components of the tracking system and its operating conditions can be achieved, which allows for rapid testing of numerous geometric - constructive variants in order to optimize the system.

The use of a virtual prototype platform allows for the possibility that, once the digital prototype is designed, the optimization of the mechanical tracking system can be easily done by modifying some specific features, mainly geometrical. Thus, a multitude of constructive variants can be tested regarding the location and the characteristics of the tracking system elements, mass distribution and so on, at reduced costs compared to the optimization based on the physical prototype construction and testing.

This paper deals with an optimization model based on the optimal design algorithm included in the ADAMS software, through the parameterization of the virtual model, which offers the possibility to perform a series of studies aiming at identifying the design parameters that decisively influence the dynamic behavior of the tracking systems. The case study is developed by considering an equatorial dual-axis tracking system, which was modeled - analyzed in virtual prototyping environment in another paper submitted to the Xth Product Design, Robotics, Advanced Mechanical & Mechatronic Systems and Innovation Conference - PRASIC [24]. The tracking mechanism includes two kinematic loops (Figure 1): ABCD - for the diurnal movement, and EFGH - for the seasonal (elevation) movement. The geometric constraints in A, C, D, E, G and H are revolute joints, while the B and F connections are modeled by translational joints.

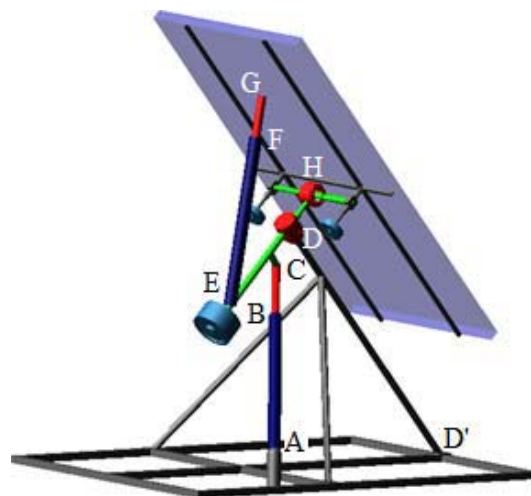


Figure 1. The virtual model of the dual-axis tracking mechanism.

2. The optimization algorithm

As stated in [24], the objective of optimizing the dynamic behavior of the tracking system is to reduce the power consumption of the motors of the actuators (for energy efficiency purposes) while reducing the magnitude of the reactions in the joints of the mechanism (in this case, by avoiding that reaction leap/peak caused by the sudden swing of the actuator for the diurnal movement).

Under these conditions, the optimization of the dynamic behavior of the tracking systems is based on taking the following steps: parameterization of the model; defining design variables; defining the objective functions for optimization and the design constraints; carrying out the analysis of design sensitivities, in order to identify the main design variables (having a significant influence on the objective functions); the actual optimization of the system on the basis of the main variables.

The parameterization of the dual-axis tracking system shown in Figure 1 for the purpose of dynamic optimization is based on the use of the points defining the structural scheme of the mechanism, in this case the points defining the locations of the joints between the elements. For this study, only the connection points of the linear actuators' cylinders relative to the adjacent elements have been considered, namely the joint A to the fixed support - for the diurnal movement, and the joint E to the intermediary support - for the seasonal movement. The coordinates of the other points are considered to be established solely on constructive considerations relative to the way the system is mounted.

As additional conditions, both the orientation of the actuators (thus the positioning of the axes of the translational joints between the cylinders and the pistons) as well as the orientation of the axes of the revolute joints between the actuators' cylinders and the elements to which they are connected (the fixed support - for the diurnal actuator, respectively the intermediary support - for the seasonal actuator), are preserved in the modeling position (the initial one, from the beginning of the simulation), changing only the locations of the joints. In addition, in the case of the seasonal actuator, as the seasonal movement takes place in the XZ plane, the global Y_E coordinate remains unchanged (at the initial value) during the optimization study.

In this way, five independent design variables, which control the model during the optimization process, have been obtained, as follows: $DV_1 \rightarrow X_A$, $DV_2 \rightarrow Y_A$, $DV_3 \rightarrow Z_A$, $DV_4 \rightarrow X_E$, $DV_5 \rightarrow Z_E$. Each design variable is defined by an initial value (corresponding to the initial design) and a variation range relative to the initial value, which has been set with the view of maintaining the tracking mechanism within acceptable construction limits.

