Wind and weight induced loads on a gear based azimuthal photovoltaic platform

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Abstract. Due to their specific constructive characteristics, such as high surfaces exposed to wind action, the height above the horizontal level and the orientation to wind flow direction, the photovoltaic (PV) platforms are subjected to high mechanical forces. Therefore, wind and weight induced loads analyses is necessary to an optimum design of these systems.

Considering different wind and weight loading cases were determined the equations of forces and torques on each axis of the system (*x*, *y* and *z*). Also, the maximum possible load was established, based on the analyses of the forces and torques daily variations.

Key words

Wind loads, azimuthal PV system, functional angles.

1. Introduction

The objective of this paper is to present the methodology used to determine the wind and weight load on a gear based azimuthal photovoltaic (PV) platform.

The overall size of the structure and transmission of the tracking system are directly depending on the loads of the PV platform. Of all the loads coming from weight, wind and snow, the main load is caused by the wind action [1].

Due to their specific constructive characteristics, such as high surfaces exposed to wind action, the height above the horizontal level and the orientation to wind flow direction, the PV platforms are subjected to high mechanical forces. Therefore, the results of this loads analyses are used as an input parameters for the design of the azimuthal PV platforms.

Considering different wind and weight loads cases were determined the equations of forces and torques on the axes of the system (*x*, *y* and *z*); were simulated the forces and torques daily variations in order to establish the maximum possible load.

2. Tracking system and simulation assumptions description

The tracking system presented in Figure 1 is a simplified constructive version of the solution subjected to a patent proposal [2]. The components of the structural scheme presented in Figure 1 are: the worm gear 1-2, the clutches C1 and C2, the double bevel gear 3-4 and 3-5, the housing 6 and the photovoltaic platform 7. The two clutches operate as normally engaged brakes spring applied and electromagnetically released.

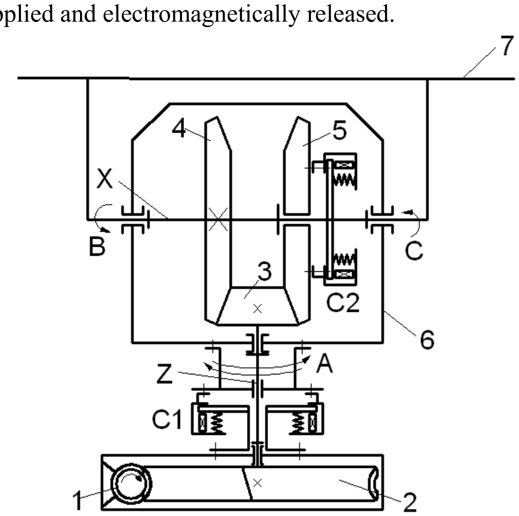


Fig.1. Azimuthal tracking system. Structural scheme

While C2 clutch is engaged and C1 disengaged, the two bevel wheels 4 and 5 – together with the shaft of *x* axis, housing 6 and the PV platform 7 acts like a unit block that will be rotated around z axis. Thus, the specific azimuthal rotational ψ^* movement is performed.

The altitudinal rotational movement α^* performed around *x* axis is achieved by disengaging C2 and engaging C1. By changing the direction of motor drive rotation the altitudinal movement can be performed in both ways: from sunrise to noon and then from noon to sunset. In the interval between two positions drive (called tracking positions), the PV platform is in the rest position: C1 and C2 are engaged, without energy consumption.

The assumptions of the analyses were draft according to the branch literature recommendations:

- according to wind zoning maps [3], the maximum wind speed for Braşov - Romania is 30 m/s; however, the recordings of the meteorlogical station of Transilvania University show that the average wind speed vary from 0 to 14 m/s [4], that is way we ascertained a value of 15 m/s;
- wind direction was considered to be towards PV surface and backwards to it;
- regarding the wind pressure distribution it was assessed to be uniform [3] and trapezoidal [5];
- the wind flow was considered to be continuously, without turbulence.

