European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'10)
Granada (Spain), 23th to 25th March, 2010

Wind loads on an azimuthal photovoltaic platform. Experimental study

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Abstract. During the dimensioning stage of the embodiment design process of the azimuthal trackers for photovoltaic (PV) platforms a very important step is input load calculation. Wind load is the main load on these kinds of systems and a correct evaluation of wind load becomes significant for dimensioning. This paper presents results and conclusions from an experimental study on wind loads depending on wind velocity and functional positions of solar tracking platforms. The results are presented as graphic diagrams and can be useful for the improvement of actual standards on wind loads.

Key words

Experimental study, wind loads, azimuthal tracker.

1. Introduction

In the actual international context, decrease of electrical consumption is a top priority at European level, as it is specified in the European directive EC 20/20/20. With this aim the renewable energy systems like PV platforms are in continuous development. They are converting solar energy into electricity by means of the photovoltaic effect.

In order to increase the efficiency of PV platforms with up to 40% [1], they can be part of dual axes tracking systems. Tracking systems are maximizing the solar radiation on the surface of panels by minimizing the incidence angle of solar ray.

The dual axes tracking systems for PV platforms, using a vertical axis and a horizontal axis (fig. 1), are called azimuthal tracking systems. Rotations around the two axes (positioned by α angle for altitudinal rotation and ψ angle for azimuthal rotation) are performed by means of different kind of mechanical transmissions.

Dimensioning of the consisting mechanical transmissions and the mechanical structure itself is an important stage in the embodiment design of a tracking system for PV platforms. The dimensioning results influence the reliability but also the costs of the tracking system. Dimensions of structure and transmission of the tracking system are directly depending on the loads of the PV platform.

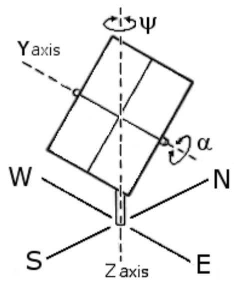

Fig. 1. Azimuthal tracking system - general diagram

From all the loads coming from weight, wind etc., the main load is the wind load [2]. This load is also the only one that creates reactions in the linear actuators used for positioning the α angle for altitudinal rotation of platform [3].

2. Wind load

Action of wind on different structures is usually evaluated either by wind pressure or by wind forces. Wind effects on buildings or specific structures depend on wind properties (medium velocity, air density, turbulences, dynamics, etc.), shape, dimensions and position of building towards direction of wind.

EN 1991-1-4 standard [4] presents calculus procedures for determining wind loads acting on buildings and other specific structures.

One situation presented in EN 1991-1-4, Eurocode1 is the one of hipped roofs. This case is not proper to be used as similar to the case of wind loads on the platform of a tracking system because the values of the pressure coefficients are only considering the external pressure on roofs and not the internal (other side) pressure appearing on open platforms. External pressure coefficients are only covering tilt angles up to 75°.

Another structures, closer to the case of tracking systems are the free-standing monopitch canopy roofs. In this case, instead of the pressure coefficients c_p, force coefficients c_f are presented (fig. 2) and they are considering wind pressure on both sides. The use of these force coefficients is limited by the range values (α = 0° ... 30°) of the tilt angle (angle between roof surface and wind direction) which is not covering all the functional positions of the tracking system's platforms. Table I presents the maximal absolute values of the force coefficients c_f, presented in [4] for the covered tilt angles α = 0° ... 30°.

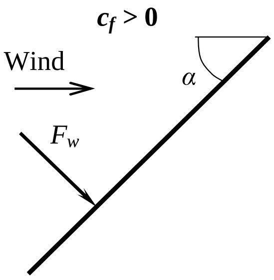

Fig. 2. Diagram of wind load on monopitch canopy [4]

Table I – Force coefficients for the case of monopitch canopy and signboards [4]

α	0°	10°	20°	30°		90°
c_f	0.5	0.9	1.3	1.8		1.8

Another similar case with the case of tracking systems can be considered the case of vertical sign boards, perpendicular towards the wind direction (α = 90°), and the value recommended by [4] is presented in Table I. This value of the force coefficient can be used on tracking systems only for two specific functional positions – sunshine and sunset.

The Russian standard for wind actions on buildings [5] presents same cases and similar values with the ones presented by [4].

