How to keep your FPV system afloat.

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How to keep your FPV system afloat.

Floating PV (FPV) is a technology with huge potential. However, as a new technology without an established state of the art yet, the risk of failures of newly built FPV plants is still high. This article gives you a hand of how a safe FPV plant can nevertheless be built and how, step by step, a new state of the art is being developed. The approach is underlined by first-hand experience from developing the state of the art of PV trackers.

First insights into specific wave flume test results give an idea of the compatibility between theoretical wave analysis and measured data.

by Vanessa Schönfelder, Alf Oschatz

The Floating PV (FPV) market has grown rapidly over the last few years. Already today, there are a large number of market players. Many of them have only built small test and pilot projects. Despite this short market life, quite some failures have already been observed. Those need to be avoided in the future to prevent millions in damage and to achieve the targeted lifetime of 20-30 years. One reason for such failures is that this new market still lacks well-established standards to minimize the risks of failure that new technologies bring. This paper is intended to support the industry in the absence of standards.

FPV joins other technologies like Agricultural PV and Parking lot PV (PV plants that are built over parking lots) in a trend towards systems that combine two uses to increase profitability and to deal with the shortage of land. This trend has already been seen with PV tracker systems which are preferred over fixed tilt PV plants because of their higher energy gain per area.

The double use for FPV is diverse: Hydropower plants, industrial water, cooling water and firefighting water bodies are clear examples of how FPV helps to make double use of water bodies. Also, if the water body is not used itself, FPV still helps to reduce evaporation by shading the water body. At the same time, module efficiency is improved by profiting from the cooling effect.

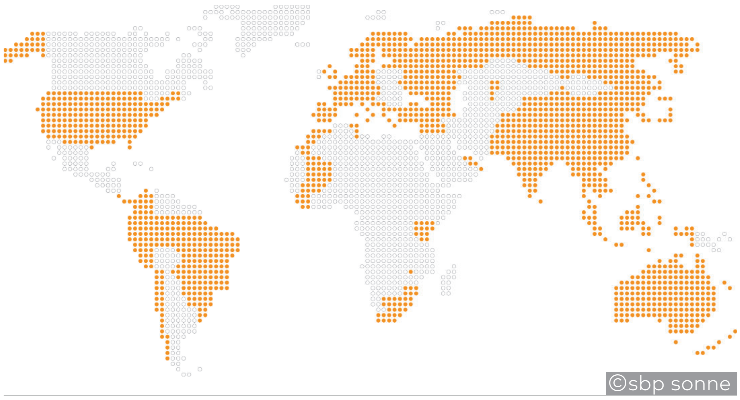
The new challenge in FPV is that the structures are exposed not only to wind but also to water, and the system still needs to be competitive against land-based options.

Looking at the example of PV trackers, a similar development could be seen a few years ago as it is happening to FPV now: When the market arose, lots of tracker failures happened due to unexpected aerodynamic behavior. However, with and for international top developers and owners we could set a new standard for PV Tracker structural verification after having gained a deeper knowledge of the aerodynamic behavior of such systems having successfully performed root cause analyses of tracker failures for the same owners and developers.

As FPV has been facing a lot of failures in the market lately – with a state of the art still missing – it is essential to develop guidelines for safe FPV designs soon, to avoid a decline in a market with high potential and importance for renewable energies which allows installation on areas which otherwise may not be useable for the necessary switch to renewables.

While there are a lot more of interesting and important topics for long term performance that we are dealing with, this first paper shall focus on the general load boundaries, extending the knowledge from tracker wind spectra, and describe what is necessary to define the load and time spectrum for wave loads and discuss the way to a qualified and fail-proof system.

A growing market and future pillar for double use PV



Floating PV systems are spreading all over the world.

In view of the current world challenge of land-use conflicts suffered by many countries, numerous initiatives and CALL for ACTIONs of dual-use PV are included in the renewable energy plan of numerous governments, including some of the leading PV nations.

