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A SIMPLIFIED CALCULATION METHOD OF ELECTRIC LINEAR ACTUATORS FOR SINGLE-AXIS SUN TRACKER

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Abstract. At present, the use of small roof-mounted photovoltaic systems is increasingly popular, so the development of a sun tracker to increase the efficiency of the photovoltaic system is essential. In this paper, we give the size analysis of a linear actuator and also its selection method for a single-axis tracker. In addition, we also provide the analysis of the power and energy of the linear actuator and its controller on a typical sunny day.

Keywords: linear actuator, single-axis tracker, photovoltaic system

1 Overview

Solar energy application has been increasingly popular in the world in recent years. In our country, the demand for photovoltaic systems becomes increasing, and the Circular 16/2017/TT-BCT "Regulations on project development and Power Purchase Agreement for Solar Power Projects" makes the market of solar electricity more and more active [1].

To improve the efficiency of photovoltaic equipment, much research has been done, and solar trackers have been manufactured [2]. The solar tracker is used to bring the surface of the device always to direct towards the sun to capture the most energy. According to the principles, the solar tracker has single-axis [3, 4] or dual-axis degrees of freedom [5–9]. The mechanical drives are also very diverse: linear actuators [3, 8], gearboxes and a DC motors [4–6], step motors [7], and screwdrivers with step motors [10].

Most of the solar tracker research does not show the selecting calculation method of the motors or other mechanical drives. For a single-axis solar tracker, many types of mechanical drives can be used. The design of the mechanical system can take many forms [3]. In this paper, a linear actuator with the drive type was selected, and its calculation method depends on the given maximum rotation angle (Fig. 1).

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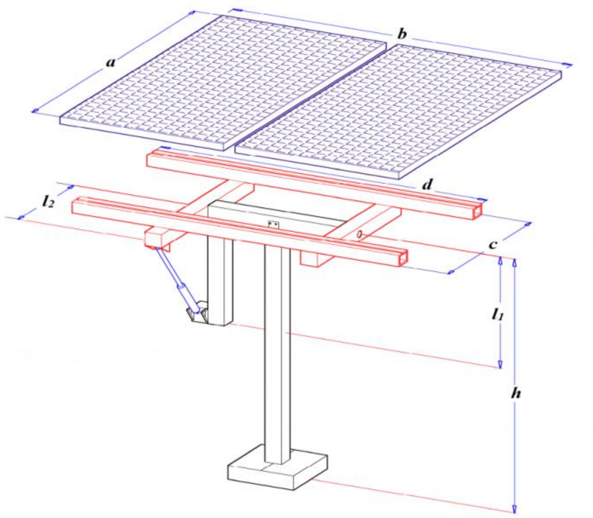

Fig. 1. Mechanical model for a single-axis solar tracker.

2 Methods and content of research

The research was conducted using the following methods:

– Data collection: collecting physical data of the solar panel and linear actuator.

– Calculation: calculating the remaining parameters on the basis of the given hypothesis.

– Experimental: manufacturing and testing the single-axis solar tracker in real conditions.

This paper proposes to design a single-axis solar tracker for two solar panels by using a linear actuator mechanism and selecting a calculation method for the linear actuator. This design uses the solar panel 250wp HSPV250Wp with a dimension of 1640 × 992 × 40 mm and a weight of 17 kg. Hence, two solar panels have an area of $a \times b$ = 1640 × 1984 mm and weight m = 34 kg. The height of the pillar is h = 1500 mm. The rectangular frame for the solar panels has a dimension of $c \times d$ = 1000 × 2000 mm. The frame bears the solar panels. The east-west rotating axis of the system is attached in the middle of the frame width.

To determine the dimensions of the linear actuator mechanism, it is necessary to define the length of l_1, l_2 as shown in Fig. 1 and 2, and the length l_3, l_4 as shown in Fig. 2. The length of l_1 must be smaller than that of the pillar h. The length of l_2 must be smaller than that of c of the frame width. To simplify the problem, we choose the following lengths:

$$\begin{cases} l_1 = h/2 \\ l_2 = c/2 \\ l_3 = c/20 \\ l_4 = h/20 \end{cases} \quad (1)$$

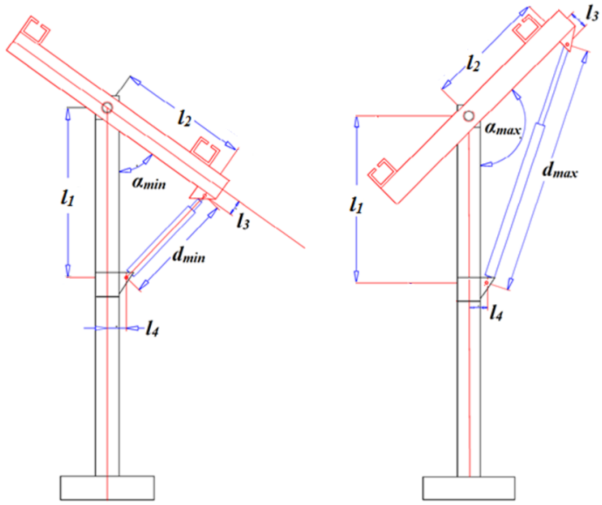

Fig. 2. Orientation system along the axis of rotation: a) smallest rotation angle; b) largest rotation angle.