As a conclusion none of the standards are entirely covering the case of wind loads on the platforms of tracking systems.

Based on the rules set by the Spanish standard NBE-AE 88 Titan Tracker company presents the specific case of wind action on platforms with the whole range of tilt angles [6]. It gives recommendations for calculus of wind load based on distribution of pressure coefficients, like the one presented in Fig. 3, for angles between platform and wind direction in the range 0° - 90°.

Table II presents values of the resulted force coefficient resulted using the pressure distribution from [6]. The force coefficient is calculated, in this case of linear distribution, as the average of the minimum and maximum pressure coefficients acting on the surface (fig. 3) with relation

$$c_f = \frac{c_{p1} + c_{p2}}{2} . \qquad (2)$$

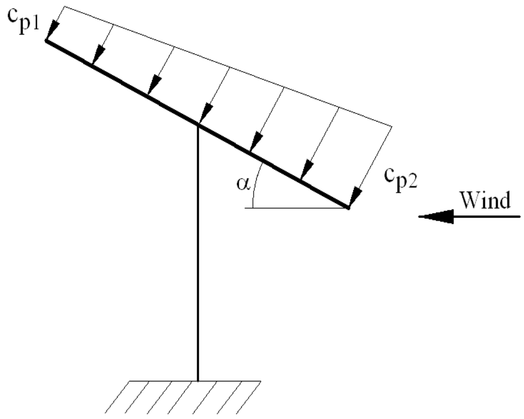

Fig. 3. Diagram of pressure coefficients distribution on tilted platforms [6]

Table II – Force coefficients for the case of tilted platforms [6]

α	0°	10°	20°	30°	40°	50°	60°-90°
c_f	0	0.4	0.8	1.2	1.2	1.2	1.2

An experimental study and a comparison with a FEM analyze has been developed for wind action dual axes tracking systems and presented in [7]. The experimental work has been developed in a wind tunnel with a section of 1200x1200 mm, on an experimental model of panel scaled 1/3 towards the real model. Pressure coefficients and forces have been determined for tilt angle of the panel in the range 0° - 50°.

The differences between the values presented in Tables I and II can lead to the conclusion that further research must be developed based on experimental study. These results should help development of standard recommendations for the specific case of tracking systems platforms.

3. Experimental setup

This paper is presenting the results of an experimental study developed in the Renewable Energy Laboratory from Transilvania University of Brașov. A wind tunnel type HM 170 [8], known as „Eiffel" (fig. 4, a), has been used. This wind tunnel is educational, with open circuit, air being taken from the atmosphere and blown back out into the open.

A reduced scale model of an azimuthal tracker has been developed (fig. 4, b) in order to simulate the functional positions of the tracker in the wind tunnel.

The experimental model 3 is placed in the measurement section 1 (see. fig. 4, a), where a linear wind flow is obtained and where the wind velocity can reach up to 100 km/h.