According to data collection, more than 60 countries are now pro-actively considering the solar deployment of FPV, with a cumulated 2.6 GW installation of 350 operational systems. From a global market perspective, while Asia is currently taking the FPV market lead, various EU countries are marching bigger steps and are on their way of catching up.[1]

Along with its substantial growth in the last few years, FPV is anticipated to further expand its market based on an annual average growth rate of about 20% in the next five years [2].

Entire FPV plants have been destroyed

Since the first installation boom of FPV systems, a noticeable number of failures has been reported. One of the most prominent and probably best analyzed failures was the incident of the 13.7 MWp FPV plant at the Yamakura dam in Japan. The power plant that probably spent the shortest time on water is the FPV plant on the Dingzhuang Reservoir in China. Only 3 weeks after being connected to the grid, the 320 MW power plant fell victim to a storm.

FPV plant failures are happening already. The picture shows one of the most prominent incidents at the Yamakura dam in Japan.
Source: Solar Power Plant Business / Nikkei Business Publication

But these are just two examples of an alarming number of incidents. Incidents that even happened to plants at environmental conditions way below their design parameters. Those incidents are a matter of serious concern, as they are not only putting the FPV market into a negative spotlight, but sooner or later may even lead to a decline in the market.

The PV tracker market can guide us

Let's have a look at how to deal with systems that lack a state of the art without accepting possible plant failures. sbp sonne first collected experience with such a system when the first single-axis PV trackers started to fail way below their design wind speeds and we were asked to analyze these failures by international top developers and owners. It was a found that many early developments had tried to derive structural knowledge from known technologies such as fixed tilt systems and from literature, but the new challenges of a moving system had not been taken into account. Therefore, it was necessary to develop further knowledge in mainly three areas: Wind statistics, shape factors (cp-values) and, most importantly, aeroelasticity.

The latter one mainly has an influence between about -45 to 45° tilt angle, which are the desired angles for high energy gain, and at 0° being an often-preferred horizontal stow position, which is a streamlined position with lower loads, but may lead to an aeroelastic disaster if no other precautions are taken.

With a good theoretical knowledge base, extended wind tunnel tests also analyzing dynamic behavior were specified, carried out and analyzed. On the basis of this knowledge, a new state of the art could be set. Still, data needs to be adapted to each site because factors that play an important role are highly site specific, e.g., surface roughness and distribution of wind speed and direction. Also, each system behaves differently depending on factors like stiffness, inertia and damping, such that the dynamic response of a system needs to be determined individually.

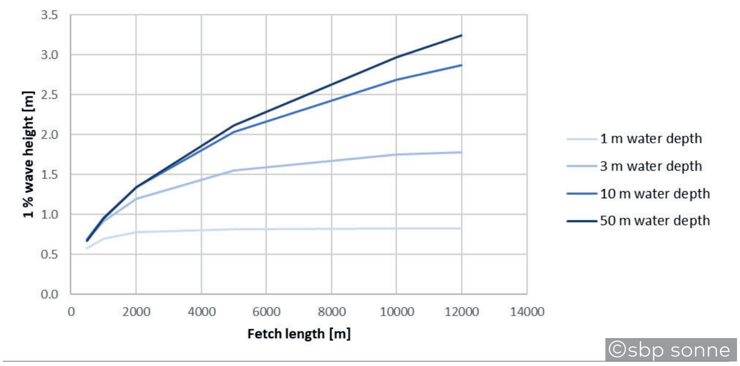
Back to the drawing boards

For transferring this approach to FPV it is now necessary to take a step back.First of all, statistics need to be regarded. From the wind statistics, wave spectra can be theoretically derived for a specified water body. Then, the shape factors of the floating system need to be analyzed. In this case, drag and inertia factors are considered. Afterwards, dynamic behavior and forces need to be regarded.

