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ScienceDirect

Energy Procedia 81 (2015) 665 – 672

Energy Procedia

[S1]69th Conference of the Italian Thermal Engineering Association, ATI 2014

The fire risk in photovoltaic installations - Checking the PV modules safety in case of fire

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Abstract

The installation of photovoltaic systems on buildings involves several problems, including the risk of fire (2011, Italy: 298 Fire fighters interventions; 2012, Germany: 390 established PV plant fires), which many countries are trying to solve.
Standards focused specifically on fire behavior of PV modules don’t exist yet. Currently, test protocols focused on other equipment are used to test PV modules fire reaction. About that, a research program was carried out to do a short analysis of PV systems fire events and to analyze the current test protocols to identify criticalities and possible improvements / protocols variants.

Peer-review under responsibility of the Scientific Committee of ATI 2014

Keywords: PV module; fire reaction; test protocol.

1. Introduction

Photovoltaic installations are becoming increasingly common in many countries, including Italy, due to the increasing sensitivity of the population and the institutions to environmental issues, the number of international initiatives aimed at the production of "clean" energy and economic incentivisation policy made in recent years (e.g.

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Peer-review under responsibility of the Scientific Committee of ATI 2014
doi:10.1016/j.egypro.2015.12.051

2013, Italy: +1.4 GWp, total installed power 17.8 GWp, 550,000 systems in operation). Moreover, even without incentives in the most recent period, the installations on Italian area are continuing, especially in the sunniest regions, thanks to the trend of decreasing costs.

The installation of photovoltaic systems involves several problems, including fire risks. In facts, the diffusion of systems like those has been accompanied by several cases of accidental combustion whose number has been growing (2011, Italy: 298 interventions of Fire Departments [1]; 2012, Germany: 390 fires of this type [2]).

The research program performed, initially, a brief analysis of the PV systems fire cases (PV on buildings) and a study of existing legislation and technical standards. After that, a program of experimental tests, based on some of the existing standard test protocols, has allowed to verify the fire behavior of some PV modules. Standard tests and variants of the previous ones were carried out. In particular, the later ones allowed a better assessment of certain typical aspects of the fire reaction performance of PV modules, mainly due to outdoor installation [3, 4].

The research program was carried out by RSE S.p.A. as part of the research for the Italian Electrical System[†] and it has allowed primarily to identify some shortcomings of existing test protocols to identify the features mentioned above, mainly relating to: inclination of the modules, presence of initial degradation in some areas of module, presence of ventilation, particularly aggressive ignition events (e.g. initial flame with enhanced power and the size and / or with longer duration). Mainly, during the tests conducted, it was found as having a significant influence on the behavior of the modules the inclination of the sample and the characteristics of the initial flame (power, size, duration).

Some of the results obtained were also discussed in IEC TC 82 “Systems of photovoltaic conversion of solar energy” and in CENELEC TC 82 “Solar photovoltaic energy systems”.

Nomenclature

Small flame tests - Flame attack on backsheet (internal area - away from the edges), Flame attack on bottom edge (main attack and initial degradation)

l_f	flame length [cm]
Δt_f	time during which the flame is in contact with sample [s]
α	angle between sample and horizontal floor
Dim.	Sides lengths of rectangular sample [cm x cm]

SBI tests - Flame attack as in the standard about position and HRR

l	width of sample [m]
h	height of sample [m]
α	angle between sample and horizontal floor
Δt_f	time during which the flame is in contact with sample [s]
HRR	Heat Release Rate of flame [kW]

2. Technical standards and legislation

The fields of legislation and standards (national and international levels) are currently under development with regard to issues of PV modules fire safety. In particular, the following documents of Ministry of Internal Affairs (Department of fire fighters, public rescue and civil protection) are currently in force in Italy:

- Note prot. n. 1324 on 07 February 2012 - Subject: "Guide for the installation of photovoltaic systems – 2012 Edition";

[†] This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development - General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency in compliance with the Decree of March 8, 2006.

- Note prot. n. 6334 of 4 May 2012 - Subject: "Clarification on the Guide for the installation of photovoltaic systems - 2012 Edition".

The first one (Note 1324) refers to the harmonized European standards for construction products, the second one (Note 6334), instead, refers to national technical standards used before the implementation of the Construction Products Directive (89/106/EEC, later replaced by Regulation no. 305/2011) and the publication of the related harmonized standards. Therefore it is clear that the issue is not yet completely solved at the legislative level.