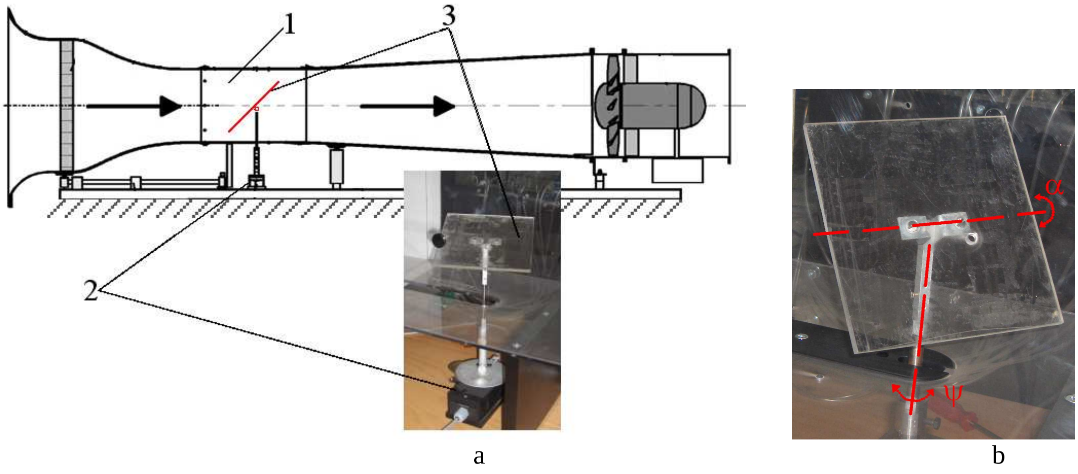

Fig. 4. Experimental stand and model

Under the measurement section, a force transducer 2 is placed. It can determine two components (F_{drag} şi F_{lift}) of the force acting on any profile placed into the wind tunnel. Figure 5 (top view of the profile) shows the directions of the measured components: F_{drag} has the same direction with the wind and F_{lift} is horizontal, perpendicular to the wind direction.

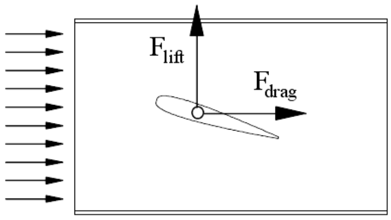

Fig. 5 Directions of the measured components

4. Experimental results

The experimental study developed in two stages:

a. Azimuthal angle variation; determination of forces acting on the platform and the force coefficient for vertical position of the platform (altitudinal angle α = 90°), with change of the tilt angle towards wind direction (azimuthal angle – ψ = 0 ... 90°, in 10° steps);
b. Elevation angle variation; determination of force coefficients for a panel positioned frontal toward the wind (azimuthal angle ψ = 90°), with change of the tilt angle towards wind direction (altitudinal angle – α = 0 ... 90°, in 10° steps).

A. Azimuthal angle variation

Determination is performed for vertical position of the platform (altitudinal angle α = 90°), with change of the tilt angle towards wind direction ψ = 0 ... 90°, in 10° steps, on the following stages.

1. Wind velocity is increased in 1 m/s steps in the range of v = 5 ... 20 m/s;
2. For each constant wind velocity the components F_{drag} and F_{lift} (see fig. 5) of the wind force acting on the model are measured;
3. The components relative to the platform of the resultant force are determined: F_n – normal to the platform and F_t – tangential towards the platform surface (fig. 6) with relations

$$\begin{aligned} F_n &= F_{drag} \sin\psi + F_{lift} \cos\psi \\ F_t &= F_{drag} \cos\psi - F_{lift} \sin\psi \end{aligned} \tag{2}$$

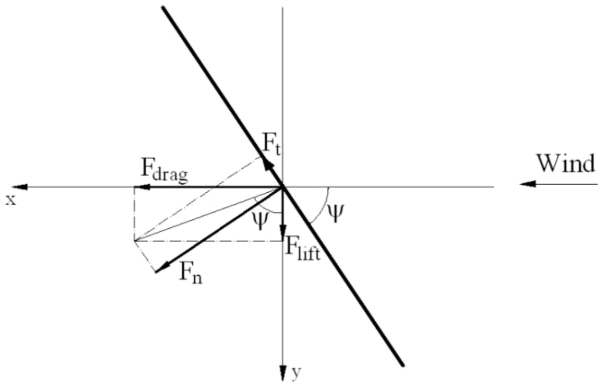

Fig. 6. Forces on the platform for azimuthal angle variation

4. Due to the fact that the surface of the panel is partially blocking the open of the wind tunnel, the wind velocity at the level of the model is bigger than the wind velocity measured at entering the measurements section. As a result the wind velocity must be corrected for further calculations with relation

$$v_{cor} = v \frac{A}{A - A_p \sin\psi}, \tag{3}$$

where A is the frontal area of the wind turbine and A_p is the area of the panel;

5. The force coefficient, without wind velocity correction and the force coefficient with velocity correction result with relations

$$c_f = \frac{F_n}{\frac{1}{2}\rho A_p v^2}, \qquad (4)$$

$$c_{f\,cor} = \frac{F_n}{\frac{1}{2}\rho A_p v_{cor}^2}, \qquad (5)$$

where ρ is the air density.

The numerical values of the parameters involved in the experimental study are: A = 90000 mm^2; A_p = 75x75 = 5625 mm^2 and ρ = 1.25 kg/m^3.

Figures 7 and 8 present the resulted force coefficients, with and without corrections of wind velocity, for sequential ψ angles, depending on wind velocity. The maximum corrected wind velocity is only 6% higher than the measures wind velocity and the difference between corrected and non-corrected force coefficient is maximum 12 %.