3. Wind loading cases

To determine the possible pressure distribution situations, we considered a *Oxyz* coordinate system, as presented in Figure 2, placed at the imaginary intersection of the transmission main shafts.

According to the above stated premises and to the experimentally results presented in a previous work [6], were established the following possible distribution cases (DC) of wind pressure (Figure 3):

- DC1–uniform distribution along the PV surface (Figure 3, a);
- DC2–trapezoidal distribution along the H dimension of the platform (Figure 3, b);
- DC3–trapezoidal distribution along the V dimension of the platform (Figure 3,c).

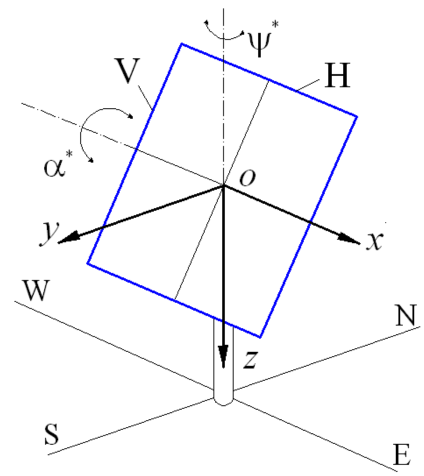


Fig.2. Coordinate system specific to the azimuthal PV platform

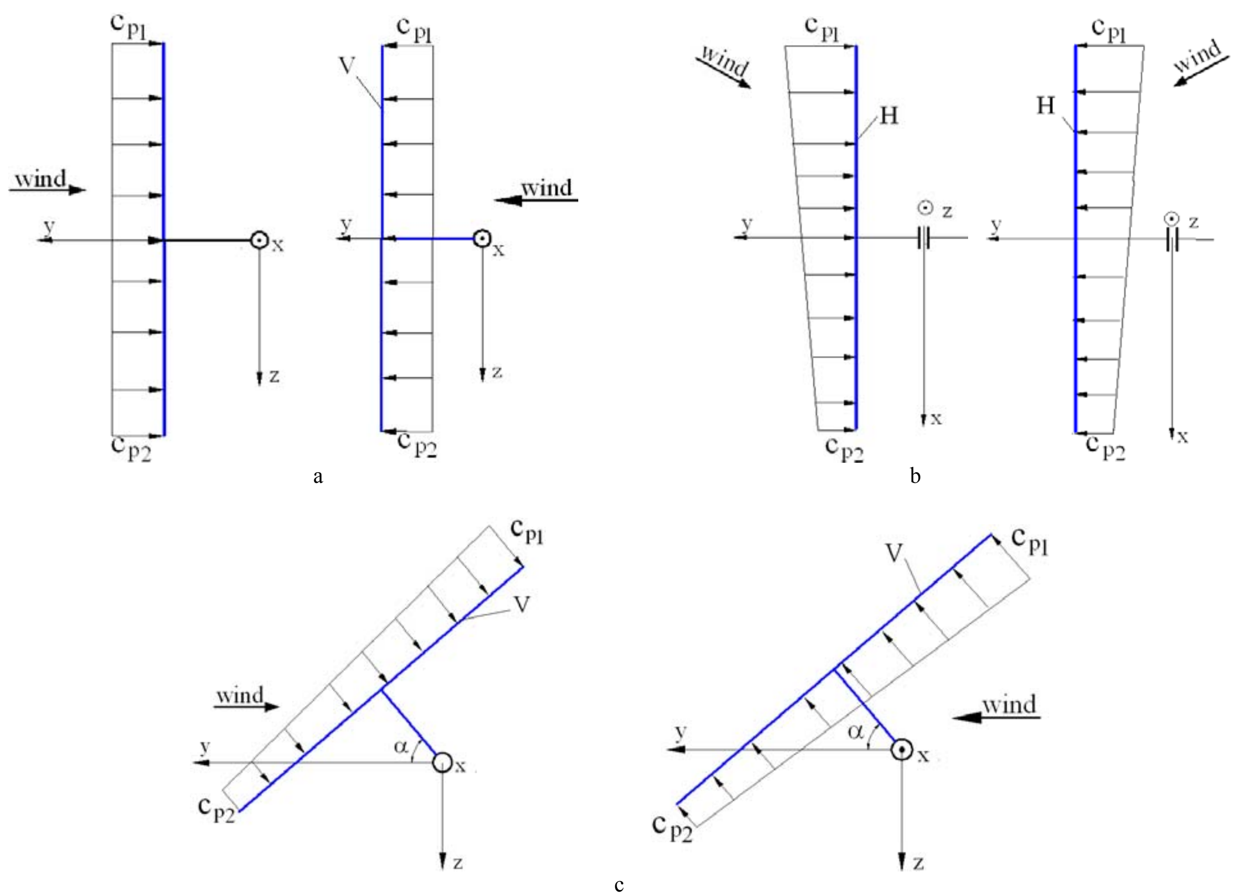


Fig.3. Wind pressure distribution cases
a – DC1; b – DC2; c – DC3

The air moving on the surface and around the PV platforms surfaces produces two types of forces: pressure forces normal to the surface and friction forces along surface, resulted from air friction with the panel surface.