As regards the technical regulations, it refers mainly to the following standards:

- IEC 61730-2:2004 "Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing" ;
- UL 1703:2002 "Standard for Flat-Plate Photovoltaic Modules and Panels";
- UL 790:2004 "Standard for Standard Test Methods for Fire Tests of Roof Coverings";
- EN 13501-1:2007+A1:2009 "Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests" (which refers to CEN/TS 15117, EN 13823, EN 15725, EN ISO 1182, EN ISO 11925-2, EN ISO 1716, EN ISO 9239-1);
- EN 13501-2:2007+A1:2009 "Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services";
- EN 13501-5:2005+A1:2009 "Fire classification of construction products and building elements - Part 5: Classification using data from external fire exposure to roofs tests" (which refers to ENV 1187:2002);
- EN 13823:2010 "Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item" (Fig. 1);
- EN ISO 11925-2:2010+AC:2011 "Reaction to fire tests - Ignitability of products subjected to direct impingement of flame - Part 2: Single-flame source test";
- CEN/TS 1187:2012 "Test methods for external fire exposure to roofs";
- CEI 82-25:2010 “Guida alla realizzazione di sistemi di generazione fotovoltaica collegati alle reti elettriche di Media e Bassa Tensione” (Guide to the realization of photovoltaic generation systems connected to electrical grids of medium and low voltage);
- CEI EN 61730-2:2009 (CEI 82-28) “Qualificazione per la sicurezza dei moduli fotovoltaici (FV). Parte 2: Prescrizioni per le prove” (Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing);
- prEN 50583:2012 "Photovoltaics in buildings" (CENELEC project);
- UNI 9176:1998 “Preparazione dei materiali per l'accertamento delle caratteristiche di reazione al fuoco” (Preparation of materials for the assessment of reaction to fire);
- UNI 8457:1987 “Prodotti combustibili suscettibili di essere investiti dalla fiamma su una sola faccia - Reazione al fuoco mediante applicazione di una piccola fiamma” (Combustion products likely to be hit by flame on one side only – Reaction to fire reaction by applying a small flame);
- UNI 9174:1987 “Reazione al fuoco dei prodotti sottoposti all'azione di una fiamma d'innesco in presenza di calore radiante” (Reaction to fire performance of products subjected to a flame ignition in the presence of radiant heat, Fig. 1);
- UNI 9177:1987 “Classificazione di reazione al fuoco dei prodotti combustibili” (Reaction to fire: combustible products classification).

a b

Fig. 1. (a) UNI 9174 (Italian standard) test; (b) EN 13823 (Harmonized European standard) test (courtesy of Istituto Giordano S.p.A.).

Inside IEC 61730-2 and in the related European and Italian standards (EN 61730-2, CEI EN 61730-2) there is the following table:

Table 1. “Fire hazard tests table” in IEC 61730-2, EN 61730-2, CEI EN 61730-2.

Test	Title	References in Standards	According to	
			IEC 61215	IEC 61646
MST 21	Temperature test	ANSI/UL 1703		
MST 22	Hot-spot test		10.9	10.9
MST 23	Fire test	ANSI/UL 790		
MST 25	Bypass diode thermal test		10.18	
MST 26	Reverse current overload test	ANSI/UL 1703		

Where (tab. 1) the test protocol related to fire behavior (Fire test) is indicated as a reference to ANSI / UL 790, “Standard for Standard Test Methods for Fire Tests of Roof Coverings” (which is also invoked by UL 1703), but in the above EU and Italian transpositions the “Fire Test” chapter is still a section “Under construction”.

Furthermore, within the prEN 50583, the standards EN 13501-1, EN 13501-2, EN 13501-5, which contain references to harmonized European technical standards for construction products, are invoked as reference for the “Safety in case of fire”, while the UL 790 is focused on roof panels. Therefore, there are standards which are invoked about the PV modules, but such standards are related to different equipments which differ from the PV modules mainly because of the materials and laying conditions.

It is, therefore, clear that, even at the level of technical regulations, standards suitable to treat all the specific characteristics of the problem are not still existing.

The fire reaction ratings are mainly based on: fire growth speed, HRR (Heat Release Rate), THR (Total Heat Release), smoke growth speed, total smoke production, spread / propagation of flame, propagation speed of flame, post-incandescence time, post-combustion time, size of fire damaged area, dripping [5].

3. Research activity

The research activity was mainly based on an experimental program which performed tests according with the harmonized European standards (EN 13823:2010 "Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item", EN ISO 11925 -2:2010 + AC: 2011 "Reaction to fire tests - Ignitability of products Subjected to direct impingement of flame - Part 2: Single-flame source test"), which had initially been listed as references by national legislation (ref. Note 1324/ 2012, Ministry of

Internal Affairs - Department of fire fighters, public rescue and civil protection, [6]), and, later, according to some variants of the previous test protocols designed in order to assess the influence of: sample inclination, HRR and size of ignition flame, sample exposure time to ignition flame and presence of sample initial degradation.

Such variants were carried out in order to better assess typical aspects of fire reaction performance of PV modules mainly due to their outdoor installation [7, 8].

Samples of PV modules used were, respectively:

- Samples 1 x 1.5 m (with PV cells), samples 0.5 x1.5 m (without PV cells), in the test according to EN 13823 (SBI);
- Samples 0.25 x 0.09 m (without PV cells), in the test according to EN ISO 11925-2 (Small flame).

(The fuel used in all tests was propane gas).

The following table lists the tests performed with their respective characteristics, respectively: Small flame (test according to EN ISO 11925-2:2010 and variants, Tab. 2), SBI (EN 13823:2010 and variants, Tab. 3).