It can be seen that the force coefficient is decreasing and tending to stabilize for high wind velocity. The stabilized values of the corrected force coefficients $c_{f\,cor\,stab}$ have been considered the values obtained for maximum wind velocity and are presented in Figure 9, in comparison with the values recommended by [4] (see Table I) and [6] (see Table II), depending on the tilt angle. Tilt angle ψ is the same with the tilt angle α from Table I and II.

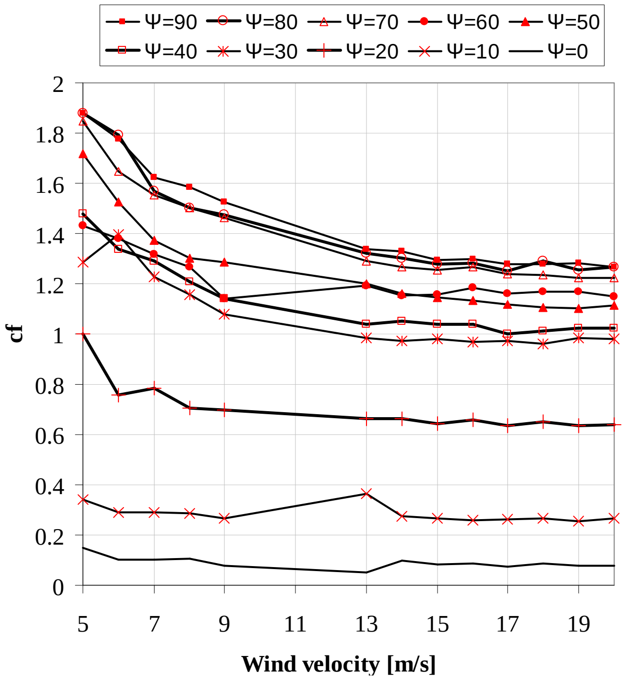

Fig. 7. Force coefficient without wind velocity correction

Figure 10 presents the variation of the calculated normal and tangential forces, depending on wind velocity, for three different ψ angle.

Figure 11 presents the variation of the calculated ratio between normal and tangential forces (F_t/F_n), depending on wind velocity, for three different ψ angle. It can be seen that this ratio is decreasing and tending to stabilize for high wind velocity. This ratio can be used for determining the tangential component along the surface of the panel (friction force) when the normal force is already determined.