Corresponding to the wind pressure distribution cases presented in Fig. 3, were determined the load cases by setting the wind force and weight application points.

The first load case, presented in Figure 4, corresponding to the uniform distribution DC1, the application point of wind force F_w coincides with the application point of the weight G (platform weight center).

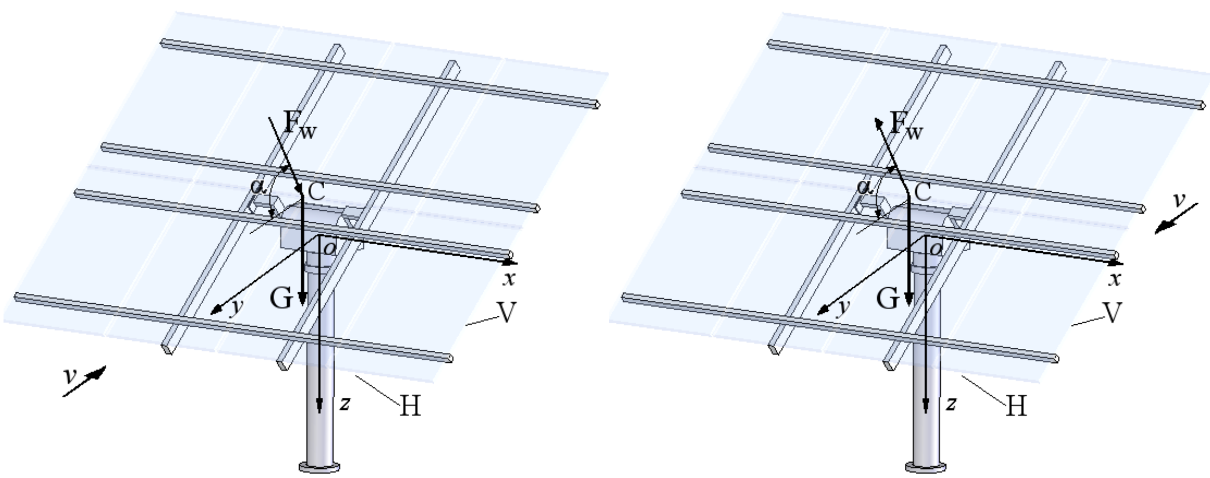
Because of the trapezoidal wind pressure distribution along the H dimension, the application point of wind force in the second load case, is set at a distance $a = 1/18\,H$ from the weight center of the platform. Thus, a torque around z axis occurs. The calculation schemes for this load case are presented in Figure 5.

Regarding the third load case, the application point of wind force F_w is at a distance $a_1 = 1/18\,V$ from the weight centre of the platform, due to the trapezoidal distribution along V dimension (Figure 6). This causes a torque around x axis.