3 Results and discussion

Fig. 2 shows the orientation system along the axis of rotation. α_{min} is the angle between the support frame and the vertical axis (pillar). α_{min} is the initial tilting angle that should be chosen to design the rotation system. For the symmetry of the system, select $\alpha_{max} = \pi - \alpha_{min}$. The selection of the initial tilting angle depends on the requirements of the sun tracking system. α_{min} varies from 0 to $\pi/2$.

We need to calculate the parameters of the linear actuator, namely the stroke (D_{str}), the fully retracted length (d_{min}), the fully extended length (d_{max}), the force (F), the speed, and the input voltage.

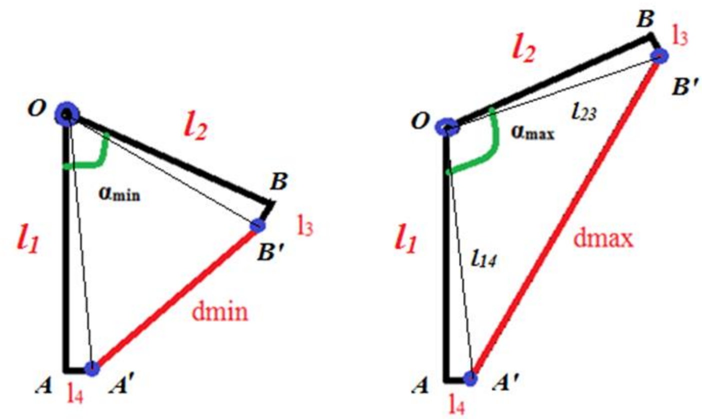

Fig. 3. Dimension calculation model for the linear actuator.

Fig. 3 shows the dimension calculation model. With the help of the model, the fully retracted length and the fully extended length of linear actuator can be calculated. We have the relationship between the dimensions as follows:

$$\begin{cases} OA' = \sqrt{OA^2 + AA'^2} \\ OB' = \sqrt{OB^2 + BB'^2} \\ A\hat{O}A' = acrtg(\dfrac{AA'}{OA}) \\ B\hat{O}B' = acrtg(\dfrac{BB'}{OB}) \end{cases} \tag{2}$$

As seen from Fig. 3, the fully retracted and fully extended length of the linear actuator is determined from the value of $d_{\min}$ and $d_{\max}$ as follows:

$$\begin{cases} d_{\min}{}^2 = OA'^2 + OB'^2 - 2OA'.OB'\cos(\alpha_{\min} - A\hat{O}A' - B\hat{O}B') \\ d_{\max}{}^2 = OA'^2 + OB'^2 - 2OA'.OB'\cos(\pi - \alpha_{\min} - A\hat{O}A' - B\hat{O}B') \end{cases} \tag{3}$$

From equations (1), (2), and (3) we find the values d_{min} and d_{max} depending on the initial minimum tilting angle $\alpha_{\min}$. The relationship between d_{min} and d_{max} is given in Fig. 4.

The smaller the value of the minimum tilting angle is, the greater is the possibility of obtaining sunlight, and the rotational energy also increases. Let us assume that the initial minimum tilting angle is $\pi/3$, and we choose a linear actuator with the following values: $d_{\min}$ = 560 mm, $d_{\max}$ = 1010 mm, and D_{str} = 450 mm.

After determining the value of the linear actuator dimension, we define the electrical and mechanical parameters of the actuator. Fig. 5 gives an analysis of the force applied to the center of rotation, where *F* is the lifting force of the actuator and *P* is the gravitational force of the solar panel and the frame.

