Semi Active Control of Solar Tracker Using Variable Position of Added Mass Control

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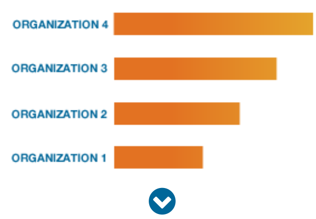
Ali Basrah Pulungan ; Lovely Son ; Syamsul Huda ; Syafii ; Ubaidillah **All Authors**



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Semi active control of solar tracker using variable position of added mass control (Conference Paper)

Pulungan, A.B.[a,b], Son, L.[a], Huda, S.[a], Syafii[a], Ubaidillah[a]
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[a]Universitas Andalas, Department of Mechanical Engineering, Padang, Indonesia
[b]Department of Electrical Engineering, Universitas Negeri Padang, Padang, Indonesia

Abstract

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This paper offers a new method to control solar panel orientation. The technique is applied by varying the position and ratio of the added mass to the total mass of solar panel, m/m_p (%). The added mass position is varied from the axis point up to the end point of the solar panel. The solar panel orientation is influenced by the moving mass position. The oscillation in solar panel caused by the moving mass is eliminated by adjusting the equivalent damping torque c_T, and the solar panel maximum orientation is varied by changing the equivalent torsion spring k_T. The simulation results proved that the solar panel orientation changed from 0 to 60,63 for parameter values m/m_p = 15%, $r/0{,}5r_t$ = 35%, c_T = 3 Nm/rad/sec and k_T = 1 Nm/rad. The ability of the system to control the orientation and ratio of m/m_p dan $r/0{,}5r_t$ is effective to reduce energy consumption of the solar panel orientation controlling system. © 2019 IEEE.

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Semi Active Control of Solar Tracker Using Variable Position of Added Mass Control

Ali Basrah Pulungan[1,2]
[1.] *Doctoral Student at Department of Mechanical Engineering*
Universitas Andalas
Padang, Indonesia

[2.] *Department of Electrical Engineering*
Universitas Negeri Padang
Padang, Indonesia
e-mail:alibp@ft.unp.ac.id

Lovely Son*
Department of Mechanical Engineering
Universitas Andalas
Padang, Indonesia
e-mail: lovelyson@eng.unand.ac.id

Syamsul Huda
Department of Mechanical Engineering
Universitas Andalas
Padang, Indonesia
e-mail: syamsulhuda@eng.unand.ac.id

Syafii
Department of Electrical Engineering
Universitas Andalas
Padang, Indonesia
e-mail: syafii@eng.unand.ac.id

Ubaidillah
Department of Mechanical Engineering
Universitas Sebelas Maret
Solo, Indonesia
ubaid.ubaidillah@gmail.com

***Abstract*— This paper offers a new method to control solar panel orientation. The technique is applied by varying the position and ratio of the added mass to the total mass of solar panel, m/m_p (%). The added mass position is varied from the axis point up to the end point of the solar panel. The solar panel orientation is influenced by the moving mass position. The oscillation in solar panel caused by the moving mass is eliminated by adjusting the equivalent damping torque c_τ, and the solar panel maximum orientation is varied by changing the equivalent torsion spring k_τ. The simulation results proved that the solar panel orientation changed from 0^0 to $60{,}63^0$ for parameter values m/m_p = 15%, $r/0{,}5r_t$ = 35%, c_τ = 3 Nm/rad/sec and k_τ = 1 Nm/rad. The ability of the system to control the orientation and ratio of m/m_p dan $r/0{,}5r_t$ is effective to reduce energy consumption of the solar panel orientation controlling system.**

Keywords*— *orientation, control, solar panel, oscillation

I. INTRODUCTION

The conversion of solar energy into electrical energy can be conducted using a solar panel system. However, the fixed system of solar panels usually have a low efficiency value which is less than 20% [1]. The efficiency can be increased by setting the orientation in the solar panels by implementing either passive or active solar tracker system [2].

The Passive tracker operates based on solar radiation with varying designs, such as shape memory alloy or thermal expansion. In general, passive tracker consist of simple structure, requires less installation equipment without additional electricity supply, and cheap [3]. However, this tracker has disadvantages as well such as its dependency of sunlight existence and less efficiency (between 2% -23% compared to a fixed system) [3]–[5].