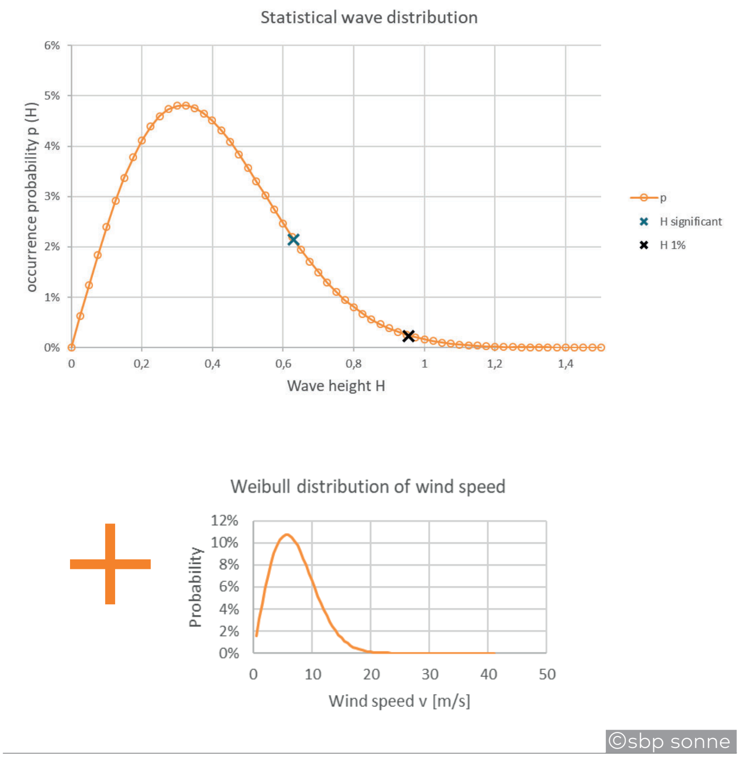
Lately, first publications specifically on the matter of FPV have been issued. Especially worth mentioning are two overview documents published by the World bank group, ESMAP and SERIS in 2018 / 2019 [3,4], and the recommended practice published by DNVGL [5] at the beginning of 2021. However, these are just first steps into the right direction, as especially the topic of waves on inland water bodies and the resulting dynamic forces on FPV plants is still treated without sufficient consideration and is still in its early stages. It must be verified that the floating structure can compensate relative displacements of the floats while passing through a wave without exceeding the stress limits of the material or causing excessive deformations to the PV modules.

Let's have a look at theory

When searching for literature on waves, mainly waves at sea can be found. There is not much literature specifically regarding waves on inland water bodies which represent the main destination of FPV plants. However, knowledge on sea waves can be used as a basis and later adapted once the site for the FPV plant is known and comprehensive wave measurements have been carried out. In inland water bodies, waves are typically created by wind that is blowing along the water surface, moving the water towards one direction by friction force.



Influence of fetch length and water depth on wave height. The wave height clearly rises with increasing fetch length as well as with increasing water depth. However, when both of these parameters reach a certain point, the influence decreases. Not shown here are further parameters influencing the wave height such as wind speed.

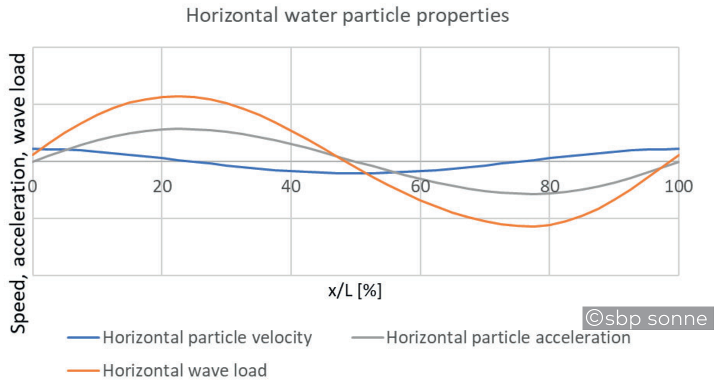


The statistical distribution of the wave height at a certain wind input is Rayleigh-distributed [7]. It needs to be superimposed with the wind distribution of the specific site to receive the wave height distribution over a lifetime.

