GENERAL ASPECTS ON THE DESIGN AND SIMULATION OF THE PHOTOVOLTAIC TRACKING SYSTEMS

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Abstract: Increasing the emissions of carbon dioxide has devastating consequences on the environment. The solution is the renewable energy sources, the solar energy conversion being one of the most addressed topics in the field. The photovoltaic systems convert solar radiation into electric energy, their efficiency depending on the degree of use of the solar radiation, which can be improved by use of tracking systems. The paper presents some general aspects on the design and simulation of the photovoltaic tracking systems. A case study is developed for evaluating the energetic efficiency of a photovoltaic module with solar tracker relative to the fixed photovoltaic system (without tracking).

1. INTRODUCTION

The continuous increase of oil dependence and other fossil fuels leads to increased energy costs which creates economic problems and political. Increasing carbon dioxide emissions would have devastating consequences on the environment. Even of large new reserves were discovered, fossil fuels would still only last for a few more years, therefore the solution is renewable energy sources, who is presented in this paper too. Devices that operate on the basis of this phenomenon are called photovoltaic cells, which can be made from several semiconductor materials as: wafer-based crystalline silicon cells, thin-film cell based on cadmium telluride or silicon, etc, but over 95% are made of silicon. These are protected from damaging elements (rain, hail, etc.) by a sheet of glass on the front side. The solar cells convert the available solar radiation directly into electricity. The efficiency of this conversion depends on the quality and the type of the solar cells, their temperature, on amount of solar radiation that falls on the solar cells and quality inverters used to convert DC. To increase the rate of incident solar radiation tracking systems are used. These are mechatronic systems that integrate mechanics, electronics and information technology. In these circumstances, the present paper presents some general aspects on the design and simulation of the photovoltaic tracking system.

2. SOLAR RADIATION

The sun is an enormous nuclear fusion reactor, although most commonly used fossil fuels and radioactive substances are found in limited quantities and in different parts of the globe. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m and, is on the average 1.5×10^{11} m from the earth[12]. As seen from the earth, the sun rotates on its axis about once every four weeks. Because the sun is such a long way from the earth, only a tiny proportion of the sun’s radiation reaches the earth’s surface, but without which life on earth could not exist. The energy is generated in the sun’s core through the fusion of hydrogen atoms into helium. Part of the mass of the hydrogen is converted into energy. Factors that influence the phenomen of photovoltaic conversion, system implementation and its components are: solar radiation, the main element photovoltaic conversion, environmental factors: wind, snow, hail, ice, the surface elements that can endanger photovoltaic modules, temperature, humidity and precipitation [6].

Earth rotates around the sun with an inclination of polar axis mattered 23.45° from the normal to the plane of its trajectory, performing a complete revolution around the sun in

365.25 days land. The main input data in the design process of solar energy conversion systems is the solar radiation, which is not evenly distributed, ranging in intensity from one geographical location to another, depending on latitude, season and time of day. Its measurement can be done using traditional tools or can be digitally recorded with a data acquisition system. Solar radiation incident on the earth's surface is composed of direct and diffuse radiation. Direct solar radiation is known and felt most directly by the people because it goes directly to the soil surface without spreading.

A common size in the literature is the solar constant has a value of 1367 W/m^2, and represents the value of direct radiation that reaches the outskirts of Earth's atmosphere. For the modeling of solar radiation can be used both methods (models) and empirical test [7]. The literature presents several models for estimating solar radiation available in clear sky conditions: Kasten model [8], Bugler model (used as a model for describing the diffuse solar component), ESRA model (expressing the amount of solar radiation at ground level by processing satellite images collected), Hotel model (for the direct component of the radiation), Haurwitz model, Spyce estimation system. In 1922, Linke turbidity factor (TL) describes the clarity of the sky. This index is the subject of many works of literature. Kleemann and Meliss have developed a simplified calculation model for rapid estimation of the amount of solar radiation available in a particular place on Earth, using the notation TR atmospheric turbidity factor and considering the air mass equal to 2.

The models proposed by Goswami, Kreith and Kreider, the model proposed by Messenger and Ventre Stine and Harrigan's model describing the angular position of the solar radius in the global system (equatorial) by two angles: declination time and angle. In addition, different models have been developed to estimate solar radiation. Angstrom traditional linear method is based on measurements of duration of sunlight, while modern methods based on artificial neural networks (ANN)[13].

