TOPIC 4: PV Systems Engineering, Integrated/Applied PV
Sub-topic 4.2/5: Engineering Design and Installation of PV Systems / Integrated PV
The research presented in this abstract includes the estimation of the mechanical load that a PV module undergoes when mounted on floating PV platform.

TOWARDS LIGHT-WEIGHT AND MECHANICALLY DURABLE PHOTOVOLTAIC MODULES FOR FLOATING APPLICATIONS

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SUMMARY OF THE ABSTRACT

With the increased demand of energy and the scarcity of the conventional energy sources, renewable energy becomes more necessary. Additionally, more renewable energy is required in order to achieve a 55% reduction of CO_2 emission by 2030[1]. Photovoltaic (PV) generation systems are the biggest contributor to the growth in renewable energy. However, further growth is limited due to the availability of suitable land.

Floating PV is an attractive solution for expanding the capacity potential for renewables. Some other advantages of floating PV installations are that they enable dual use of water reservoirs and that the cooling effect on the PV modules increases their efficiency significantly. Within the project Marine Solar POtential and Technology Study (MarineSPOTS), we study the possible deployment of floating PV at the North Sea, by investigating the energy yield production, the integration to the grid, the durability and the environmental impact of such PV plant.

One of the major durability concerns of a floating PV installation is the mechanical load that the PV modules undergo, due to strong winds that might occur at open water and the movement induced by the waves. This study focuses on quantifying the impact of the mentioned stressors. For the achievement of this goal, multiple simulations and experiments for validation are conducted. Initially, the effect of configuration of the PV modules (e.g. inclination and orientation) is examined. Additionally, various thicknesses of PV glass are assumed, for the optimization of the mechanical stability and weight/material consumption. Finally, a dynamic mechanical load test is compared to simulations, in order to estimate the influence of the vibration on the stresses developed within a PV module, due to varied wind speed.

Preliminary results show that a low-angle east-west configuration is preferable to a high-angle south configuration from the mechanical perspective and that thinner PV glass with 2 mm thickness (glass-glass structure) may be adequate for off-shore PV installations, although its durability needs to be evaluated for dynamic mechanical load due to wind and wave speed variation. Furthermore, a method to compare the mechanical stress occurring within a PV module due to varied wind speed and the stress due to dynamic mechanical load testing is being developed and will be extended to include wave induced vibrations.

[1] Council of European Union, “Fit for 55”, https://europa.eu/!7G9njr

EXPLANATORY PAGES

AIM AND APPROACH

The aim is to evaluate and compare the static and dynamic mechanical load that a PV module encounters when installed on an off-shore PV platform and their impact on the stress developed within a PV module. Regarding the static load due to wind, different simulations were performed using COMSOL Multiphysics. The inhomogeneous wind load (pressure in Pa) was estimated as a consequence of a turbulent air flow. The wind speed was assumed as 13 m/s, which is the maximum speed among various months from different years (average values, the gusts are not included). The turbulent flow was applied on a cross-section of a PV module (2D simulation) either with a tilt of 35º for the south-face configuration, or 15º with a second module on the rear side for the east-west configuration (Fig. 1a, c). The pressure profiles above and below the PV module were extracted and extrapolated to a 3D simulation, in order to calculate the spatially distributed von Mises stress developed within the full PV module. The structure is glass-glass, including Ethylene Vinyl Acetate (EVA) encapsulant, 144 half-cells, edge-sealant and frame. The module was assumed to be clamped (constrained points) at 6 points over its length, three on top and three on the bottom (Fig. 1b). For the weight - mechanical durability optimization, the thickness of the glass was set to three different values 2, 2.5 and 3 mm.

