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(RESEARCH ARTICLE)

# Mathematical model of a rotary 3D format photo electric energy device

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## Abstract

This article provides a theoretical analysis of the mechanical and energy issues of a newly developed 3D rotating photovoltaic device. In addition, a 3D model of the photovoltaic device has been developed. Also, a digital modeling program has been developed to study the mechanical parameters and external influences on the surface temperature of a photovoltaic device. The results obtained in new program are presented.

**Keywords:** Solar Panels; Temperature; Forced Convection; Wind; C sharp; Moment of Inertia; Angular Velocity; Pyramid.

## 1. Introduction

Solar panels exchange heat energy with the environment through radiation. However, the heat energy coming from the sun and falling on the surface of the solar panel is greater than the heat radiation energy of the solar panel to the environment so the surface temperature of the solar panel is higher than that of the environment [1-2]. According to the experimental results, the surface temperature of the solar panel rises to a value 63% higher than the ambient temperature. For example, when the ambient temperature is 35 $^{0}$C, the surface temperature of the solar panel rises to 57 $^{0}$C [3-6]. Another method of heat transfer available is convection heat transfer [8-9]. If the air layers around the solar panel move, it will cause the heat energy on the surface of the solar panel to be transferred to the environment. This ensures that the surface temperature of the solar panel does not differ significantly from that of the environment. Of course the question arises here, isn't there always wind? The solution to this is simple, if there is no wind, if we move the device itself, we can move the molecules with high temperature around it and exchange them with the molecules with low temperature. This causes forced convection. Since this process is continuous, the surface temperature of the device is approximately equal to the ambient temperature [14].

## 2. Method

### 2.1. Theory

Suppose there is a connection between the intensity of light falling on a solar panel and the power of electricity as follows.

$$P_c = P_{in} - P_{dis} \qquad (1)$$

Here:

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$P_c$ – electrical power

$P_{in}$ – power that is incident to surface of solar panel

$P_{dis}$ – dissipative power

The dependence of light intensity and temperature is as follows:

$P_{in} = I \cdot \alpha \cdot S$ (2)

$P_{dis} = U_L \cdot (T_c - T_a) \cdot S$ (3)

$P_c = \eta \cdot I \cdot S$ (4)

Here:

I-intensity of light

S- surface of solar panel

η – efficiency of solar panel

$U_L$ – heat loss coefficient

$\eta \cdot I \cdot S = I \cdot \alpha \cdot S - U_L \cdot (T_c - T_a) \cdot S$ (5)

$\eta \cdot I = I \cdot \alpha - U_L \cdot (T_c - T_a)$ (6)

If we find $T_c$ here

$U_L \cdot (T_c - T_a) = I(\alpha - \eta)$ (7)

$T_c - T_a = I / U_L(\alpha - \eta)$ (8)

$T_c = T_a + I \cdot \alpha / U_L(1 - \eta/\alpha)$ (9)

If we calculate $U_L$ in NOCT, we say η = 0

$$U_L = \frac{a * I_{NOCT}}{T_{C,NOCT} - T_{\alpha,NOCT}} \quad (10)$$

So,

$T_c = T_a + I/I_{NOCT} \cdot (T_{C,NOCT} - T_{\alpha,NOCT}) \cdot (1 - \eta_c/\alpha)$ (11)

$T_c = T_a + I_\alpha/I_{NOCT} \cdot (U_{L,NOCT} / U_L) \cdot (T_{C,NOCT} - T_{\alpha,NOCT}) \cdot (1 - \eta_c/\alpha)$ (12)

The convection coefficient due to wind was studied empirically by Skoplaki and the following formula was determined for the forced convection coefficient of solar panels made of polycrystalline silicon [4].

$h_\omega = 5.7 + 3.8 \cdot \upsilon$

When there is a difference between the surface of the solar panel and the ambient temperature, the process of energy exchange due to radiation also occurs [10-13].

$h_{rad} = \delta \cdot \varepsilon \cdot (T_c^4 + T_s^4)$ (13)

or

$h_{rad} = \delta \cdot \varepsilon \cdot (T_c^2+T_s^2)(T_c+T_s)(T_c-T_s)/ (T_c+T_\alpha)$ (14)

Here:

$T_s$ – temperature of sky

ε - heat absorption coefficient

δ – Boltzmann constant

$h = h_\omega + h_{rad}$ (15)

If in initial time temperature will be $T_c$-$T_\alpha$, so h=hω will be $U_L$ = h.