3. ABOUT THE TRACKING SYSTEMS

Having in view the operating principle, there are two fundamentals types of tracking systems: passive and active trackers. The passive trackers are based on thermal expansion of a Freon-based liquid from one edge of the tracker to another because of the heat sensitive working fluid [4]. The active trackers are based on electrically operated positioning drives, which need motors, gearboxes, mechanisms, couplings etc. Usually, the active systems are based on planar or spatial linkages, gears, chain and belt transmissions

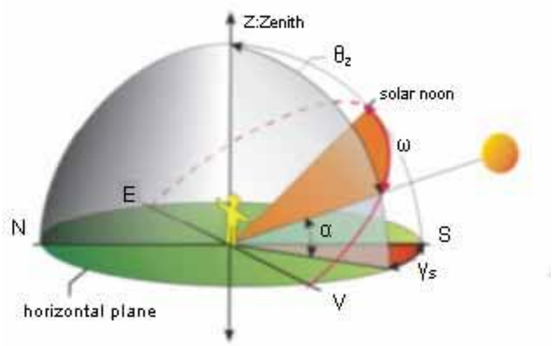

Figure 1. The Sun-rays angles

During a year, the Earth describes an elliptical rotating around the sun, and on the other hand, during the day, performs a complete rotation around its axis (which generates sunrises and sunsets). In order to determine a geometric algorithm for conversion systems orientation, angular parameters that relate to the position of the observer position of the sun are illustrated in figure 1, as follows:

- altitude angle α - the angle between a straight line from the apparent position of sun to the point of observation and the horizontal plane through that point of observation
- zone angle ω - is the angle measured between the projection on the equatorial plane equatorial plane of the line joining Earth's center to center of the sun and the straight line with the center of the sun Center of the Earth when the sun is at solar noon zone
- zenith angle θ_z - the angular distance of the sun from the vertical, i.e. the angle subtended by a vertical line to the zenith and the line of sight to the sun, i.e. 90° minus the solar altitude angle
- azimuth angle γ_S - the projected angle between a straight line from the apparent position of the sun to the point of observation and due north. The angle is measured clockwise using the projections on the local horizontal plane, 0-360°.
- declination angle δ – is the angle between the equatorial plane and the rays of the sun. The angle of solar declination changes continuously as Earth orbits the sun, ranging from -23.5° to +23.5° (positive when the Northern Hemisphere is tilted toward the sun).

For the design process of the tracking system two rotational motions can be considered: the daily motion, and the yearly precession motion. To ensure the highest possible conversion efficiency of solar energy into electricity is necessary that the sun's rays to fall perpendicularly on the surface of the module.

The single-axis tracking system is a system which follows the Sun throughout the day, facing east in the morning and west in the afternoon. These systems have the yield smaller because have only one motor source. The dual-axis trackers combine two motions being able to distinguish three types tracking systems: azimuthal, equatorial and pseudo-equatorial.

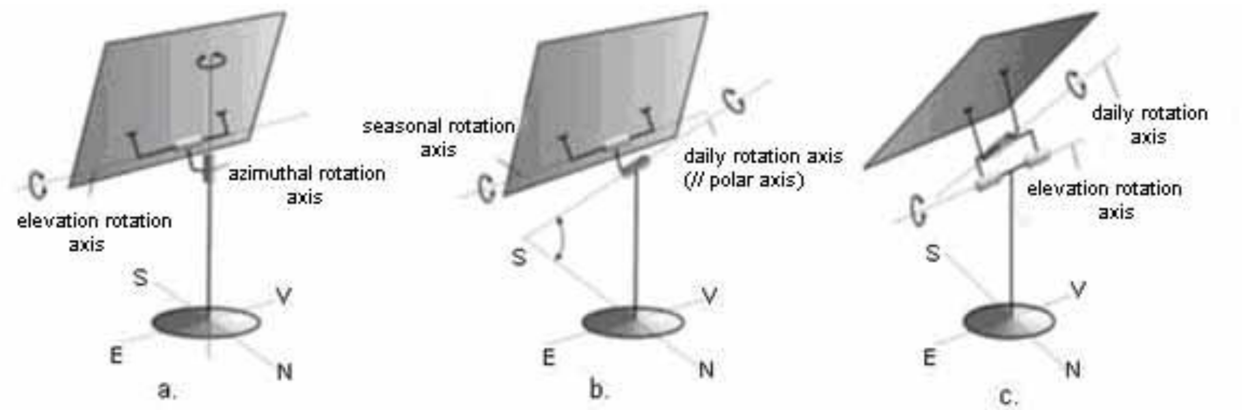

Figure 2. The types of tracking systems

The tracking systems can be further divided, according to the sequence of rotations, into the following (fig. 2):

a. azimuthal tracking systems - systems that have axes aligned with the axis of rotation taking place after two rotations relative paths leading sun in the sky, thus requiring synchronization (correlation) movements throughout the day.

b. equatorial tracking system - systems that have axes of rotation arranged so as to maintain the polar axis parallel to the earth rotation axis, which determines that the seasonal variation of the Sun's position in the sky; these systems are usually avoided because generates constructive problems.

c. pseudoequatorial systems - systems with an axis parallel to the axis of rotation that causes the seasonal variation of the sun in the sky position and orientation axis for diurnal swing; these systems are more stable, thus more used.