The objective of the optimization is to identify the values of the design parameters for which the system behavior is optimal. In ADAMS, the objective function is defined by a measure, which tracks the time variation of the dynamic parameter of interest. The measure is a specific ADAMS object that allows investigating the behavior of a (predefined or user-defined) feature of the model during or after carrying out the analysis. The objective function (which is also called design objective, functional cost or performance index) is a numerical representation of the quality, efficiency, cost, or stability of the system, representing a numerical quantification that distinguishes/evaluates multiple design variants; optimal design is ensured when the objective function is, as the case may be, minimized or maximized.

At the same time, a number of design constraints can be defined, which impose restrictions on the structure and/or operation of the tracking system, for example, the system has to fall within a certain working space or certain parameters do not exceed predetermined limit values. The optimization study improves, as far as possible, the objective function without violating the design constraints. Constraints are frontiers that directly or indirectly eliminate the unacceptable system design, often taking the form of additional goals in the design of the tracking system. Each design constraint generates a relationship of inequality, while during the optimization process the constraint value is kept under or equal to zero.

The objective of optimizing the dynamic behavior of the tracking system in study is to minimize the power consumption of the two linear actuators (for energy efficiency purposes) while reducing the magnitude of the joint reactions (more specifically, to avoid the reaction peak caused by the swing of the actuator for the diurnal movement [24]).

The objective of the parametric design study is to examine design sensitivities, i.e. to identify the design variables with a major influence on the objective functions to be optimized; only these variables are taken into account in the optimization process of the tracking system (the secondary variables, having a low/insignificant influence, will be disregarded).

3. Results and conclusions

As mentioned previously, for the equatorial tracking system concerned, the design variables consist of the overall coordinates of the points of articulation where the actuator cylinders are placed on the panel support (for the diurnal movement), or on the supporting pillar, respectively (for the seasonal

movement). The objectives to be analyzed during the parametric design studies have been defined on the basis of the measures by which the reaction in joint A and the power consumptions for the diurnal and seasonal movements are modeled, with the aim to observe the maximum value of these measures during the dynamic simulation/analysis of the tracking system.