The wave height depends on wind characteristics such as velocity and duration of the wind, but also on water body characteristics like the length of the water surface exposed to wind impact (fetch length) and bathymetry (underwater topography). If this information is known, a wave spectrum can be obtained, starting with the wave height and wave period as a basis.

Different formulas exist that relate the mentioned input parameters to significant wave height and wave period. Comparing several wave theories and with support of a wave expert it was decided to use the 'Shore Protection Manual' (SPM) as a basis for the wave height calculations. From the significant wave height, the 1% wave height can be obtained. On this basis, a waveform can be derived. The form of a wave can be described with basic theories.

The easiest description of a wave is the linear wave which can be used for low sea states. For the analysis of high waves, the more advanced Stokes waves may be used. With the help of the theories, information on water particle speed and acceleration for each position in the wave as well as over time can be evaluated [6].

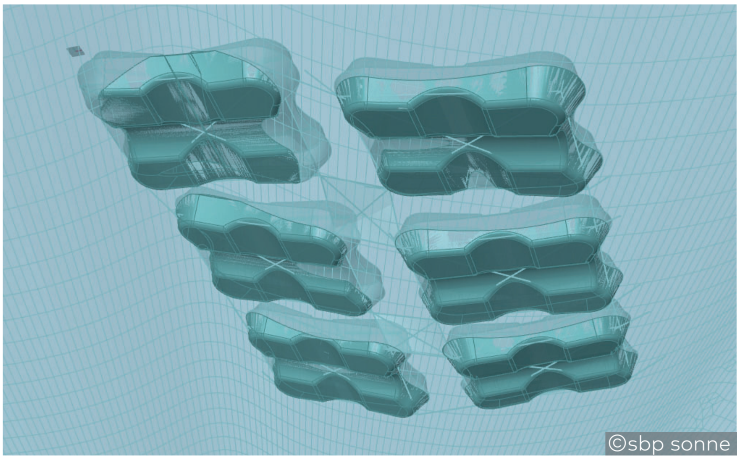


Water particle properties. Stokes' 5th wave theory gives information on water particle speed and acceleration for each position in the wave. With this information, a simplified load calculation can be performed.

Wave flume tests have proven the theory

Once the expected waves have been derived, it is necessary to determine the kinematic movement of the floats in the waves. As a first approach, a simplified model was implemented into a 3D model. With the help of a dynamic relaxation process, the floating system can be adapted to the wave form.

Next, we look at the resulting forces acting on the structure. Here, again, first estimations can be derived from wave theory. However, the literature is also limited here, and gives hardly any information on special float shapes and their kinematic and dynamic behavior.



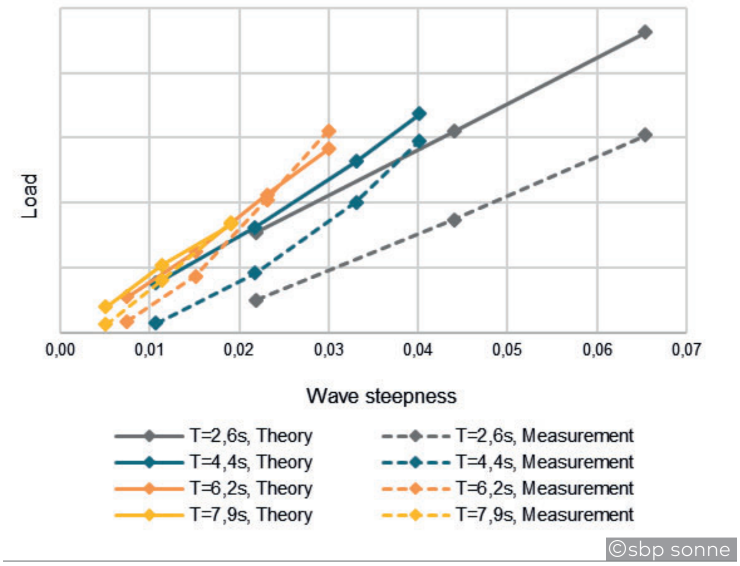
Kinematic behavior of floats. With the help of a 3D program the movement of the floating system in waves is analyzed.