However, varying wind speed may cause vibration of a PV module, which can accelerate its degradation. For this reason, the dynamic mechanical load due to wind was examined. Initially, a dynamic mechanical load test was conducted on a glass-backsheet PV module (the experiment will be repeated for glass-glass structure) with frequency of 16.6 Hz (fundamental resonance frequency, as indicated from previous experiment) while the acceleration of the oscillation was measured. The actual oscillation frequency of the PV module was extracted by Fast Fourier Transform (FFT) and the vibration amplitude was calculated. The purpose of this experiment is to validate the theoretical simulation. Furthermore, the variation of pressure due to varied wind speed by 0.5 m/s (larger variations can be simulated in the future for extreme cases) was estimated and the von Mises stress maps within the PV module were extracted, in order to evaluate if the dynamic mechanical load testing is adequate for off-shore PV applications. It must be noted that sudden increase of the wind speed was assumed, while the research will be extended to the simulation of transient wind speed, according to real data obtained for occurring wind gusts.

SCIENTIFIC INNOVATION AND RELEVANCE

Offshore PV development is crucial for the increase of the energy production by renewables (*1*). Additionally, multiple advantages are listed, such as avoidance of land occupation, higher efficiency of PV modules due to reduced thermal impact and many more (*2*). However, a thorough investigation is required for the optimization of the energy production and how the specific loading scenarios such as high wind loads and wave motions at open water affect the reliability (*3*).

The scientific innovation of the presented work is that mechanical simulations for both static and dynamic load are included, validated by dynamic mechanical load testing. In literature, either the static (*4*) or dynamic loads (*5–7*) are studied, but no attention is given to their respective contribution in the overall reliability. Moreover, the simulations and experiments reported fail to establish a correlation between the deformation due to wind loading and the internal stress levels generated as a consequence (*8*). Finally, we show a potential cost and weight saving which can be realised by reducing the glass thickness without compromising load bearing capabilities.

RESULTS (OR PRELIMINARY RESULTS) AND CONCLUSIONS

The first optimization study considers the configuration of the arrays. Fig. 1 demonstrates the pressure distribution around a PV module, due to wind with speed 13 m/s and direction from right to left, and the resulted von Mises stress within the PV module. We observed that a higher pressure (maximum 129 Pa) was developed for the high inclination south configuration, while the low inclination east-west configuration underwent lower pressure (maximum 72 Pa) (Fig 1a, c). Regarding the translation of the pressure to von Mises stress distributed within the PV module, the highest value of stress was concentrated near the clamps (Fig. 1b, d) and it was equal to $7 \cdot 10^6$ N/m^2 and $5.5 \cdot 10^6$ N/m^2 for the high and low inclination, respectively. Moreover, a higher elastic deformation was estimated for the high inclination, equal to 1.54 mm over 1.18 mm for the low inclination.

