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First developments of a new test to evaluate the fire behavior of photovoltaic modules on roofs

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ABSTRACT

A new test for photovoltaic (PV) modules exposed to an external fire source on roofs is proposed, and first results are presented. This is a simplification of the standards commonly in use for testing PV modules as roofing parts, roofing components or building components. Most of the tests required different fire scenarios and the use of burning brands such as wood cribs. In our study we proposed replacing wooden burning brands with a propane burner, the output of which is close to the one that can be observed in the burning of wooden cribs 500 g and 2 kg in size. The fire behavior was assessed by measuring smoke evolution, burning drips, flaming debris, and the time to burn-through of monocrystalline, polycrystalline and amorphous silicon panels. Two different configurations of the burner were tested, with the fire source on the top of the module or under the tilted module, respectively. The fire behavior of the modules was dependent on the burner output (16 to 46 kW), but also on the construction type of the panel (glass/glass or glass/plastic sheet) and on the position of the fire source (top or bottom). These preliminary tests for further development of the procedure yielded encouraging results for the evaluation of PV panels on roofs.

1. Introduction

Photovoltaic (PV) energy production is one of the most promising and technological mature technologies for renewable energy production. Different technologies of PV modules are commercially available. Thick-layer technologies are still dominant, making up around 86% of the market in 2010, as they were developed first and have the highest solar module efficiency of up to 18%. These 86% are shared between polycrystalline silicon and the monocrystalline technologies (53% and 33% of the total market, respectively). The new thin-layer technologies shared 12% of the market, with amorphous or micromorphous silicon thin layer technologies amounting to 5%, CdTe another 5% and CIGS just 2%. The remaining 3% are new emerging technologies. [1]

When fires occur on buildings, PV panels mounted on the roofs are exposed to flames. Therefore information about the burning behavior and fire resistance of PV modules and determination of their hazard potential are necessary. Different test methods have been developed in the past to assess fire behavior of roofs in the case of external and internal fires [2–4]. They vary, depending on the classification of PV modules as roofing materials or building components, and the country or region of the standard application. In the German DIN 4102 standards [5–7] or the European ISO 11925-2, [8] PV modules are tested as building products and building components. In particular, they can be tested as roofing materials according to DIN 4102-7. [5] In DIN 4102-7, the roofing materials are subjected to a fire through burning brands made of 600 g wood wool in a wire frame (300 mm × 300 mm × 200 mm). The resistance against flying sparks and radiated heat is evaluated in terms of fire behavior and dimensions of the damages (carbonized and destroyed zones). However this test did not include explicitly the case of photovoltaic modules as roofing materials, and how to evaluate them within the test.

CEN/TS 1187 [9] is a further test method in the European Union for external fire exposure to roofs. Four different single test procedures are applicable in the European Union, and every EU country decided which of the test procedure are mandatory. However at the moment no single harmonized test procedure had been proposed and the discussion is still ongoing. The first test procedure CEN/TS 1187 -Test 1 is in application in Germany. Test 1 (T1) is the only method from the four methods to assess all the different parameters such as fire spread across the external surface of the roof, the fire spread within the roof (not addressed by T4); the fire penetration (not addressed by T2); the production of flaming droplets or debris falling from the underside of the roof or from the exposed surface (not addressed by T2). Moreover T3 is not applicable to geometrically irregular roofs or roofs mounted

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appliances. In the T1 test, the fire brands are made of wood wool in a basket and applied to the roof. Even if the T1 has the best easy handling from the four tests, this method required the preparation and the conditioning of the wood wool, the basket, and the preparation for the test is time-consuming. Moreover the fire load applied on the surface is fixed, and cannot be varied to adapt to different fire scenarios. The evaluation of the behavior of the module in case of a fire from the outside of the module is also not foreseen in this test. The international IEC 61730-2 standard, [10] which is based on the American standard UL790, [11] describes the requirements for both materials and components as roof coverings exposed to simulated fire sources from outside a building. This test applies to the entire PV module. The burning brand test and the spread of flame test are requirements for PV module safety qualification according to the UL790 standard. The burning brands are made of wood cribs from 10 g to 2 kg in size. In this test the fire behavior of the panels is evaluated with the influence of wind; and different fire scenarios are simulated with the different wood cribs sizes. The reactions to fire in terms of appearance of sustained flaming, production of flaming or glowing brands, exposure or falling away of the roof deck are reported. However the test is not easy to handle, and requires the construction of the wood cribs, the conditioning of them which is time consuming. The ignition of the burning brands is not always reproducible, and the fire load exposed on the PV surface is restricted to the three scenarios from the class A, B and C. In this test too, a fire from the bottom side of the module is not foreseen. Previous research by Krüger et al. [12] on commercially available PV panels of different technologies and structure types, in accordance with CEN/TS 1187-1 and the burning brand test of IEC 61730-2 showed that the panels are exposed to outputs between 15 and 60 kW coming from the burning brands, depending on the classification and test methods used.