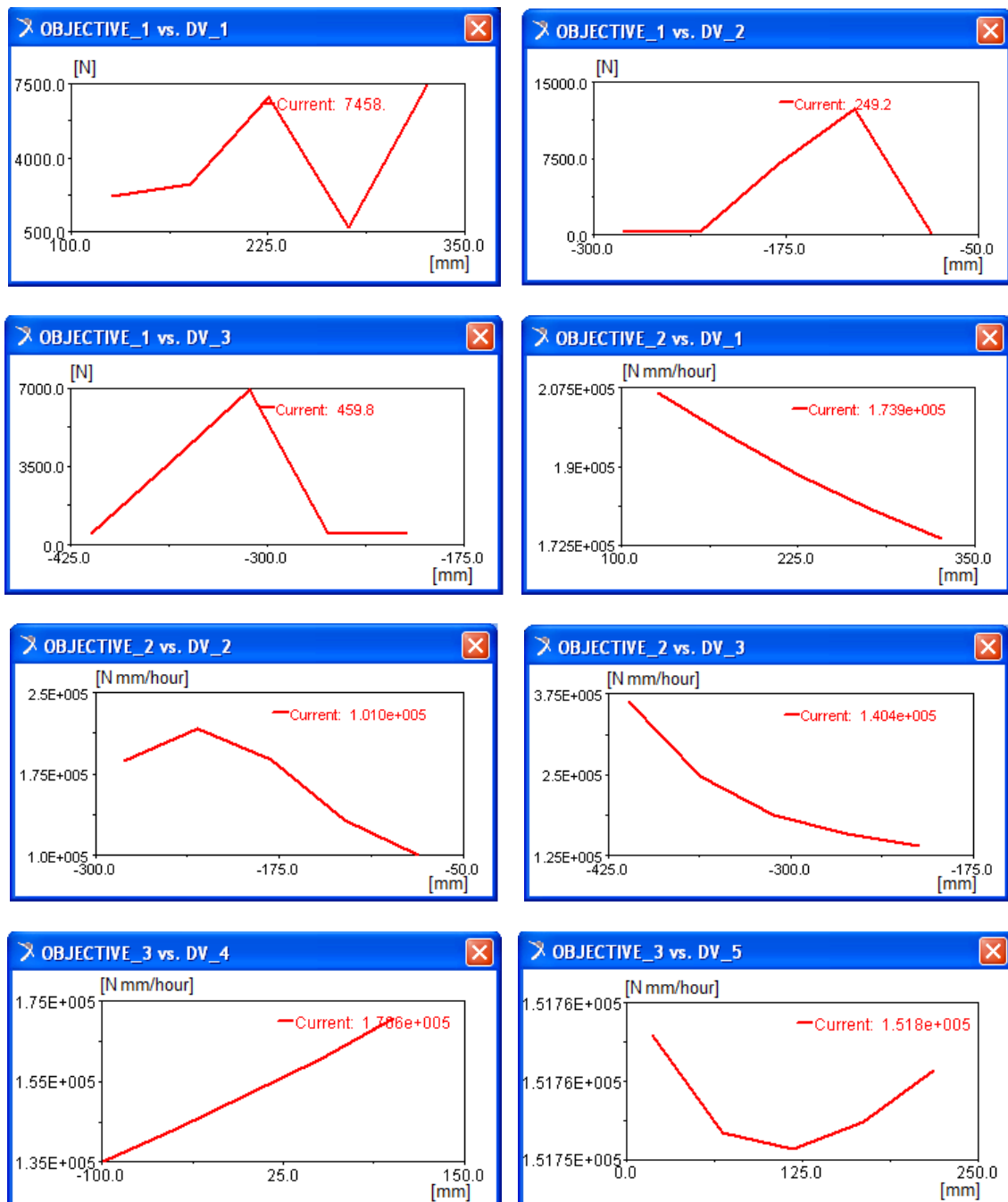


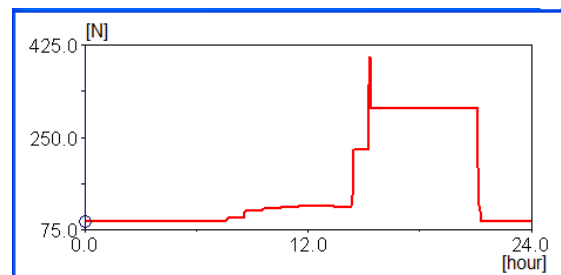
Figure 2. The results of the parametric design studies.

The design study is performed for each design variable individually, in its value range. Thus, using the selected design variables and the indicated objectives, the diagrams in Figure 2 were obtained, based on which the sensitivity of the objectives to the variation of the design variables is evaluated (in diagrams, on the ordinate there are the values of the design variable, and on the abscissa there are the values of the objective function).

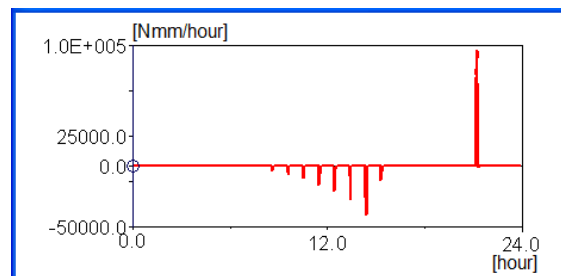
Following the study of parametric design, the following main design variables resulted: for objective 1 (reaction in joint A): DV_1, DV_2, DV_3; for objective 2 (power consumption of the linear actuator for the diurnal movement): DV_2, DV_3; for objective 3 (power consumption of the linear actuator for the seasonal movement): DV_4. The dynamic optimization of the tracking system behavior will be performed based on these variables, giving up the secondary variable DV_5.

The actual optimization is done progressively for each objective, with the specific main design variables, starting with objective 1; this means that the optimal option for an tracking system resulting from the optimization study for objective 1 becomes the initial option for the optimization of objective 2 and so on.

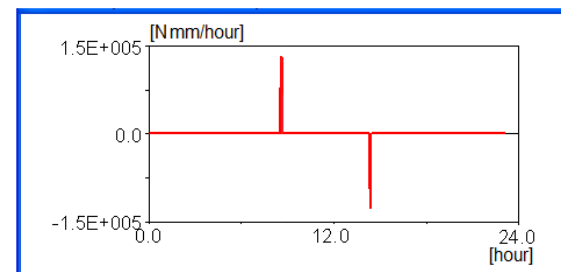
The results obtained based on optimization are shown in Figure 3, as follows: the reaction force in the revolute joint A (a), and the power consumptions for the diurnal (b) & elevation (c) motions. Compared to the results obtained for the initial model (before optimization) presented in [24], a significant reduction in the power consumptions and coupling reactions can be observed, while maintaining the system within rational construction limits, which proves the viability of the optimization algorithm implemented in this research.



a.



b.



c.

Figure 3. The results of the optimization process.