$T_c=T_a + (I\alpha/(5.7+3.8\upsilon)) \cdot(1-\eta_c/\alpha)$ (16)

$T_c=T_a + (I\alpha/(5.7+3.8\upsilon)) \cdot(1-\eta(T_c)/\alpha)$ (17)

$\eta(T_c)= \eta_{ref} (1-\beta(T_c-T_{ref}))$ (18)

$T_c=T_a + (I\alpha/(5.7+3.8\upsilon))\cdot(1- \eta_{ref} (1-\beta(T_c-T_{ref})/\alpha)$ (19)

$T_c=T_a + (I\alpha/(5.7+3.8\upsilon))\cdot(1- \eta_{ref}/\alpha+ \eta_{ref}\beta/\alpha (T_c-T_{ref}))$ (20)

$T_c=T_a + (I\alpha/(5.7+3.8\upsilon))\cdot(1- \eta_{ref}/\alpha+ \eta_{ref}\beta T_c/\alpha- \eta_{ref}\beta T_{ref}/\alpha)$ (21)

$T_c(1-(I\alpha/(5.7+3.8\upsilon)\cdot(\eta_{ref}\beta/\alpha))=T_a+ I\alpha/(5.7+3.8\upsilon))\cdot(1- (\eta_{ref}/\alpha)-\beta\eta_{ref}T_{ref}/\alpha)$ (22)

$T_c=(T_a+(I\alpha/(5.7+3.8\upsilon))\cdot(1- \eta_{ref}/\alpha-\beta\eta_{ref}T_{ref}/\alpha))/(1-(I\alpha/(5.7+3.8\upsilon)\cdot(\eta_{ref}\beta/\alpha))$ (23)

The surface temperature of a solar cell is determined by the above expression.

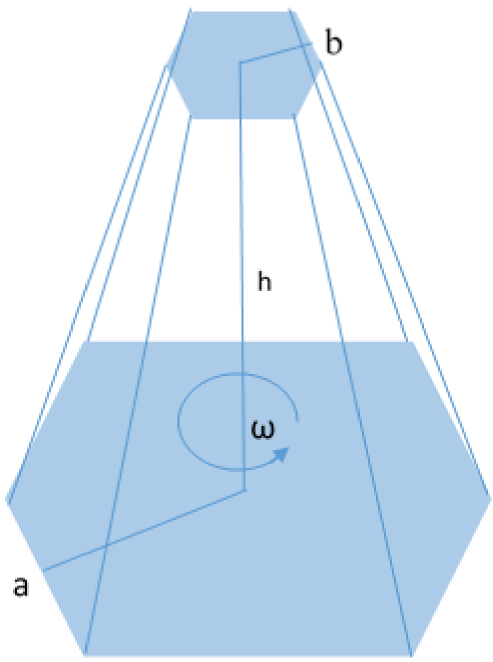



***Figure 1*** *Drawing of a photoelectric power device. h is the height, a is the length of the side of the lower base, b is the length of the side of the upper base, ω*

*is the angular velocity of the device.*

Here:

$\eta_{ref}$ is efficiency in $T_{ref}$ temperature.

Since the device we have developed is in the form of a pyramid, let us see that its mechanical properties i.e. the rotational speed of the device depend on the installed motor power, the moment of inertia of the device and the air resistance.

The moment of force applied by the motor to the device is used to give the device a certain acceleration and to overcome the frictional force of the air.

$$M_t=M+M_{ish} \quad (24)$$

$$\begin{cases} M=I\varepsilon & (25) \\ dM_{ish} = F_{ish}dr & (26) \end{cases}$$

Because the device is in the form of a pyramid, different frictional forces are affected at different heights. If the $d_r$ part of the radius of the device is affected by the $dM_{ish}$ friction force moment, we can determine the total friction moment by integrating it along the radius.

$$F_{ish} = k\upsilon = k\omega r \quad (27)$$

At low speeds of the device we know that the resistance force is directly proportional to the first level of speed.

$$dM_{ish} = k\omega dr \quad (28)$$

$$M_{ish} = \int_{r_2}^{r_1} k\omega r dr \quad (29)$$

$$M_{ish} = \frac{k\omega(r_1^2-r_2^2)}{2} \quad (30)$$

$$M_t = I\varepsilon + \frac{k\omega(r_1^2-r_2^2)}{2} \quad (31)$$

According to Newton's second law for rotational motion dynamics, the rotational moment of force of a device is determined by M = Iε. Angular acceleration is in turn the first-order product of angular velocity.

$$\varepsilon = \frac{d\omega}{dt} \quad (32)$$

Where M_t is the moment of force applied to the device by external forces.

