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A study of power quality loss in PV modules caused by wind induced vibration located in Vienna

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Abstract

Mechanical vibrations of a solar module mounting rack cause oscillations in the orientation of the module towards the sun. The resulting intensity oscillations of the incident light generate an a.c. current at the module's terminals.

We have investigated this effect in the laboratory by means of a vibration table and outdoors, where wind forces induce vibrations to the mounting rack. Although the collected results are specific and restricted to our experimental set up and the regional environmental situation we deduce that vibration induced current transients and oscillations of a solar module's output most often will be the dominant origin of distortion in the low frequency regime.

Keywords: Low frequency disturbance; Vibrations; Photovoltaic power generator; Power quality

1. Introduction

With the steady growth of photovoltaic systems and the ongoing trend towards large scale grid connected power stations, new challenges in assuring power quality arise (Bartlett et al., 2009; Bollen and Häger, 2005). This has invoked numerous investigations about the proper interfacing for preserving power quality and avoiding electromagnetic interference (Bollen et al., 2008; Chicco et al., 2009).

However only little research has been done in the study of distortion, caused by the power generator itself, which is transmitted to the subsequent electric conditioning system (Piazza et al., 2004). As yet the research focus clearly lies on dealing with the symptoms of distortion, rather than looking at its causes. Especially the effect of vibrational disturbances has barely been researched at all. This makes it very hard to avoid any unwanted effects during the planning and design of PV stations beforehand. For the optimization of a PV station the effect of vibrational disturbances is a very important variable. This applies particularly when choosing a proper mounting construction, or when designing the circuitry. Additionally it has to be taken into account when designing maximum power point trackers, especially those working with the perturbation and observation (P&O) method.

The goal of this research is to provide a rough assessment of vibrational effects and their impact on a PV station. For this indoor and outdoor measurements have been carried through. Indoor we worked with a well defined laboratory set up, whereas the outdoor measurements are clearly exemplary and locally. However some novel results could be found. These include the behaviour of the solar cell under different circuit arrangements, the dependency of vibrational disturbances in regard to the operating point and a rough quantitative estimation of the magnitude of the effect.

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Beside the intrinsic noise of the photovoltaic cells numerous external sources can introduce current transients, spikes and oscillations, as illustrated by Fig. 1.

These noise sources cover a wide frequency range from below 1 Hz typical for cloud movements (Jewell and Unruh, 1990) up to 10 GHz which is caused by satellite communication channels.

Although the externally introduced current noise at the terminals of a single module may not exceed several mA in amplitude, electrical interconnections of an assembly of modules summarises the noise amplitudes, which are conducted to the power conditioning unit.

Current transients in the low to very low frequency regime are extremely hard to remove in the circuitry by a low pass filter without the reduction of the useful d.c. output.

Because of the need to optimise the exposure of solar modules to the incident sun light they are placed on mounting constructions which easily are stimulated to vibrate. These vibrations cause changes of the module's surface orientation with respect to the incident sun rays. As a consequence light intensity oscillations cause current oscillations at the module's output.

In space applications scientists are aware of this problem and efforts were undertaken to reduce the vibrations transmitted from the satellite to the solar array paddle (Matsuno et al., 1996). For terrestrial photovoltaic applications the resonance frequency of a mounting construction is in the low to very low frequency range. As previously reported noise amplitudes below 100 Hz sometimes became the major contribution to the observed noise spectra and were attributed to wind induced vibrations (Drapalik et al., 1996).

Especially large photovoltaic power stations, with at least 1 MW_P are often placed in sparse regions with high sunlight exposure. This leaves the power plant exposed to wind forces, without there being any natural obstacles, resulting in higher wind speeds near ground level (Wieringa, 1986).

The effect of wind velocities has been included many times as an important variable in the performance of photovoltaic power plants (Moore et al., 2005; Moore and Post, 2008). However the effect of this variable remains

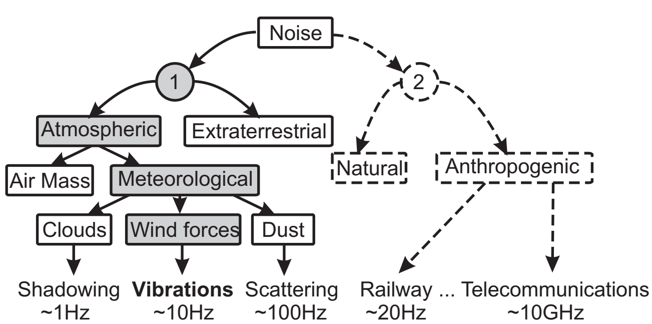

Fig. 1. Origin of externally introduced noise in photovoltaic solar cells, examples and typical frequency ranges: Light fluctuations (1) are branched as continuous line, radio frequency emissions (2) are represented as dotted lines.

uncertain or is directly linked to the thermal condition of a solar module (Hiyama and Kitabayashi, 1997; Jones and Underwood, 2001). While the wind cooling results in a slightly increased performance of the PV-Plant, the entailed vibrational disturbances are often ignored.

Currently we investigate the effect of vibration induced current oscillations in detail in the laboratory and under outdoor conditions in Vienna. In this contribution we present some exemplary results from our measurements in order to illustrate the importance of mechanical vibrations as a major source of distortion.

In the laboratory we examined the effect of changing light intensity distribution caused by the vibrations relative to the incident light beam over the area of the solar cells, with respect to different loads and circuit arrangements (i.e. parallel, serial and single). Thus we were able to derive some basic characteristics of the behaviour of ultra low frequency distortion in solar modules.

To supplement and confirm our results, a simulation with the circuit simulation program Qucs[1] has been undertaken.

2. Experimental indoor

In order to conduct the measurements a vibration table has been constructed. The solar cell was exposed to some mechanical strain and a roughly sinusoidal change of the incoming light flux. This set up tries to emulate the real ambient conditions of a solar cell with respect to vibrational disturbances as accurately as possible, while still being reproducible.

It basically consists of a subwoofer that has been mounted on a self constructed aluminium rack. The subwoofer's membrane was coupled to an acrylic glass plate forming the vibration table. The vertical Z-axis of the vibration table is displaced by a sinusoidal excitation of the subwoofer at different frequencies

Onto the acrylic glass plate a holder is fixed where solar cells can be easily attached and removed by a hook and loop fastener. The device allows changing the angle of misorientation determined by the cell's surface vector and the optical axis of the light source within a horizontal plane. This angle was later varied to determine the angle dependency of the distortion signal. The solar cells are illuminated by a halogen lamp (12 V/20 W).

Furthermore a tilted mirror was fixed to the acrylic glass. It reflects a laser beam that first passes an aperture, towards a linear sensor array (TAOS TSL 1401). The array consists of 128 photodiodes. Thus we are able to measure the deflection of the vibration table with an accuracy of 250 μm.

To test the different solar panels under various load conditions a circuit has been designed. It consists mainly of 8

[1] Quite universal circuit simulator at http://qucs.sourceforge.net/index.html.