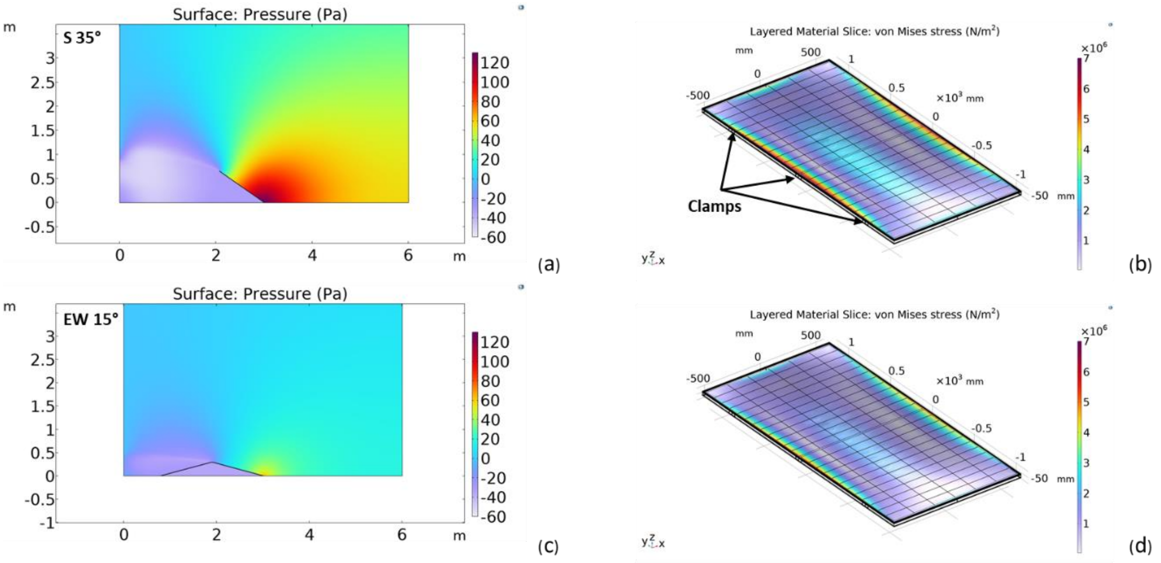

Figure 1 Pressure distribution around a PV module, due to wind with speed 13 m/s and direction from right to left, and the resulting von Mises stress within the PV module for (a-b) south (S) and (c-d) east-west (EW) configuration.

Afterwards, three different PV glass thicknesses were examined, for the weight-stress optimization. The results show that the maximum von Mises stress was obtained at the top and the bottom of the PV module, near the clamps (Fig. 2). The maximum values were between $5.5 \cdot 10^6$ N/m^2 and $3.5 \cdot 10^6$ N/m^2, from the thinnest to the thickest glass sheet. It must be noted that these values were estimated with the clamps assumed as constrained points. Varied values may be obtained for different types of clamping. All the resulted values were much lower than the ultimate tensile strength of the PV glass (~$50 \cdot 10^6$ N/m^2 for the 2 mm glass and ~$69 \cdot 10^6$ N/m^2 for the other thicknesses) (*9*, *10*), making all the thicknesses appropriate for PV installation, however the research will be continued for additional mechanical load due to vibration and wave movement.

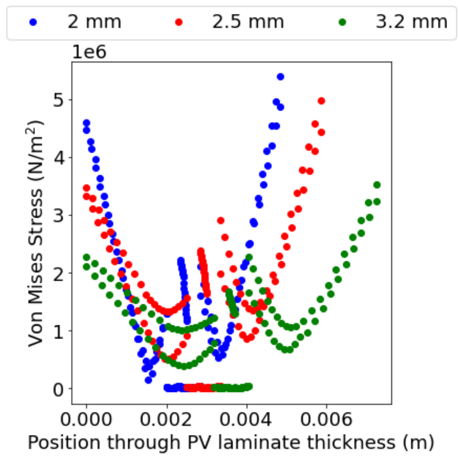

Figure 2 Von Mises Stress calculation over the position through the PV laminate with varied glass thickness.

Although static mechanical load simulations may provide thorough insights regarding PV durability over wind load, the consideration of vibration due to varied wind speed is important. Fig. 3 demonstrates a scenario where the wind speed increased instantly from 13 m/s to 13.5 m/s. The pressure applied to the PV module varied significantly within the next 0.2 s, as represented in Fig. 3a and 3c, with the developed von Mises stress changing between $7.1 \cdot 10^6$ N/m^2 and $4.3 \cdot 10^6$ N/m^2 (maximum) as shown in Fig. 3b and 3d. The study will be continued by taking into consideration larger wind speed variations and the resonance caused by them. Moreover, the speed increase will be simulated as a transient effect, according to real wind gust data, Furthermore, vibration due to wave movement will be accounted.

Finally, a dynamic mechanical load test was conducted for the validation of a simulation, which evaluated the occurring von Mises stress within the PV module. In the future, the experiment will be repeated for a glass-glass PV module, instead of glass-backsheet, and clamping for off-shore PV installation will be included. The FFT analysis of the acceleration signal produced by the experiment (Fig. 4a) showed that applied 16.6 Hz frequency caused 10 Hz resonance on the PV module and elastic deformation with 9.9 mm amplitude. Identical acceleration set to the simulation for a glass-glass PV module (Fig. 4b) deformed it by 3.85 mm maximum and the maximum von Mises stress was equal to $10 \cdot 10^6$ N/m^2, higher than the value obtained by the simulation of varied wind speed. In the future, the frequency applied to the simulation will be set according to the dynamic mechanical load test on the glass-glass PV module.