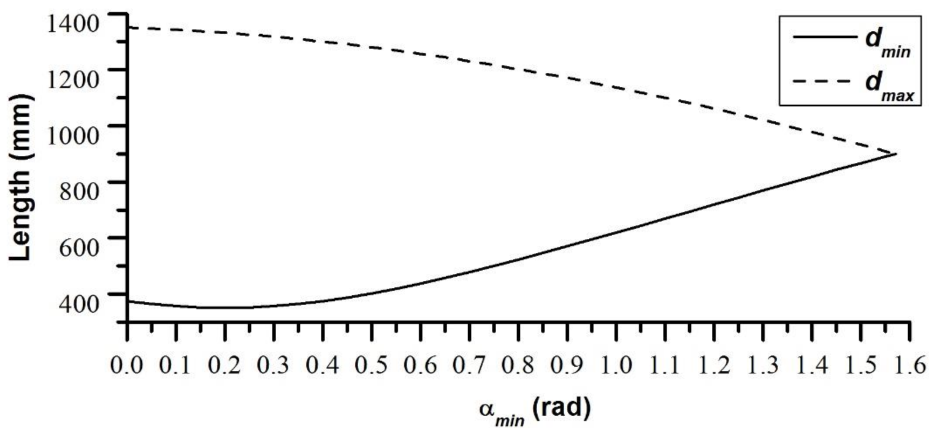

Fig. 4. The dependence of dimension on the initial minimum tilting angle $\alpha_{\min}$.

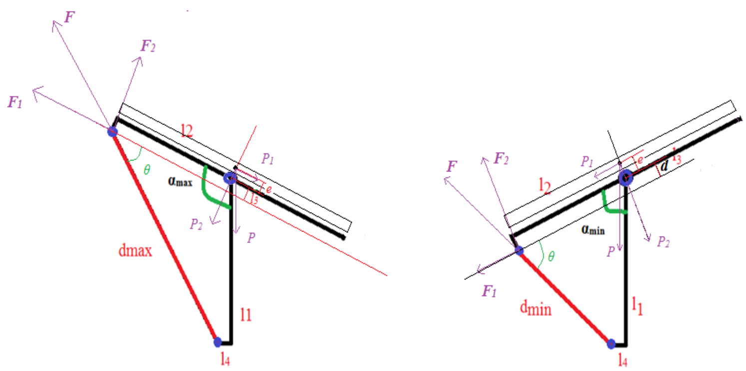

Fig. 5. Analysis of the force on the tracking system.

The torque of the actuator at the center of rotation of the tracking system is

$$M_{act} = F_1.l_3 + F_2.l_2 = \mathrm{F}(\cos(\theta).\mathrm{l}_3 + \sin(\theta).\mathrm{l}_2) \tag{4}$$

The eccentric moment of the tracking system is

$$M_e = P_1.e = mg.\cos(\alpha).e \tag{5}$$

where m is the weight of the solar panels; e is the eccentricity – the distance from the center of the panel to the center of rotation of the system in the direction perpendicular to the panel; α is the angle between the solar panel and the vertical axis.

The moment of wind relative to the axis of rotation system is [11]

$$M_{wind} = C_M.0.613.v_{wind}{}^2.A.b \tag{6}$$

where C_M is the coefficient of wind moment, depending on the angle between the wind direction and the solar panels; v_{wind} (m/s) is the wind speed; A (m^2) is the surface area of the solar panel; b is the width of the solar panel relative to the rotation axis.

Normally, when calculating the wind moment, we choose the maximum resistance moment, then $C_M = 0.6$ [11]. Assuming that the tracking system is in action when the wind level is 6 (maximum speed 13.8 m/s).

For this system, there are three roller bearings corresponding to the points O, A ', B'. The friction torque on the normal roller bearings is very small compared with the total torque, so it can be ignored in this case.

In the case of an intermittent rotating system, the starting up process is repeated several times, so the equation including the moment of inertia is

$$M_{qt} = J.\varepsilon_{\max} \tag{7}$$

where ε_{max} (rad/s^2) is the angular acceleration of the system when starting up; J (Kg.m^2) is the moment of inertia of the rotation part.

The torque balance equation of the rotation system around point O is given as follows:

$$M_{qt} = M_{act} - M_e - M_{wind} \quad (8)$$

Fig. 6 shows the dependence of the force F of the actuator on the tilting angle of and at different wind levels when research tracking system has initial angular acceleration $\varepsilon_{max} = 0.01$ (rad/s^2).

Fig. 6 shows that when the wind speed is level 6 and the tilting angle is in the range from $\pi/3$ to $2\pi/3$, the actuator of the tracking system must have a force $F > 1400$ N.

Thus, the tilting angle, actuator dimension, and force can help select the type of the linear actuator. In this paper, the linear actuator type HF-TGA-A 450-12-4 with stroke 450 mm, input voltage 12VDC, speed 4 mm/s, force (Max load) 1500 N, fully retracted (555 mm) length and fully extended (1005 mm) length was selected.