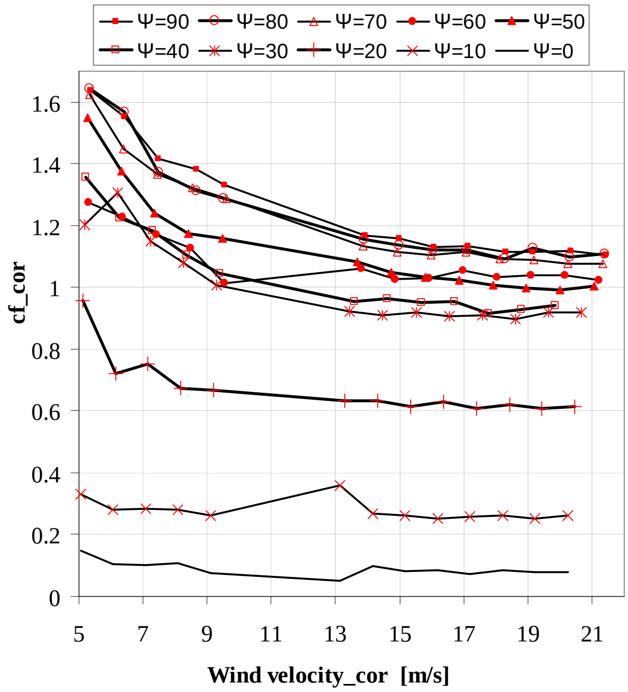

Fig. 8. Force coefficient with wind velocity correction

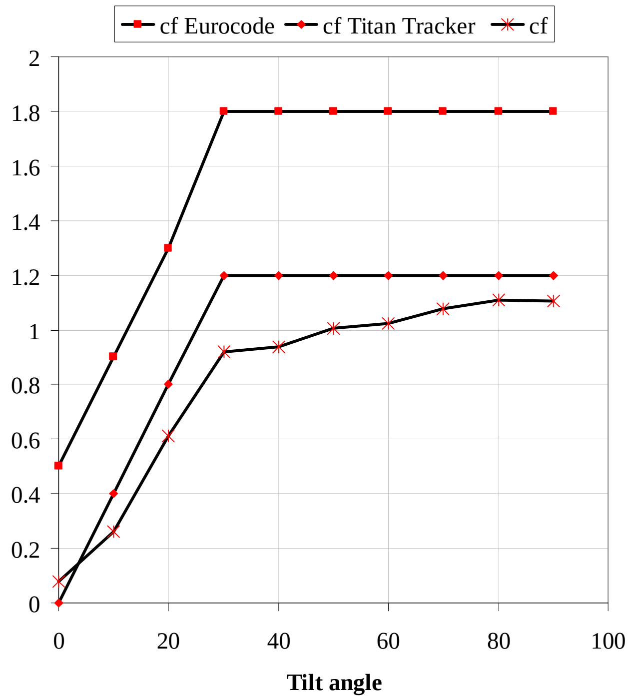

Fig. 9. Force coefficients comparison

Figure 12 presents the variation of the calculated ratio between normal and tangential forces (F_t/F_n), considering an average of the values obtained for wind velocity higher than 15 m/s, depending on the ψ angle.