I is the moment of inertia of the device relative to the axis of rotation.

k is the coefficient of air resistance

ω is the angular velocity of the device

$$I\frac{d\omega}{dt} + \frac{k\omega(r_1^2-r_2^2)}{2} = M_t \quad (33)$$

Let us proceed to the solution of this differential equation (33),

$$\frac{d\omega}{dt} + \frac{k\omega(r_1^2-r_2^2)}{2I} = \frac{M_t}{I} \quad (34)$$

$$\gamma = k\frac{(r_1^2-r_2^2)}{2I} \quad (35)$$

if we define,

$$\frac{d\omega}{dt} + \gamma\omega = \frac{M_t}{I} \quad (36)$$

The solution of the differential equation is as follows.

$$\omega = \frac{M_t}{I\gamma} + Ce^{-\gamma t} \quad (37)$$

If we say ω = 0 at initial time t = 0, then

$$6 = \frac{M_t}{I\gamma} + C \qquad C = -\frac{M_t}{I\gamma}$$

$$\omega = \frac{M_t}{I\gamma} + 1 - e^{-\gamma t} \quad (38)$$

the solution in the view occurs.

$$\omega = \frac{2M_t}{k(r_1^2+r_1^2)}\left(1\text{-}e^{-\frac{k(r_1^2-r_2^2)}{2I}}\right) \quad (39)$$

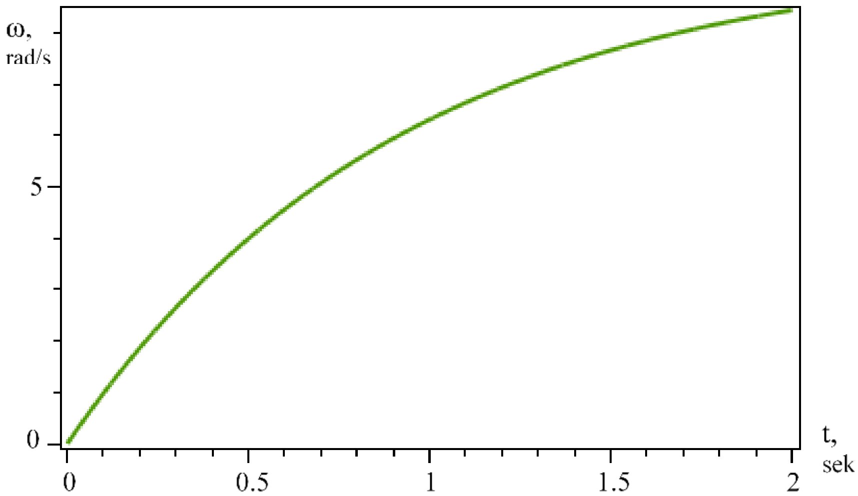
From this formula we can draw the following conclusions. The device moves with acceleration during the initial times of movement, and after a certain time it reaches a constant speed. This is because the moment of friction is equal to the moment of force that the motor gives to the device. This event occurs in about 1-2 seconds. This phenomenon depends on the moment of inertia of the device, the resistance of the air, and the power of the motor.

Here the moment of inertia is determined as follows.