Generally, wave induced forces can be divided into viscous forces and inertial forces. Viscous forces are form drag and friction drag. Form drag is caused by flow separation. Friction drag is a result of skin friction. Inertial forces are generated by the pressure gradient in an accelerated fluid flowing around a component. They are proportional to the acceleration of the water particles [8].

Depending on wave length and dimension of the floating body, different approximations can be used for calculation of the wave force on the body. As a simplified theoretical approach, the modified Morison formula [9] is used. However, this theoretical approach needs to be checked and refined with the help of measurements. The interplay between kinematic movement and resulting loads is an important aspect that needs to be analyzed just as the effect of the floats upon each other, which cannot be sufficiently represented with the theoretical approach.

Wave flume test. The picture shows one of various test assemblies in the wave flume. First, a single float was tested under different wave and loading conditions. Later, the influence of the floats within a row was tested. Test facility: Technische Universität Braunschweig, Leichtweiß-Institute for Hydraulic Engineering and Water Resources

In one of our customer projects we are taking intensive measurements in a wave flume, which we compared with the theoretical approach. For the theoretical values an estimate of the drag and inertia coefficients was used, based on coefficients for fully submerged bodies. First, tests on a single float were performed to verify the theoretical input values and compare theory against measurements. Afterwards, a float row was tested and shadowing, kinematic interaction and summation of forces due to different positions of the floats in the waves were analyzed.



Comparison of theoretical wave loads with test data. Tests in a wave flume have shown that the theoretical values give a good estimate of the loads that actually result from a wave. For the chosen input values, especially for long waves, theoretical and tested values correlate well. However, for shorter waves the theory provides higher values than the measurement. Still, the measured absolute force values are considerable.

First results showed a high level of conformity between theory and practical tests. With the set form coefficients a good correlation was noted, especially regarding longer waves. For shorter waves, the theoretical calculation returned somewhat higher values. The highest forces result of steep waves. The steepest waves that are expected for a small water body only need to be considered for short waves as the wave height is limited. Even though those values are smaller than the ones calculated in theory, the forces from water acting on the float are still considerably high. Simple checks of standard FPV solutions indicate a gap between the loads that these systems can handle and the loads that can be found in wave tests even for small inland water bodies which leaves us worried.

Summary

Let's have a quick look back on what we've learned. In general, a new market goes along with risks due to a missing state of the art. Those risks can lead to significant failures. For the FPV market, these failures are already happening. Experience from the PV tracker market has given us a clear procedure that should be followed in the development of a new state of the art: First, the influence factors on the system need to be designed. Then, knowledge in these areas needs to be gained with the help of comprehensive tests. For FPV, these are mainly three topics: The first topic is statistics of wind and resulting waves. The second topic are the float specific coefficients, drag and inertia coefficients. The third topic are resulting dynamic forces. Knowledge on all of these topics is best gained with extensive tests. First test results verify quite high forces on floats for the waves resulting from a 25-year-wind speed.

About us

sbp sonne has been working in the renewable energy sector for over 35 years. As a solution provider for solar energy, we research new technologies, develop products and assist and consult during production up to commissioning. The portfolio features a wide range of components and systems for both solar thermal and photovoltaic power plants. Today, we are arguably the leading international engineering office in the field of solar energies, both for Concentrating Solar Power and Photovoltaics. Our services in Concentrating Solar Power (CSP) and Photovoltaics (PV) are spread over more than 25 countries on 4 continents, with over 14,000 MWp of commercial PV projects as structural and consulting engineers and as technology provider for over 700 MW of commercial CSP projects.

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