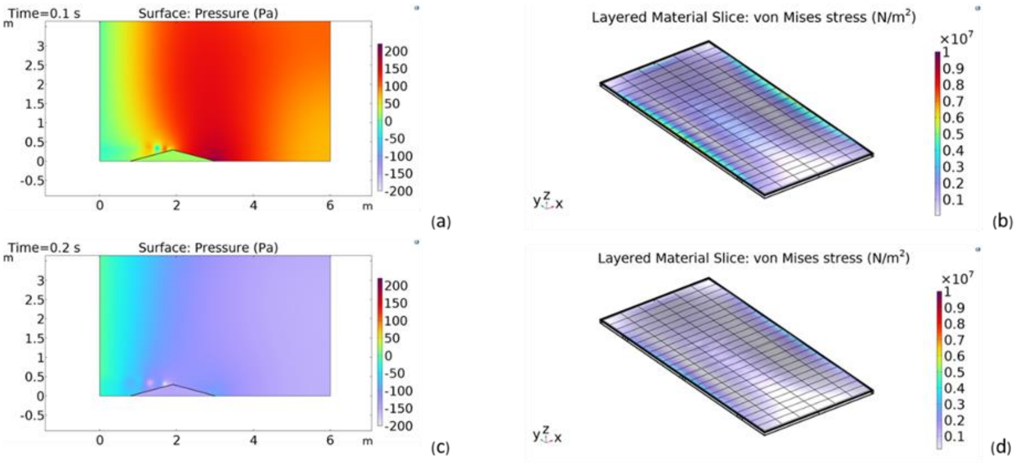

Figure 3 Variation of pressure applied to a PV module due to instant 0.5 m/s wind speed increase and the developed von Mises stress within the PV module after (a-b) 0.1 s and (c-d) 0.2 s.

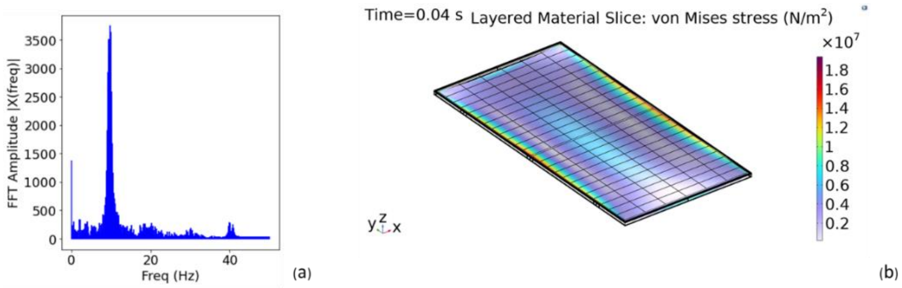

Figure 4 a) Fast Fourier Transform (FFT) analysis of the acceleration signal produced by the dynamic mechanical load test on a glass-backsheet PV module and b) simulation of von Mises stress distribution within a glass-glass PV module theoretically subjected to dynamic mechanical load test.

In conclusion, a low angle east-west configuration is mechanically more stable than a high angle south configuration, as the tilt of the PV modules is crucial for the pressure that they undergo. The simulation will be repeated for higher loads of wind, to simulate extreme conditions. Thinner glass, up to 2 mm may be a viable solution considering the static wind load, however, further analysis is required regarding the vibration impact and the effect of mechanical load due to wave movement. Finally, the dynamic mechanical load test will be repeated for a glass-glass PV module and transient wind speed increase instead of instant will be assumed, according to field data.

ACKNOWLEDGEMENTS

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