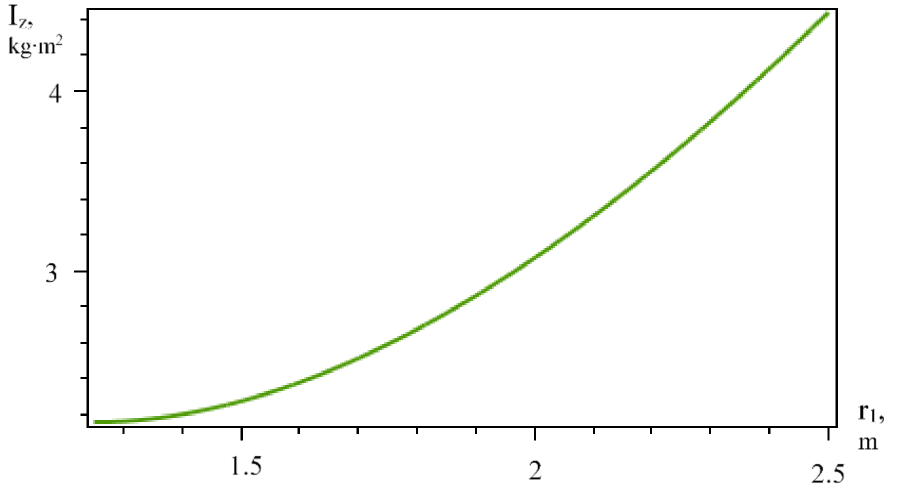
$$I_z = \frac{2m(a^2-b^2)}{a^3-b^3}\left(\frac{1+\cos^2 a}{24} + \frac{h^2\sin^2 a}{5(a-b)^2}\right) \quad (40)$$

$$\alpha = \operatorname{arctg}\left(\frac{2h}{\sqrt{3}(a-b)}\right) \quad (41)$$

## 3. Results

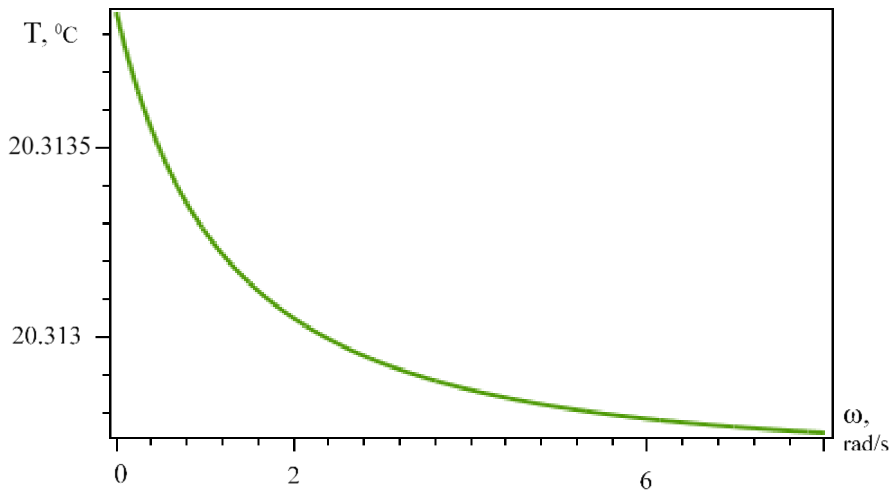



***Graph 1*** *Change of angular velocity for 2 seconds after the photoelectric device starts moving.*




***Graph 2*** *Dependence of the moment of inertia of a photoelectric device on the lower radius of the device*

According to the theory developed above, a program called STVertical was created in the C # 9.0 programming language. In the program, the differential equation of the above formula (36) was solved by the numerical method. A 3D model has also been developed to provide a better understanding of the structure and operation of the device [14].




***Graph 3*** *The dependence of the surface temperature of a photoelectric device on the speed of rotation.*

## 4. Discussion

We know that due to the presence of air resistance, the angular velocity of the proposed device increases exponentially in 2 seconds (Graph 1). Then, the device starts spinning at the same speed. This is because the moment of resistance of the air is equal to the moment of force applied by the motor to the device.

By changing the height, top and bottom radii of the device, we can develop a technically better version of the device. It is known from the dynamics of solids that a change in the height, top and bottom radii of a pyramid causes a change in its inertia. A change in inertia, in turn, causes a change in the speed of the device. This means that the surface temperature of the solar cells also changes.

The program based on all developed theories was registered by the Intellectual Property Agency of the Republic of Uzbekistan under the name DGU09198 "STVertical" on 24.09.2020 [15-17]. The possibilities of this program are wide and it is possible to process the results and compare them with the results obtained in practice.

## 5. Conclusion

According to scientific studies, the surface temperature of solar panels has changed due to wind. Let's say there's no wind, but we can move the device. That's why we decided to turn the device on. We tried to find a technical and theoretical solution to it above. The results show that the surface temperature of the device does not change partially when the angular velocity is 8 rad / s. The above theoretical solutions show that the surface temperature of the device does not increase over time.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

To the best of our knowledge, the named authors have no conflict of interest, financial or otherwise.

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