Currently there is no uniformity among all these tests for PV modules, such that the requirements depend on the end applications. Most of the tests require the use of burning brands like wood wool or wood cribs, and the ignition of such incendiaries is not easily reproducible. Some other tests like the Single-Flame Source Test (Ignitability) Apparatus [8] required the modules to be cut in order to evaluate their reaction to a small flame. Moreover, no simple test simulates a fire starting from organic materials gathered under the modules on a roof.

In this paper, a new versatile and simple test was proposed to evaluate the fire behavior of solar panels on roofs exposed to an external fire source. To this end a propane burner was set up, offering the advantages of a simple and adaptable output compared to burning brands. A burner output of between 15 and 50 kW was chosen to simulate the fire exposure resulting from burning brands like in the CEN/TS 1187-1 and the IEC 61730-2 burning brand tests. The test has the advantage to offer an easy handling, a cost effective and a variable fire load inputs to evaluate photovoltaic modules exposed to fire, in term of fire propagation, fire penetration, appearance of sustained flaming, production of flaming droplets or debris and the damages. The test also offers the possibility to evaluate the fire behavior with a fire from underneath the module, a configuration which is not addressed in the actual standards for roofs and roof coverings. Two different configurations of the burner were investigated to simulate fires from both outside and inside. Commercially available PV panels representing the three best-selling technology types were chosen. The panels were tested at different burner outputs to evaluate the response of the panels to different fire load levels. The results obtained comprised a basis for setting fire protection requirements for solar panels as a building product on roofs.

2. Materials and methods

2.1. PV modules

Three different silicon modules were used in this study. Since mono- and polycrystalline thick modules represent the majority of panels on the market, they were of particular interest to evaluate fire behavior on roofs. The monocrystalline silicon thick film panels were of the glass/plastic construction type, with a glass sheet on the front side and a plastic sheet on the back, mounted with an aluminum frame ($1676 \times 998 \times 41\ mm^3$) from Eurener (MEPV-Monokristalline 230, 230 Wp). The polycrystalline thick film panels were also of the glass/plastic construction type with an aluminum frame ($1658 \times 834 \times 46\ mm^3$) from Mitsubishi Electric (PV-TD185MF5) with 185 Wp electrical power. The last type were amorphous silicon thin-film panels of the glass/glass construction type without a frame ($1321 \times 711 \times 7\ mm^3$) from EPV Solar (EPX-5X series), with 50 Wp electrical power. The material ethyl vinyl acetate (EVA) was used in all of the panels to encapsulate the photovoltaic cells.

2.2. Constructions for the fire tests

Two different configurations of the burner for the fire applications were tested in this study, with a fire from the outside and a fire from the inside (see Fig. 1). For this, a propane gas burner was used with a propane flow controlled using a pressure reducer. The burner output was calculated and calibrated by measuring the mass of propane consumed over a running time of 5 min. A heat of

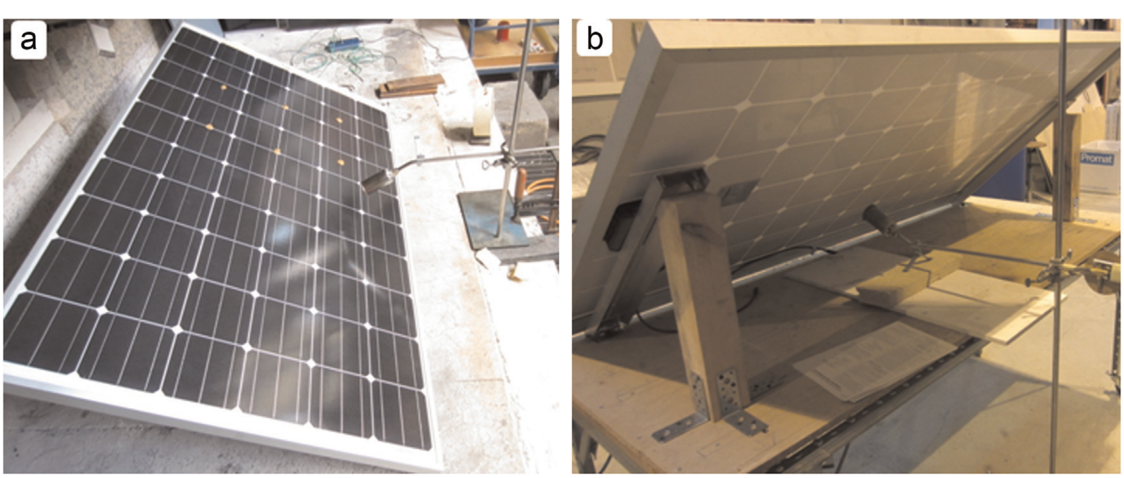

Fig. 1. Configuration of the propane gas burner and the photovoltaic module for a fire application from the outside (a) and from the inside (b).