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Analysis of external dynamic loads influence to photovoltaic module structural performance

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ABSTRACT

Efficiency of modern photovoltaic (PV) systems decreases significantly when the crystalline structure of PV modules is damaged due to climatic factors, such as wind and mechanically similar dynamic effects. General certifications of PV modules consist of only static tests (according to Photovoltaic standard IEC 61215 and IEC 61646), however in reality, PV modules are operating in a dynamic environment. The purpose of the article is to show that for the certification of PV modules the dynamic characteristics of PV modules must be accounted also. Nowadays PV modules are used in different dynamic objects like cars, boats etc., where dominant loads are of dynamic environment. This paper presents theoretic and experimental studies. For the investigation of dynamic loads acting on PV modules, a testing stand has been designed. PV modules were loaded with cyclic dynamic loads. During the experiment, the PV modules were loaded with external excitation, the excitation amplitude is not exceeding more than 7 mm. During the experiment, the PV modules were excited, in the frequency range of 0 to 40 Hz and the sweep generating mode was used. The aim of this excitation to simulate different weather conditions. Experimental and theoretical results showed the reaction of PV modules in different weather conditions (which means that the effect of different wind speeds is evaluated). The proposed assessment methodology can be applied successfully when designing PV modules and accounting for mechanical dynamic effects.
In conclusion, it is not accurate and appropriate to evaluate the safety and stability of PV modules just through the existing static analysis in IEC 61215. The dynamic effects of the loading on PV module also need to be paid attention to. The attention needs to be paid to the dynamic effects of the loading on PV module.

1. Introduction

The mass production and development of the technology result in decreased costs of solar elements, today solar energy is used not only in industry but also in domestic applications [1–3]. Roofs and walls are covered with solar elements [4–7]. Effectiveness is a very important indicator [8] for photovoltaic systems, and different weather conditions lead to a decrease in the productivity of PV modules. The wind has an important role in this process since inclined PV modules are a barrier against the airflow from the fluid engineering point of view. Turbulence effects in the incident flow and the flow above and below the module could influence the flow and the occurring forces and affect the module, as illustrated in Fig. 1 [9]. Turbulences and stall can cause periodic excitation of the PV modules, too. Air accumulates on the inflow side and causes a higher pressure. An area with turbulences

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and lower pressure can be found at the flow-averted side. The varying pressure difference between the two module sides leads to movement and oscillations. The mounting system and the PV-module have to stand the occurring forces.

Such factors as the already mentioned wind as well as temperature fluctuations are very important when assessing durability and operation efficiency of individual solar elements or the entire system [10–13].

PV modules are exposed to external mechanical loads, such as snow and wind loads. These loads are either static (snow or wind for building integrated modules) or highly dynamic when wind impact triggers oscillations. It is obvious that the dynamic loads are more likely to cause fatigue of materials, especially of PV-cells and connecting wires. The structure of some crystalline photovoltaic modules is often damaged, and that can lead to micro-cracks induced by the dynamic mechanical loads [14–16]. These micro-cracks negatively affect the conversion effectiveness of the energy of light into electricity and stimulates further degradation of the module. This results in decreased light energy conversion efficiency and the work quality of solar module [17–19]. To reduce the efficiency loss, it is necessary to evaluate the weather effects [20,21] on the solar elements. As one of approaches a numerical simulation of weather conditions can be performed [22,23].

For the qualification of building-integrated photovoltaic, the dynamic mechanical load should be under consideration as an additional test. However, both existing standards (IEC 61215 and IEC 61646 [24,25]) and literatures deal mostly with traditional PV modules with a toughened glass front panel and the influence of the mounting configurations on both the static and dynamic performance of the PV modules are not paid attention to.

In the paper [26] the static performances of three PV systems are investigated by applying 2400 Pa and 5400 Pa uniform loads in accordance to IEC 61215 standard. The dynamic performances of these of three PV systems are also studied via loading a dynamic load with an amplitude of 2400 Pa and frequencies ranging from 0 Hz to 100 Hz.

In another paper [27] there is the information about the correlation between the wind velocity and the PV module deflection. The outdoor measurements of the deflection show their dynamic behavior under wind loads and the correlation between wind velocity and deflection. In paper [27] presented the correlation between pressure p onto the module and the deflection y of the module in the centre in the range between −10 and +10 mm:

$$p = -62.689y - 0.21895y^2 - 0.1127y^3. \quad (1)$$

This model is very useful for the design of indoor test-facilities for dynamic mechanical loads.

Knowledge about the dynamic behavior of the modules, e.g. their resonance frequencies and occurring oscillations in real outdoor exposure is necessary to define suitable accelerated indoor tests. Environment vibration tests (EVT) are suitable to explain the dynamic behavior of the modules.

EVT is the dynamic test when excitation occurs naturally, for example against the air flow when the ground fibrillation, traffic-induced excitation and so on. Excitation powers are not measured, and object's response is measured.

The EVT is also known as Natural Input Modal Analysis (NIMA), Operational Modal Analysis (OMA) or Output-Only Modal Analysis. Excitation power in the Civil engineering is stochastic and comparable to wind, to earthquake waves or to human movement [23].

The EVT describe the linear behavior of structure, since the amplitudes of vibration are small. The method can be used to describe the linear behavior of the structure under investigation, including its individual parts or the entire structure. According to the received information it can create dependence algorithm of time and amplitude [28,29]. The modal analysis involving output-only measurements present a challenge that requires the use of special modal identification technique, which can deal with very small amplitudes of ambient vibration that are usually contaminated by noise. Excitation source can be a breeze, periodic or random seismic effects or other sources. Ivanovich and others [30,31] argues that the dynamic test method was first used in 1970 and later it was used more and more often. Such a method was applied when studying dam, buildings and bridges [32–34,36,37].

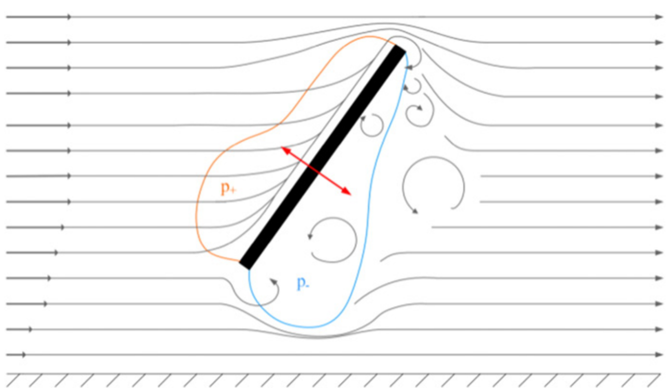

Fig. 1. Scheme of a free standing module in the air flow (black) with positive (orange) and negative pressure range (blue) as well as resulting movement (red) due to flow separation [9].