The force produced by the wind action was determined using the pressure coefficients:

$$F_w = \frac{1}{2}\rho v^2 c_p S \qquad (1)$$

where ρ represents air density; v – wind speed; c_p – pressure coefficient [5]; S – surface area of wind action. Based on the calculation schemes were developed the equations of forces and torques on each axes of the system, as presented in in Tabel I, II and III.



a b

Fig.4. Calculation schemes for the first load case
a – towards surface action; b- backwards surafce action

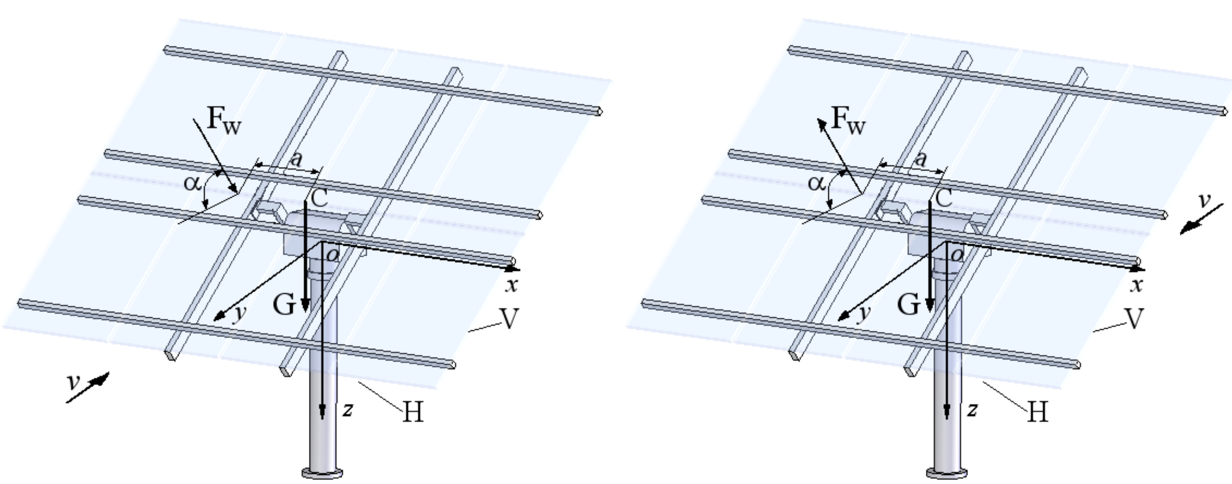


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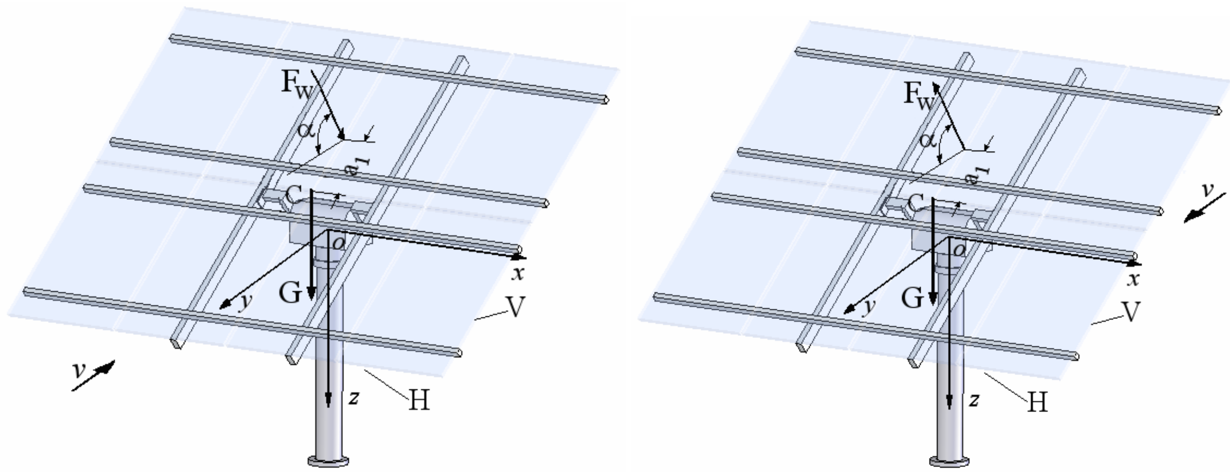
Fig.5. Calculation schemes for the second load case
a – towards surface action; b- backwards surafce action