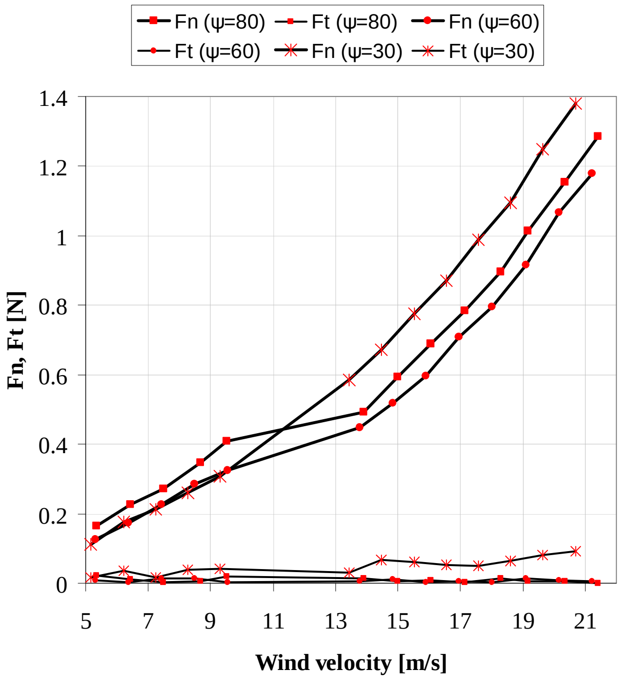

Fig. 10. F_n, F_t variations

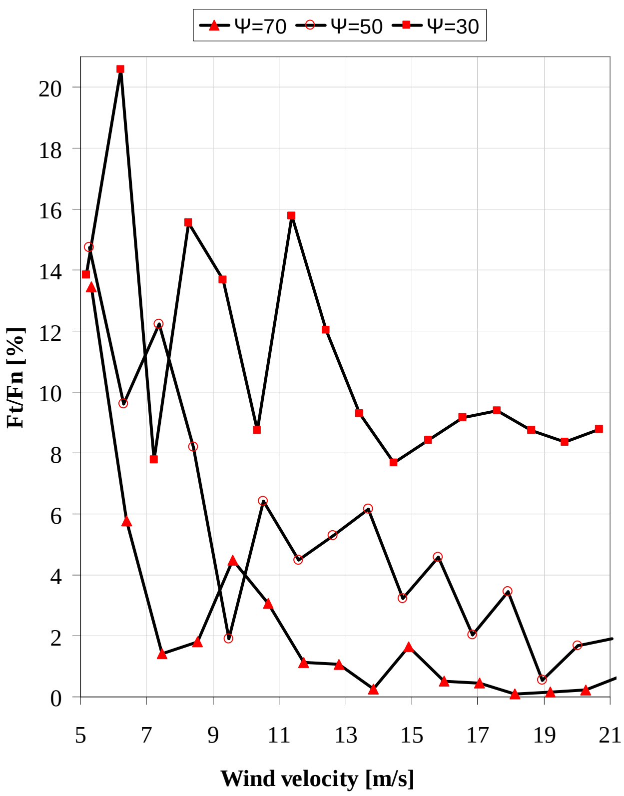

Fig. 11. F_t/F_n variation, depending on wind velocity

B. Elevation angle variation

Determinations are performed for the model positioned frontal toward the wind (fixed azimuthal angle ψ = 90°), with change of the tilt angle towards wind direction (altitudinal angle – α = 0 ... 90°, in 10° steps), in the following stages. Loads must be similar with previous determinations since α angle is similar with ψ angle from the previous determination (angle between wind line and the plane of the platform).

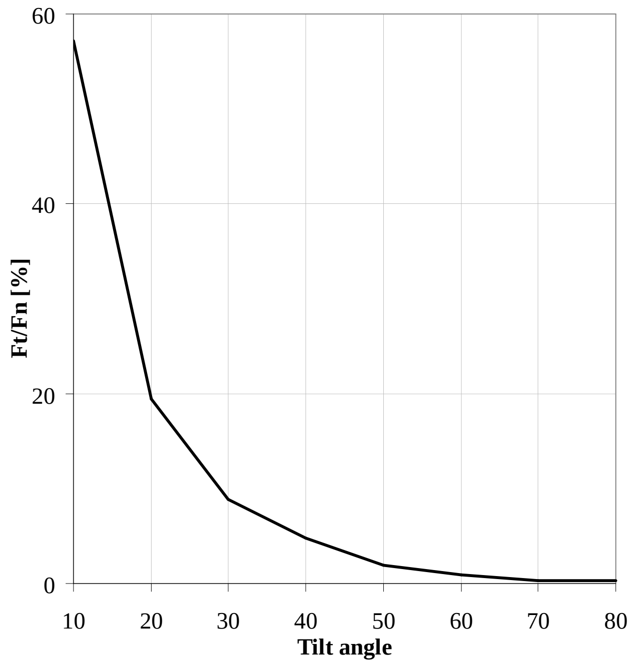

Fig. 12. F_t/F_n variation, depending on tilt angle

1. Wind velocity is increased in 1 m/s steps in the range of v = 5 ... 20 m/s;
2. For each constant wind velocity the components F_{drag} and F_{lift} (see fig. 5) of the wind force acting on the model are measured; In this case the lift force F_{lift} is approximately equal to 0, for all determinations because the profile is positioned symmetrical towards the wind line;
3. Due to the fact that measurement only offers the F_{drag} component of the R total resultant on the platform, the F_n component – normal to the platform is calculated with an assumed approximation (fig. 13) with relations

$$R = \frac{F_{drag}}{\sin(\alpha+\varphi)};$$
$$F_n = R\cos\varphi = \frac{F_{drag}}{\sin(\alpha+\varphi)}\cos\varphi, \tag{6}$$

where φ is the friction angle calculated as $\varphi = \arctan {F_t}/{F_n}$, the ratio ${F_t}/{F_n}$ being calculated in the previous determination, depending on tilt angle (see fig. 12).

4. Due to the fact that the surface of the panel is partially blocking the open of the wind tunnel, the wind velocity at the level of the model is bigger than the wind velocity measured at entering the measurements section. As a result the wind velocity must be corrected for further calculations with relation

$$v_{cor} = v\frac{A}{A - A_p \sin\alpha};\qquad (7)$$

5. The corrected force coefficient is calculated with relation (5).

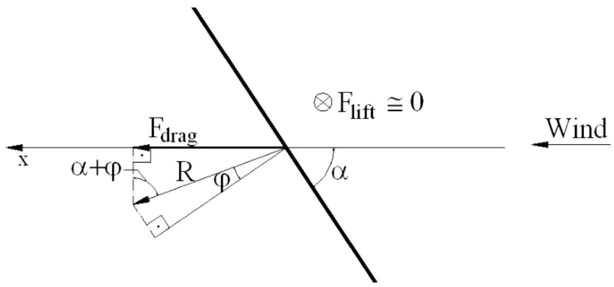

Fig. 13. Forces on the platform for altitudinal angle variation

Figure 14 presents the resulted corrected force coefficients, for secvential ψ angles, depending on wind velocity. It can be seen that the force coefficient variation is similar with the values resulted during previous determinations (A).