On the basis of all the previous information about the dimension, force, minimum tilting angle, and torque, the mechanical parts were manufactured at the electric workshop of Quang Tri Branch, Hue University. The tracking system completely meets the requirement (Fig. 7). Combined with the rotary angle controller studied in [12], the tracking system was tested in reality. This rotary angle controller includes a board arduino, an adapter 12VDC, and a light sensor.

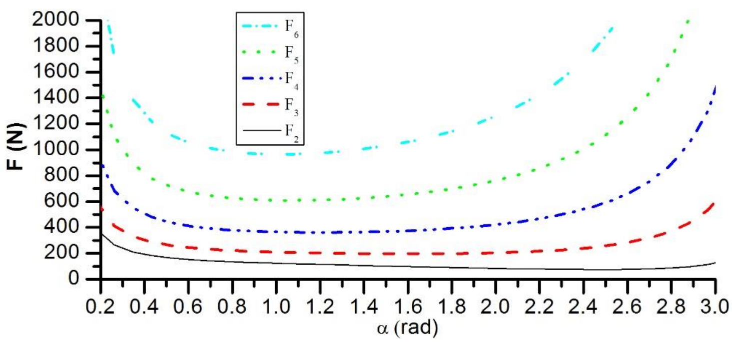

Fig. 6. Dependence of the force F of the actuator on the tilting angle.

Fig. 7. The real image of the tracking system.

The authors conducted the real experiment from 5/4/2018 to 20/5/2018. It should be noted that the strongest wind speed was observed at 6.6 m/s on 16/5/2018 and the tracking system worked steadily. This shows that the selection calculation method and the tracking system design were appropriate.

The Data Acquisition and Control Interface 9063 device of the Labvolt company was used for measuring and analyzing the power and energy of the actuator and its controller on a typical sunny day (8/5/2018). The obtained results are shown in Fig. 8. On that day, the energy of the linear actuator and its controller was about 36 Wh. It is clear that the peak positions of the power line correspond to the moment when the linear actuator displaces/works; it minimizes the tilt angle between the surface of solar panels and the sun. The first peak position of the day was between 5h51′25′′ and 5h53′05′′: during this time, the tracking system turned the solar panel from west to east. Other peak positions took place around 9h22′40′′ to 13h49′52′′. These positions reflect the rotate power of the tracking system. They correspond to the change of angle α. The smaller the initial tilt angle α_{min} is, the longer the time interval increases.

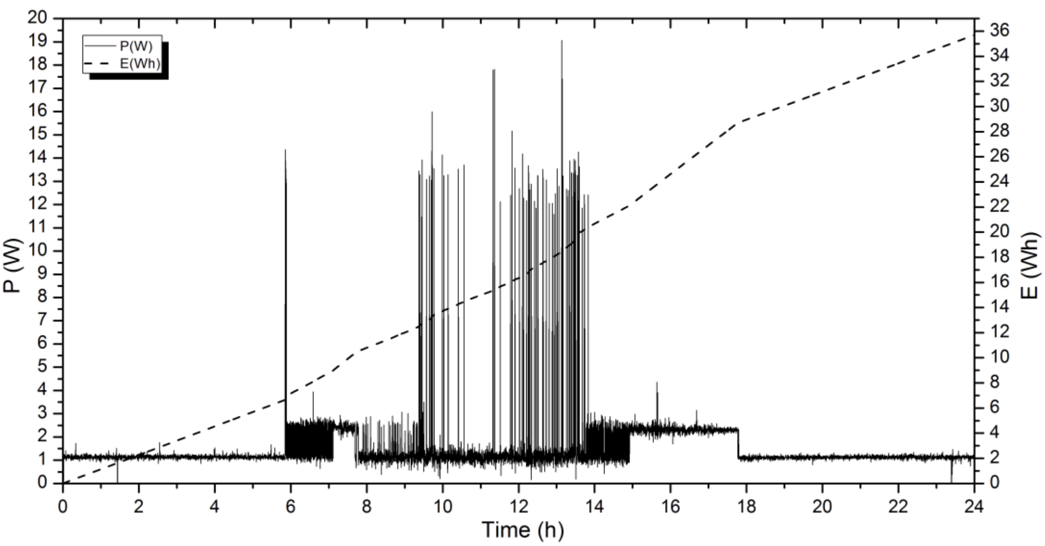

Fig. 8. Power and energy of the actuator and its controller during a typical sunny day (8/5/2018).

4 Conclusions

The paper presents a simplified calculation method of the linear actuator for the tracking system from the tilting angle, actuator dimension, and force. In addition, it also analyzes the power and energy of the actuator and its rotary controller during a typical sunny day. The test results show that the tracking system is steady at the wind speed of 6.6 m/s. For objective reasons, the article does not mention the performance of the solar panels. The authors hope it will be completed and published in the next article.

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