a b

Fig.6. Calculation schemes for the third load case
a – towards surface action; b- backwards surafce action

Table I. – Load case 1

	Towards surface	Backwards surface
$F_x =$	0	0
$F_y =$	$F_w \cos\alpha$	$F_w \cos\alpha$
$F_z =$	$G + F_w \sin\alpha$	$G - F_w \sin\alpha$
$M_x =$	$Gb\cos\alpha$	$Gb\cos\alpha$
$M_y =$	0	0
$M_z =$	0	0

Table II. – Load case 2

	Towards surface	Backwards surface
$F_x =$	0	0
$F_y =$	$F_w \cos\alpha$	$F_w \cos\alpha$
$F_z =$	$G + F_w \sin\alpha$	$G - F_w \sin\alpha$
$M_x =$	$Gb\cos\alpha$	$Gb\cos\alpha$
$M_y =$	0	0
$M_z =$	$aF_w \cos\alpha$	$aF_w \cos\alpha$

Table III. – Load case 3

	Towards surface	Backwards surface
$F_x =$	0	0
$F_y =$	$F_w \cos\alpha$	$F_w \cos\alpha$
$F_z =$	$G + F_w \sin\alpha$	$G - F_w \sin\alpha$
$M_x =$	$Gb\cos\alpha - F_w a_1$	$Gb\cos\alpha + F_w a_1$
$M_y =$	0	0
$M_z =$	0	0

In Tables I, II and III, b is the length of the arm connecting the shaft of *x* axes and the PV platform (Figure 7) and α represents the daily solar elevation angle. According to [1] daily solar elevation angle is determined by the following relation:

$$\alpha = \sin^{-1}(\sin\delta \sin\rho + \cos\delta \cos\rho \cos\omega) \quad (2)$$

where **δ** is the declination angle and **φ** represents the im plementation site latitude.

The constructive solution of the azimuthal tracking system presented enables performing azimuthal and altitudinal angular strokes closed to the daily solar angular strokes.