References

- [1] Alexandru C and Comșit M 2008 The energy balance of the photovoltaic tracking systems using virtual prototyping platform *Proceedings of the 5th IEEE International Conference on the European Electricity Market EEM 2008* pp 253-258
- [2] Alexandru C and Pozna C 2008 Virtual prototype of a dual-axis tracking system used for photovoltaic panels *Proceedings of the IEEE International Symposium on Industrial Electronics ISIE 2008* pp 1598-1603
- [3] Alexandru C 2009 The design and optimization of a photovoltaic tracking mechanism *Proceedings of the 2nd IEEE International Conference on Power Engineering, Energy and Electrical Drives POWERENG 2009* pp 436-441
- [4] Flores-Hernández D A, Palomino-Resendiz S, Lozada-Castillo N and Luviano-Juárez A 2017 Mechatronic design and implementation of a two axes sun tracking photovoltaic system driven by a robotic sensor *Mechatronics* **47** pp 148-159

- [5] Hoffmann F M, Molz R F, Kothe J V, Nara E O B, Pablo L and Tedesco C 2018 Monthly profile analysis based on a two-axis solar tracker proposal for photovoltaic panels *Renewable Energy* **115** pp 750-759
- [6] Alexandru C and Tatu I N 2013 Optimal design of the solar tracker used for a photovoltaic string *Journal of Renewable and Sustainable Energy* **5** pp 1-16
- [7] Çinar S M, Hocaoğlu F O and Orhun M 2014 A remotely accessible solar tracker system design *Journal of Renewable and Sustainable Energy* **6** pp 1-12
- [8] Ioniță M and Alexandru C 2012 Dynamic optimization of the tracking system for a pseudo-azimuthal photovoltaic platform *Journal of Renewable and Sustainable Energy* **4** pp 1-15
- [9] Vieira R G, Guerra F K, Vale M R and Araujo M M 2016 Comparative performance analysis between static solar panels and single-axis tracking system on a hot climate region near to the equator *Renewable & Sustainable Energy Reviews* **64** pp 672-681
- [10] Altuzarra O, Macho E, Aginaga J and Petuya V 2015 Design of a solar tracking parallel mechanism with low energy consumption *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* **229** pp 566-579
- [11] Edgar R, Stachurski Z and Cocharad S 2016 Optimisation direct normal insolation of rectangular PV platforms *Solar Energy* **136** pp 166-173
- [12] Mauro S, Battezzato A, Biondi G and Scarzella C 2015 Design and test of a parallel kinematic solar tracker *Advances in Mechanical Engineering* **7** pp 1-16
- [13] Nsengiyumva W, Chen S G, Hu L and Chen X 2018 Recent advancements and challenges in solar tracking systems (STS): A review *Renewable & Sustainable Energy Reviews* **81** pp 250-279
- [14] Seme S, Stumberger B, Hadziselimovic M 2016 A novel prediction algorithm for solar angles using second derivative of the energy for photovoltaic sun tracking purposes *Solar Energy* **137** pp 201-211
- [15] Sharaf Eldin S A, Abd-Elhady M S and Kandil H A 2016 Feasibility of solar tracking systems for PV panels in hot and cold regions *Renewable Energy* **85** pp 228-233
- [16] Sinha S and Chandel S S 2016 Analysis of fixed tilt and sun tracking photovoltaic-micro wind based hybrid power systems *Energy Conversion and Management* **115** pp 265-275
- [17] Alexandru C and Pozna, C 2009 Dynamic modeling and control of the windshield wiper mechanisms *WSEAS Transactions on Systems* **8** pp 825-834
- [18] Alexandru C and Alexandru, P 2010 The virtual prototype of a mechatronic suspension system with active force control *WSEAS Transactions on Systems* **9** pp 927-936
- [19] Alexandru C and Alexandru, P 2011 A comparative analysis between the vehicles' passive and active suspensions *International Journal of Mechanics* **5** pp 371-378
- [20] Alexandru P, Macaveiu D and Alexandru C 2012 Design and simulation of a steering gearbox with variable transmission ratio *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* **226** pp 2538-2548
- [21] Bernard A 2005 Virtual engineering: methods and tools *Journal of Engineering Manufacture* **219** pp 413-421
- [22] Tarniță D, Marghitu D 2013 Analysis of a hand arm system *Robotics and Computer-Integrated Manufacturing* **29**, pp 493-501
- [23] Tarniță D, Catană M and Tarniță D N 2014 Contributions on the modeling and simulation of the human knee joint with applications to the robotic structures *Mechanisms and Machine Science* **20** pp 283-297
- [24] Marcu A, Alexandru C and Barbu I 2018 Modeling and simulation of a dual-axis solar tracker for PV modules *Proceedings of the Xth Product Design, Robotics, Advanced Mechanical & Mechatronic Systems and Innovation Conference PRASIC 2018*