Meanwhile, the active tracking system is classified into two types, i.e. single axis tracker and dual axis tracker. These tracker are operated by using electric motor as its actuator. Several studies revealed that the active solar tracker either using single axis or dual axis were able to increase energy efficiency higher than the fixed solar panel system [6]–[11]. The efficiency was increased up to 29.37% in average [12].

Although the active tracking system is able to provide better efficiency compared to other types; the literature [13] shows that the energy loss in the system is high during operation due to the presence of additional units and joint motion. The daily average energy consumption of the actuator in a single axis active tracking system is estimated to be around 14% -28% of the energy produced, this energy consumption is required for each different weather condition. While the increase in energy produced by using a single axis tracker is around 12% -20%.

Another problem with active trackers is the possibility of miss-tracking and control system failures that can be caused by a failure on the sensor [13]. Moreover, another research claims that there is an interference in the form of oscillations due to the movement of the tracker [3]. The oscillation occurs because of no existence of damper system on the active tracker. Therefore it needs a stable and no oscillation control system that can follow slow solar movements. Based on those explanations, the solar tracking system must consider the tracking axis configuration, the optimization of movement and the appropriate control system to obtain higher efficiency [14].

To avoid the possibility of oscillations due to the change of orientation, it is better to add mass, adjust damping, and control the stiffness value. This control system used in this solar panel orientation is called as a semi-active system. The utilization of the semi-active control system is expected to be able to reduce the energy consumption since a mass can still move with a minimum energy.

II. SEMI ACTIVE CONTROLLER

Semi active control system is known as a system which is its properties can be changed without any external energy. The varying techniques of semi-active control can be implemented by controlling the mass, damping, and rigidity [15].

Semi-active dampers have varying attenuation properties so they can be adjusted by reducing the vibration perceived by the receiver. One of the semi-active control methods is by using MR (Magneto Rheological) fluid damper. This damper can be controlled by varying the current injected to the damper in real time and can produce a large damping force. The use of this damper can control the bridge response, with support of 69% [16].

Another semi-active control method is Semi-Active Stiffness Dampers (SASD) which consists of cylinders filled with fluids, pistons, and valves controlled by motors. The motor regulates valve openings, thus it controls the flow of thick fluid (such as oil) and adjusts the damping coefficient in real time [17]. These Semi-Active Stiffness Dampers

(SASD) have been developed with Resetting Semi-Active Stiffness Dampers (RSASD) [18]. This system works by adding stiffness to the system when the valve is closed and removing the energy absorbed when the valve is open.

The element of mass or inertia is assumed to be a rigid object; which can obtain or lose kinetic energy when there is a change in speed. The moment of inertia in rotational motion expresses the measure of the object's ability to maintain the velocity of an object's motion when it is rotating. The ability of an object to rotate is determined by the magnitude of the moment inertia. The object will be more difficult to rotate when the value of inertia moment is getting greater otherwise the rotating object is also difficult to stop if its moment of inertia is too large [19].

In mass rotational motion with a small angle θ, the large equation of torque can be written:

$$J\ddot{\theta} + c_\tau \dot{\theta} + k_\tau \theta = \tau \quad (1)$$

With τ is the amount of torque (Nm), c_τ *is* the equivalent of torque attenuation (Nm/rad/sec), and k_τ is constant equivalent torsion spring (Nm/rad). If gravity is appeared at a distance of Δx from the point of axis, the torque equation can be written:

$$J\ddot{\theta} + c_\tau \dot{\theta} + k_\tau \theta = mg\Delta x \cos\theta \quad (2)$$

If Δx = r, then;

$$J\ddot{\theta} + c_\tau \dot{\theta} + k_\tau \theta = mgr \cos\theta \quad (3)$$

The c_τ or k_τ values are set in order to keep the solar panels from oscillation.