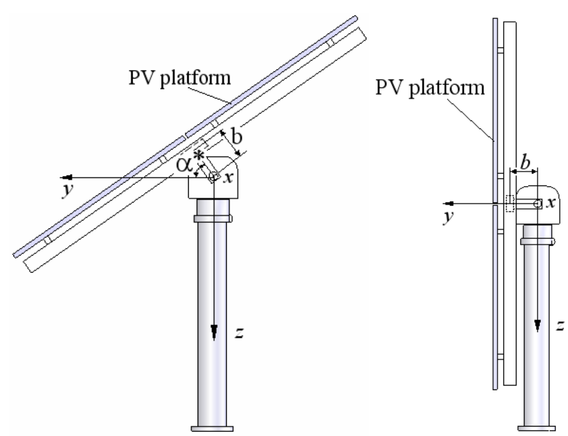


Fig.7. The representation of α* and b

4. Numerical simulations and discussions

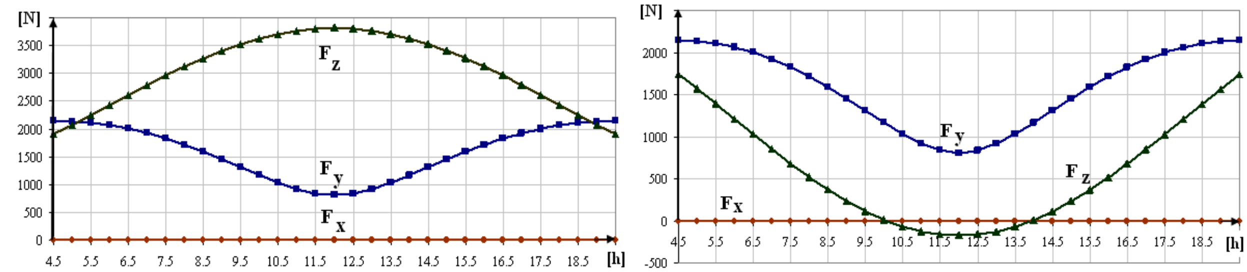
To simulate the forces and torques variations we assumed that the azimuthal tracker is equipped with 8 PV modules of two types, resulting this way a surface of 13 m^2. The weight of the modules and of the frame attached is G = 1820N.

The loads variations were analyzed for equinoxes and summer solstices. On solstices day the solar angular strokes Δα and Δψ [7], and azimuthal PV system angular strokes Δα* and Δψ* are maximum; it was considered that the rotational movements of the azimuthal PV system α* and ψ* are made continously, in order to follow as close as possible the daily solar angles.

The forces variations for summer solstice day differ according to wind action direction (Figure 8). The variation of F_z is symetrical to solar noon. The slope is increasing from sunrise up to noon and is decreasing to sunset when wind acts towards the PV platform (Figure 8a).

When the wind direction is considered to be backwards the PV platform, the F_z variation is opposite to the previous situation: it decreases from sunsrise to noon and then increases back to the sunset at the same value as in the sunrise position. In the solar time interval 10-14, the component of the wind force on *z* axes is exceeding the weight system, therefore F_z is negative in this interval.

The force F_y varies in the same manner for both wind direction assumptions: from a high value in sunrise position to a lower value in noon position and back to a high value in sunset position (Figure 8a and Figure 8b).

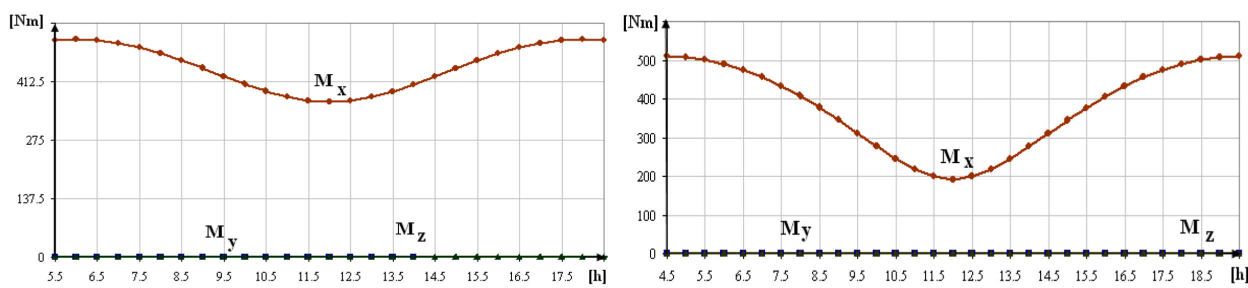


a b

Fig.8. Forces variation for summer solstice day for load case 1
a – wind action towards PV platform; b – wind action backwards PV platform

In the first load case due to F_w application point, the weight of the system *G* is the only one generating a torque on *x* axes (Figure 9). The maximum load appears at sunrise and sunset position, as a result of the azimuthal PV system position. At solar noon, in summer solstice day, the altitudinal angle α* of the azimuthal PV system has the highest value (almost 65°) and the load generated by the system weight reache the lowest value (Figure 9 b).