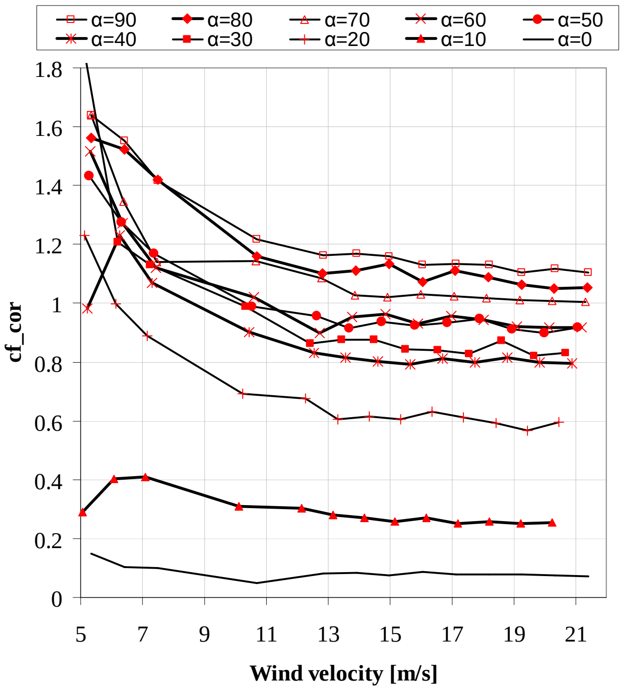

Fig. 14. Force coefficient with wind velocity correction

5. Conclusion

Few conclusions can be drawn based on the results presented in Figures 7 ... 10 and 12.

This paper is presenting experimental results on a very small scale panel but these results (force coefficients, F_t/F_n ratio) should be similar to the case of normal PV panel platforms.

The force coefficient is higher for low wind velocity (when resulted forces are very small) and is decreasing and tending to stabilize for high wind velocity. Force coefficients are relatively close and with higher values for high tilt angles (α or ψ = 40° ... 90°). Smaller values are obtained for smaller tilt angles and rapidly decreasing with decrease of tilt angle. Values for tilt angle equal to 0° are approximately equal to 0. These values (see fig. 7) are relatively different towards the values presented in Eurocode [4] but closer to the values presented by [6].

The resulted tangential force, calculated by the F_t/F_n ratio is very small for high tilt angles (α or ψ = 40° ... 90°, see fig. 10), but important in the case of small tilt angles, when the normal force is very small.

An improvement of EN 1991-1-4 Eurocode 1 should be performed in order to cover all the situations of wind load on PV platforms tracking systems.

Acknowledgement

This paper is supported by the "PLATSOL-PV" PNII Programme, financed by the Romanian Government and by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/6/1.5/S/6".

References

[1] T. Huld, M. Šuri and D. Dunlop, “Comparison of Potential Solar Electricity Output from Fixed-Inclined and Two Axis Tracking Photovoltaic Modules in Europe”, in Progress in Photovoltaics: Research and Applications, 2008, Vol. 16, pp. 47-59.

[2] R. Messenger and J. Ventre, “Photovoltaic Systems Engineering”, 2nd ed., CRC Press, London (2004), pp. 179-189

[3] L. Ching-Yao, ”Analysis of Structural Deformation in a High Concentrated Photovoltaic System”, available at http://thesis.lib.ncu.edu.tw/.

[4] EN 1991-1-4, Eurocode 1: “Actions on structures . General actions — Part 1-4: Wind actions”, 2004

[5] GOST 27751-88: Part 5. Wind loads (in russian). Anexa 4, 1988

[6] J. Cabanillas, ”The Wind and the Panacea of the Stow Position in the Solar Trackers”, www.titantracker.es

[7] C. Coşoiu, A. Damian, R. Damian and M. Degeratu, ”Numerical and experimental investigation of wind induced pressures on a photovoltaic solar panel”, in Proceedings of the 4th IASME/WSEAS International Conference on Energy, Environment, Ecosystems and sustainable development, Algarve, Portugal, 2008, pg. 74-80

[8] HM170 Technical data available at www.gunt.de