In some cases, a mathematical model is required to represent the actual system. The moment of inertia of a mass in the orientation setting of the solar panel is modeled as a solid rectangular object shown figure (1) with the following equation:

$$J_x = m \cdot \left[\left(a^2 + b^2 \right) / 12 \right] \quad (4)$$

Where:

J_x = moment of inertia (kgm2)
m = mass of objects (kg)
a = wide (m)
b = long (m)

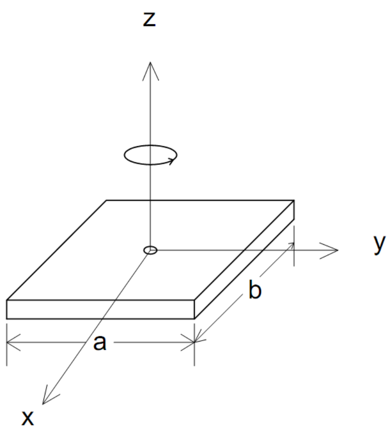

Figure 1. Rectangular solid object

III. Simulation and Results

The new solar tracker is developed by setting the orientation of solar panels by using variable position of the added mass control with a certain distance from the axis point. The moving mass is conducted by applying lower power stepper motor. The change in position causes an imbalance in the solar panel which lead an orientation change in the solar panel. To avoid the possibility of oscillation, a damper system is used to keep the solar panels in the stable position.

A. Design

The design of this orientation control system uses a 250 Wp solar panel with dimensions of 1196 x 541 x 30 mm, and weighs 7 kg. Control orientation consists of three parameters, namely mass, damper and stiffness. The mass and stiffness value is obtained from static analysis, while the damper value is based on dynamic analysis. The system design will be simulated using a trajectory with a length of r equal to the length of the solar panel. The mass that will move in the trajectory has a relative weight to solar panel weight m/m (%) and the distance from the symmetrical axis relative to the half-length of the trajectory r/0.5r (%). Value determination of each parameter is used to obtain an orientation angle θ° from 0° to 60°. To avoid oscillation while changing the orientation, the constant value of c is adjusted, but in this simulation the equivalent values of c_τ and k_τ are used. The following is the system design which will be simulated;

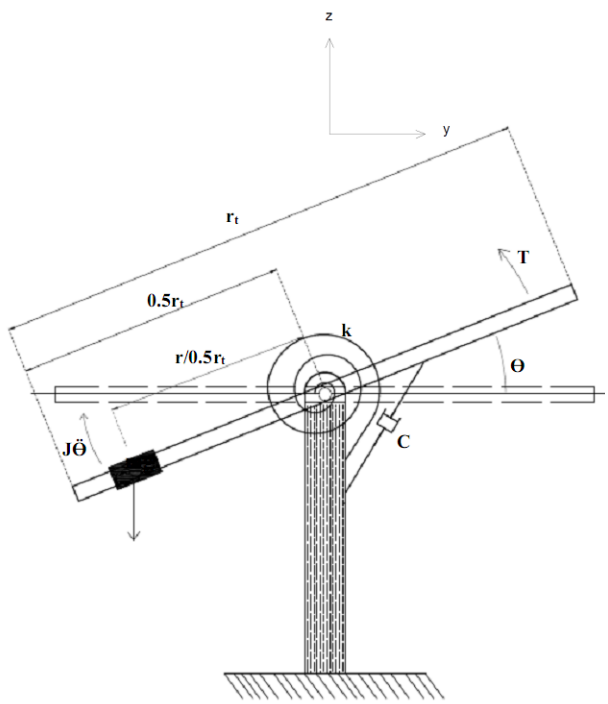

Figure 2. Design parameters of semi active control system

B. Simulation

The solar panel orientation simulation test is carried out by assuming that the axis point is the system's balance point. The friction force in the orientation system is also assumed to be so small that it can be ignored. The simulation consists of four cases, in each case the best parameter values will be taken based on the desired orientation angle of 60°. The following is a simulation test for each case:

Case A;

Case A is a simulation test given the constant value of m/m_p, c_τ, and k_τ respectively 15%, 3Nm/rad/sec, and 1 Nm/rad. While $r/0.5r_t$ (%) value is given, 35%, 40%, and 50% with the result shown in graphs in figure 3.