Comparing the two diagrams it can be noticed that the values of the loads on *x* axes are mainly influenced by the position of the PV platform, being higher for lower rotational angles, in sunrise and sunset positions.



a b

Fig.9. The torques variations considering wind action towards the PV platform for load case 1
a- equinox day; b- summer solstice day

In the second load case both wind and weight forces generate torques (Figure 10). Similar to load case 1 the torque on *x* axes, M_x is the result of the system weight *G* and varies in the same manner. The torque on *z* axes, M_z occurs, as the resultant of wind pressure is located at a certain distance $a = 1/18\,H$ from the weight center. The M_z variation is similar to M_x variation but the reached values are lower.

Regarding the third load case in solar time interval 8-16, torque resulted from weight action is lower than the torques resulted from the horizontal component of wind force (Figure 6, a). The resultant of the torques has negative values in this time interval (Figure 11, a).

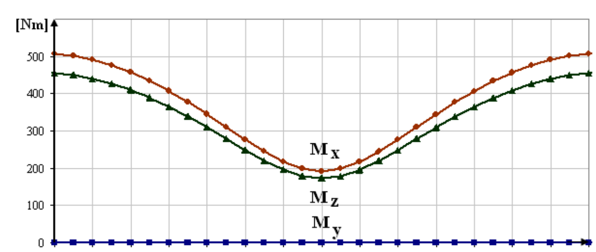


Fig.10. The torques variations for summer solstice considering wind action towards the PV platform for load case 2

This variation is not similar to the variation of the torque in the assumption of wind action backwards the PV platform (Figure 11, b). In this case the torque on x axes reaches the highest values, around 1000 Nm.

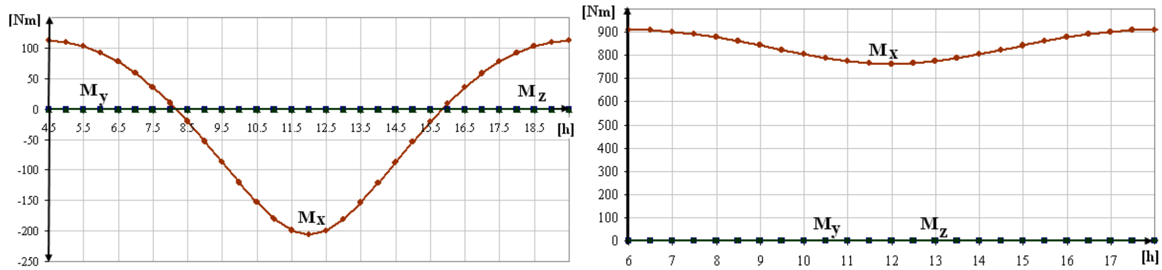


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Fig.11. The torques variations for summer solstice considering wind action towards the PV platform for load case 3
a – wind action towards PV platform; b – wind action backwards PV platform

4. Conclusions

The paper presented the methodology used to determine the wind and weight load on a gear based azimuthal (PV) system. The analyses was based on different wind and weight loads assumptions, and resulted in the maximum possible loads in relation to the functional angles of this azimuthal PV system.

The main conclusions are:

- F_x is maximum in the extreme positions of the PV platforms, at sunrise and sunset, when the altitudinal angle α* is close to 0; it has the same symmetrical variation to solar noon, no matter of wind action: it decreases from a maximum value in the sunrise to a minimum value at noon and then up again to maximum in sunset
- F_z variation depends on wind action direction; it reaches the maximum at noon when wind direction is forward PV platforms and minimum backwards wind direction;
- M_x is the most concerning load, it has the highest values for all the load cases presented.

The maximum values obtained are presented in Table IV.

Table IV. – Loads values

Load case	F_x [N]	F_y [N]	F_z [N]	M_x [Nm]	M_y [Nm]	M_z [Nm]
1	0	2150	3800	520	0	0
2	0	2150	3800	520	0	460
3	0	2150	3800	910	0	0

The results of this loads analyses are used as input parameters for the design of the azimuthal PV platform. To an optimum design of such types of systems, the maximum loads should be considered. So, the proper operation in the climatic conditions of the implemnattion site is ensured.

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