The orientation of photovoltaic modules may increase the efficiency of the conversion system up from 20% to 50%.[2], [3] The tracking systems are mechanical systems that integrated mechanics, electronics and information technology. These mechanisms are driven by linear actuators or rotary motors which are controlled the optimal positioning of the module relatively to the sun position on the sky.

The sun-tracking system can be done in two ways after the brightest point in the sky with sensors (for variable weather conditions may introduce errors in detection of real sun position) areas used for thermal stability (they have a more complex control system); predefined trajectories of the sun (using motion in steps, using weather data) [1].

The opened-loop systems are based on mathematic algorithms/programs that may provide predefined parameters for the motors, depending on the sun positions on the sky dome, so the errors introduced by the use of the sensors may be avoided. Regarding the literature shows the control system in closed-loop control systems based on the use of the distinguished position photo sensors sun in the sky. Because they can introduce errors in detection position of the sun, they are used in areas with thermal stability. An advantage of the closed-loop control system is the fact that use of feedback makes the system response relatively insensitive to external disturbances and internal variations in system parameters.

From the controller point of view, different control strategies are used, such as classical techniques as PID algorithm or more advanced strategy such as fuzzy logic controller - FLC. The design of a low cost two-axis solar tracker for obtaining a high precision positioning of the PV panel is made considering a control-board that is able to support different PID and FLC control strategies. An evolution of the fuzzy control concept is the fuzzy logic neural controller (FNLC), which allows the PV system to learn control rules [11].

4. CASE STUDY

A case study is developed for evaluating the energetic efficiency of a photovoltaic module with solar tracker relative to the fixed photovoltaic system (without tracking). For developing the virtual prototype of the tracking system in study, a software platform was used. This includes the following software products: CAD (Computer Aided Design) – CATIA of Dassault Systems, for creating the geometric model of the mechanical device, which contains data about the mass & inertia properties of the parts; MBS (Multi-Body Systems) – ADAMS/View of MSC Software, for analyzing, optimizing, and simulating the mechanical system; DFC (Design for Control) – ADAMS/Controls Toolkit of MSC Software, for designing the control system. The tracking system is approached in mechatronic concept, by integrating the mechanical device and the control system at the virtual prototype level. In this way, the physical testing process is greatly simplified, and the risk of the control law being poorly matched to the hardware prototype is minimized.

The key word in designing tracking systems is the energy efficiency. A photovoltaic system is efficient if the orientation is provided the following condition: $\varepsilon = E_T - E_F - E_C >> 0$, where E_T is the amount of electricity produced by the panel with tracking system, E_F is the amount of energy produced by the same module without orientation (fixed), and E_C defines the amount of energy that is consumed in the tracking. In the current conditions, the maximization of the efficiency parameter ε through the optimal design of the tracking system became an important challenge in the modern research and technology.

The tracking system in study, which was attained by using a structural synthesis method based on the Multi-Body Systems (MBS) theory [5], is a pseudo-equatorial tracker (fig. 3). The both motions (daily and elevation) are generated with linear actuators, which integrate screw-nut mechanisms for assuring the irreversibility of the motion in the stationary positions (between the motion steps). The main task in designing the tracking system is to maximize the energetic gain by increasing the solar input and minimizing the energy consumption for tracking. The PV module can be rotated without brakes during the day-light, or can be discontinuously driven (step-by-step). The maximum incident radiation can be obtained for the continuous motion, but in this case the operating time of the motor is high, and there are necessary large transmission ratios. In these conditions, we used a step-by-step tracking strategy, which was developed considering the correlation between the optimal field for the daily motion and the number of the steps. The idea is to minimize the angular motion field and the number of steps without significantly affecting the incoming solar radiation.

The paper presents the exemplification for the summer solstice day. The angular field for the daily motion is 160° (0° in the initial position / sunrise), the orientation being done in 11 motion steps. The return of the system in the initial position is made after sunset, with continuous motion. The photovoltaic module is kept fixed in the morning (4.26-6.91) and evening (17.01-22.00). With these data, the imposed motion law of the PV module is shown in figure 4.