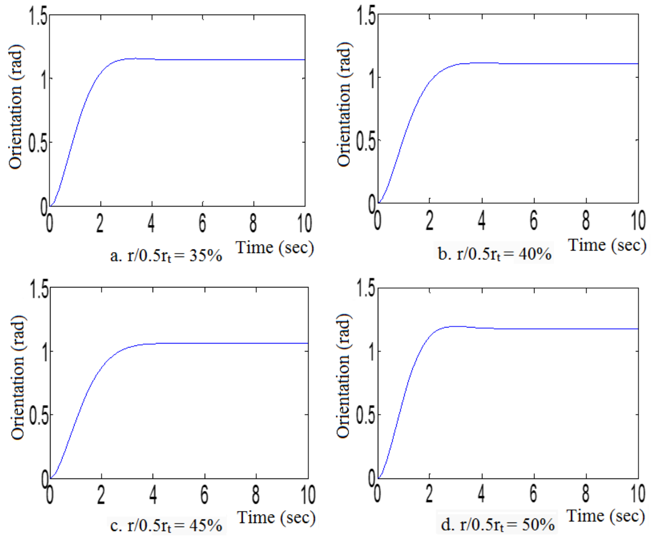

Figure 3. Simulation results of case A

Based on these results, the best $r/0.5r_t$ value was obtained at 35% with an angle of 60.63°. For $r/0.5r_t$ > 35%, it can cause the overshoot to appear in the system response. The value of $r / 0.5r_t$ = 35% will be used as the value of the constant $r / 0.5r_t$ in the following cases. Comparison between orientation angles based on $r/0.5r_t$ value can be seen in figure 4.

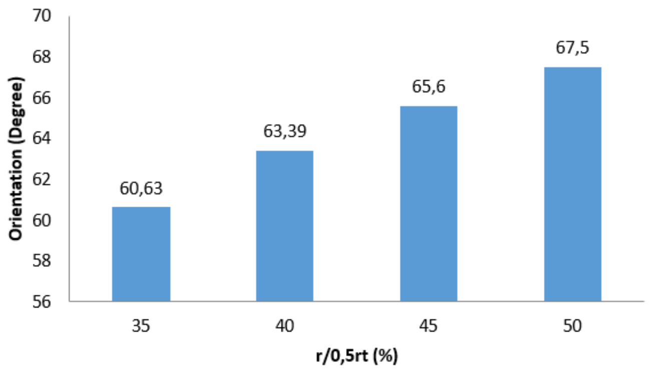

Figure 4. Simulation results of case A

Case B;

In case B the simulation test is carried out by giving the values $r/0.5r_t$, c_τ, and k_τ constant, $r/0.5r_t$ = 35%, c_τ = 3Nm /rad/sec, k_τ = 1Nm/rad and m/m_p (%) given 15%, 20%, 25% and 30% with results seen in figure 5.

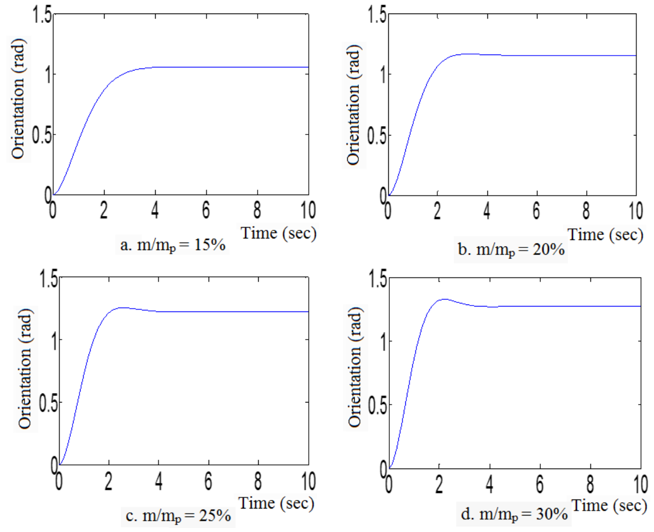

Figure 5. Simulation results of case B

Based on these results, the best m/m_p value is obtained at 15% with an angle of 60,63°. This value will be used as the constant m/m_p value in the following cases. For the value of m/m_p > 15% can cause overshoot on the system. The orientation angle obtained for each m/m_p value is shown in figure 6.