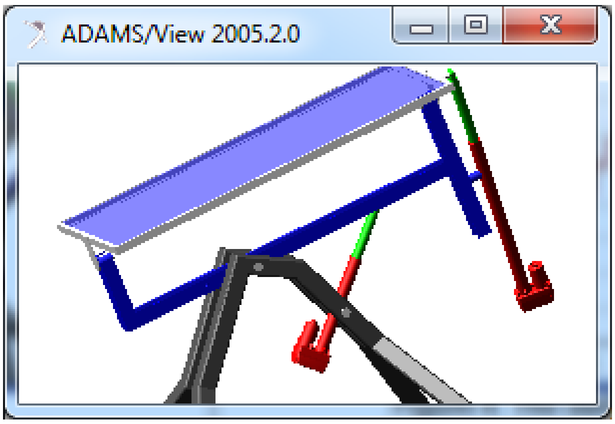

Figure 3. The pseudo-equatorial tracking system

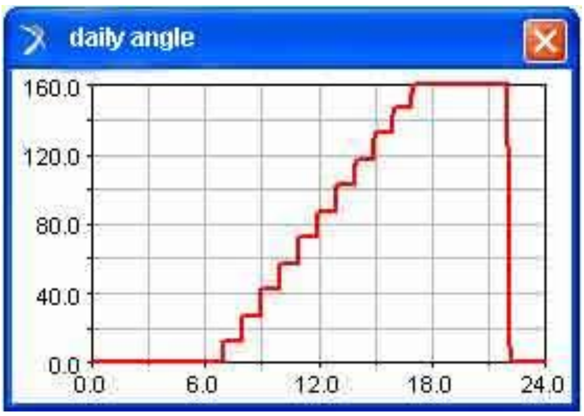

Figure 4. The daily motion law

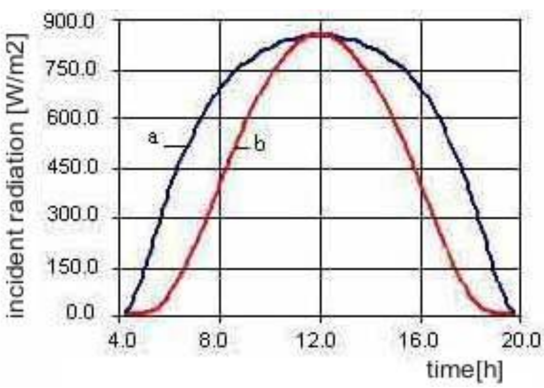

Figure 5. The incident solar radiation

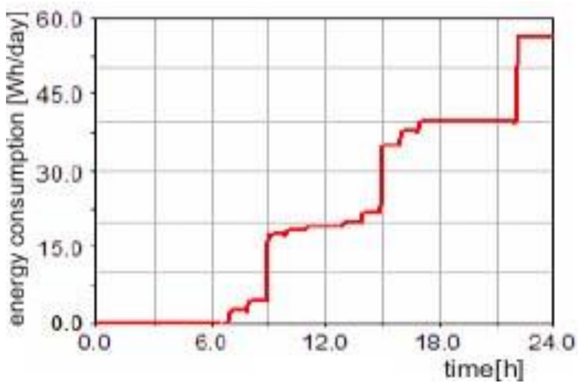

Figure 6. The energy consumption for tracking

With this motion law, the incident solar radiation, which was obtained by using the Meliß's empirical model [12], is shown in figure 5 (curve "a"), to which it corresponds the quantity of electric energy produced by the PV module E_T = 1755 Wh/day. Meanwhile, if the module would be kept fixed (in the solar-noon position) it would result E_F = 1231 Wh/day (the radiation curve “b” in figure 5).

Thus, the optimum variant for tracking system was obtained, at which the total energy consumption for orientation is $E_C \approx 57$ Wh/day (fig. 6), thereby the energetic balance was achieved, $\varepsilon = E_T - (E_F + E_C) = 1755 - (1231 + 57) = 467$ Wh/day. This demonstrates that the designed tracking system is energetic efficient, the energy contribution obtained by tracking being nearly 38% relative to the fixed module.

5. CONCLUSIONS

A tracking system is efficient if the energy consumption required for orientation is small, while the contribution of incident radiation is significantly improved relative to the case of fixed module. Compared to the fixed module, the tracked system collects a far greater amount of solar energy, and therefore generates a significantly higher output power. Regarding the future research in the field, the study will continue with developing and modeling the control system of the tracking mechanism, following the mechatronic concept.

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