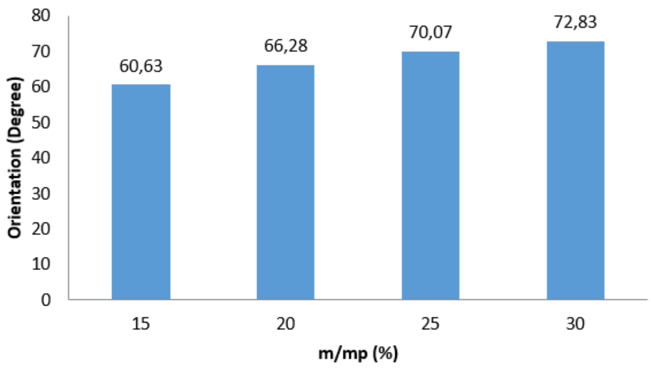

Figure 6. Simulation results of case B

Case C;

The constant value is $r/0.5r_t$ = 35%, m/m_p = 15%, k_τ = 1Nm/rad and the value of c_τ is set with values: 1Nm/rad/sec, 2Nm/rad/sec, 3Nm/rad/sec and 4Nm/rad/sec with results seen in the graph in figure 7.

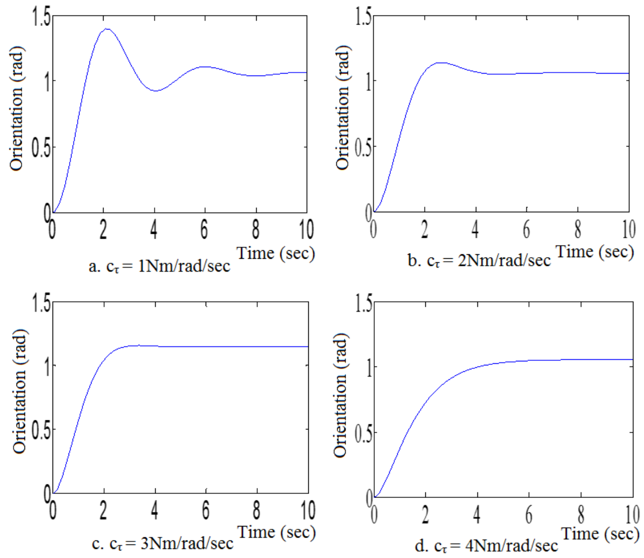

Figure 7. Simulation results of case C

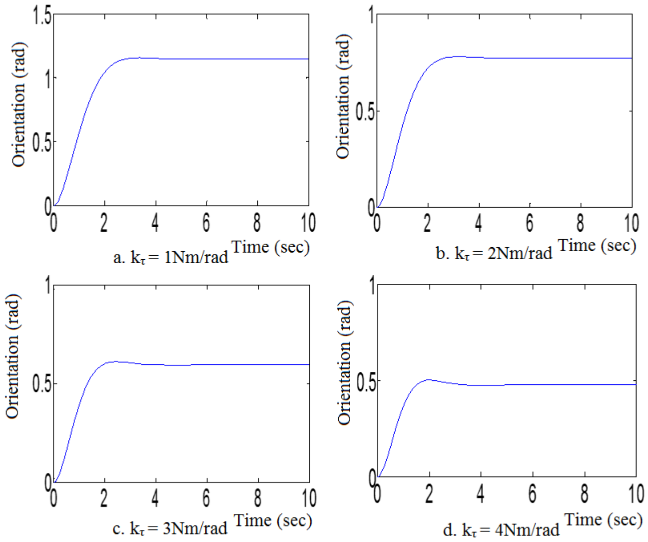

Figure 9. Simulation results of case D

Based on these results, the best c_τ value is obtained, which is 3Nm/rad/sec with an angle of 60.63°. This value will be used as the constant c_τ value in the next case. For a value of c_τ < 3Nm/rad/sec, it can cause overshoot and oscillation. Whereas for c_τ > 3Nm/rad/sec, it is obtained a long time for steady state. All orientation angle from every c_τ variation can be seen in figure 8.

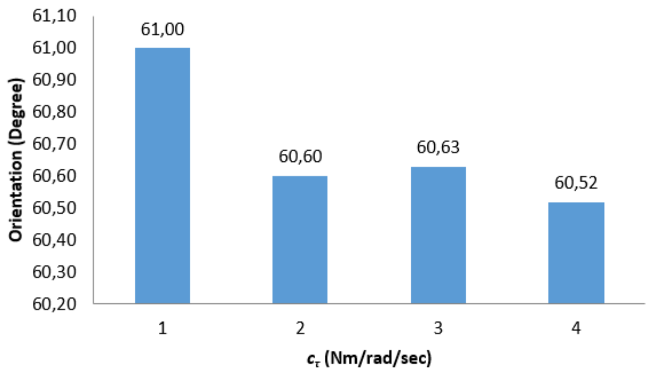

Figure 8. Simulation results of case C

Case D;

Constant value in this case: $r/0.5r_t$ = 35%, m/m_p = 15%, c_τ = 3Nm/rad/sec and the value of k_τ is set with values, 1Nm/rad, 2Nm/rad, 3Nm/rad and 4Nm/rad, with results shown in figure 9.

Based on these results, the best k_τ value is obtained, which is 1Nm/rad/sec with an angle of 60.63°. The value of k_τ > 1Nm/rad/sec will cause overshoot and the orientation angle θ° < 60,63°. Comparison between orientation angles based on k_τ value can be seen in figure 10.

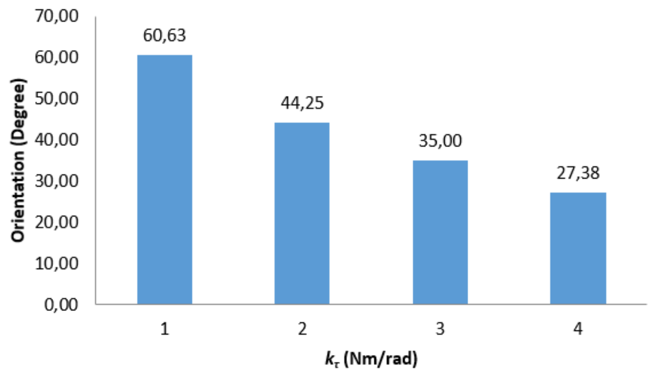

Figure 10. Simulation results of case D

According to the results of the simulation test, the best value of each parameter is obtained: $r/0.5r_t$ = 35%, m/m_p = 15%, c_τ = 3Nm/rad/sec and k_τ = 1Nm/rad. These values produce a orientation angle of the solar panel of 60,63°. Therefore, setting the mass, damper and stiffness parameters can be used as solar panel orientation control parameters.

C. *Energy Consumption Analysis*

The moving mass is conducted by applying lower power stepper motor. The stepper motor can work properly if it has the appropriate voltage for each coil in each step. The speed of the stepper motor depends on/off time of the coil, so to determine the maximum speed based on the characteristics of the torque versus step-rate (pulses per second or pps).

As shown in figure 2, the orientation control solar panel is using trajectory in form of lead screw which will be rotated by stepper motor. The lead screw in this case has the efficiency η_s = 86%, while the linear distance (s) equal with trajectory (r_t) = 541 mm, the added mass of the object (m) = 1.05 kg, θ = 60,63^0 and time (t) = 1.0 sec. Then the average power needed to drive the lead screw is [20]:

$$P_{avg} = \left[\left(m \cdot g \cdot \sin\theta \cdot S\right) / t\right] \cdot \left(1/\eta_s\right) \tag{5}$$

Where:

P_{avg} = average power (watt)
m = mass (kg)
g = gravitational constant (9,8 m/s^2)
S = linear distance (m)
t = time (sec)
θ = Solar panel orientation (degree)
η_s = lead screw efficiency (%)

Then:

$$P_{avg} = \left[\left(1,05 \cdot 9,8 \cdot \sin(60,63) \cdot 0,541\right) / 1,0\right] \cdot \left(1/0,86\right)$$
$$P_{avg} = 5,64 \text{ W}$$

The electrical power that can be produced by solar panels in this simulation test is a maximum of 250 Wp. While the average power consumption for the drive is 6,47 watt. Therefore, if the electrical power produced by solar panel compared with the power consumption for the drive, this system only consume 2,26%. It can be said that the use of the proposed method is effective in reducing energy use for the orientation of solar panels compare to single axis active tracking system which is estimated to be around 14% -28% of the energy produced.

IV. CONCLUSION

According to the results of the simulation test, the best value of each parameter is obtained: r/0.5rt = 35%, m/mp = 15%, cτ = 3Nm/rad/sec and kτ = 1Nm/rad. These values produce a orientation angle of the solar panel of 60,63°. Therefore, setting the mass, damper and stiffness parameters can be used as solar panel orientation control parameters. The ability of the system to control the orientation is effective to reduce energy consumption of the solar panel orientation controlling system.

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