About the tests carried out according to Small flame procedure, they were performed with the following configurations:

- Flame attack on backsheet (internal area - away from the edges);
- Attack of flame on the bottom edge (side length 9 cm);
- Flame attack on backsheet (internal area) after the initial degradation (previous attack of flame on the bottom edge).

The test were carried out with samples of same sizes (0.25 x 0.09 m) and with different values of: flame application time, flame size and HRR and sample inclination.

The tests carried out according to SBI procedure were performed with the following configurations:

- Num. 2 samples (0.5 x1.5 m, 1 x 1.5 m) both in vertical position;
- Num. 1 sample (0.5 x1.5 m) in vertical position;
- Num. 1 sample (0.5 x1.5 m) in an inclined position;

The test were made with different values of: flame application time and sample inclination.

(The flame attack was always as in the standard about position and HRR).

Table 2. Tests list according to EN ISO 11925-2:2010 (Small flame: Standard) and variants (Small flame: Variant).

Test num.			Sample	Flame attack (internal area)			Flame attack (bottom edge)			Initial degradation (bottom edge flame attack)		
			Dim. [cm x cm]	l_f [cm]	Δt_f [s]	α	l_f [cm]	Δt_f [s]	α	l_f [cm]	Δt_f [s]	α
1	Small flame	Standard	9x25	2	30	90°						
2	Small flame	Standard	9x25	2	30	90°						
3	Small flame	Variant	9x25	3.5	30	90°						
4	Small flame	Variant	9x25	2	150	90°						
5	Small flame	Variant	9x25	2	330	90°						
6	Small flame	Variant	9x25	3.5	150	90°						
7	Small flame	Variant	9x25	3.5	330	90°						
8	Small flame	Variant	9x25	2	150	60°						
9	Small flame	Variant	9x25	3.5	330	60°						
10	Small flame	Variant	9x25	3.5	330	60°				3.5	240	90°
11	Small flame	Variant	9x25	3.5	330	60°				3.5	240	90°
12	Small flame	Variant	9x25	2	300	30°						
13	Small flame	Variant	9x25	2	330	30°						
14	Small flame	Variant	9x25	3.5	330	30°						
15	Small flame	Variant	9x25	2	330	30°				2	240	90°
16	Small flame	Variant	9x25	3.5	315	30°				3.5	240	90°
17	Small flame	Variant	9x25	3.5	330	30°				3.5	240	90°
18	Small flame	Variant	9x25				2	120	60°			
19	Small flame	Variant	9x25				3.5	240	60°			
20	Small flame	Variant	9x25				2	240	30°			
21	Small flame	Variant	9x25				3.5	240	30°			

Table 3. Tests list according to EN 13823:2010 (SBI: Standard) and variants (SBI: Variant).

Test num.			Small sample			Big sample			Flame attack	
			l [m]	h [m]	α	l [m]	h [m]	α	Δt_f [s]	HRR [kW]
1	SBI	Standard	0.5	1.5	90°	1	1.5	90°	1200	31
2	SBI	Variant	0.5	1.5	90°				45	31
3	SBI	Variant	0.5	1.5	60°				45	31
4	SBI	Variant	0.5	1.5	90°				200	31
5	SBI	Variant	0.5	1.5	60°				200	31

Some pics from the tests listed are placed below (Fig. 2: Small flame tests; Fig. 3: SBI tests). In particular, from Small flame pics (Fig. 2) is clear that the standard protocol (test 1) is not very significant about the assessment of sample characteristics, while the results are much more evident in case of variant protocol, which was performed with more challenging conditions for the sample. Even about SBI pics (Fig. 3) is evident that variant test conditions were more demanding for the samples than standard test conditions.

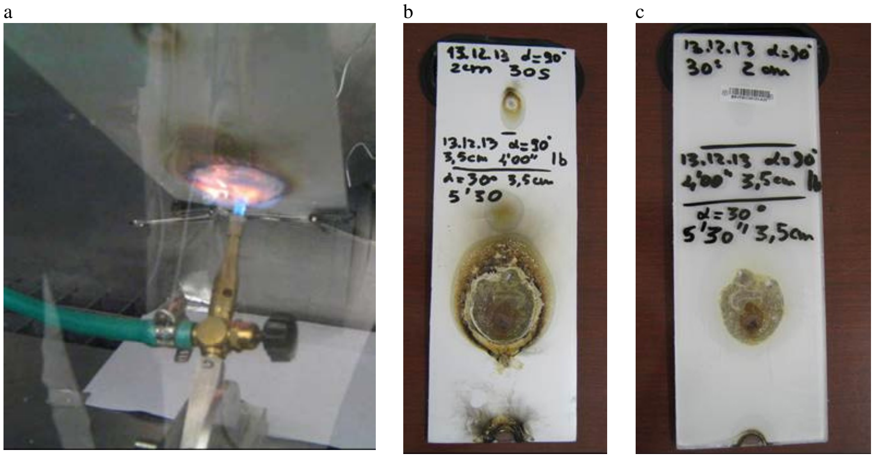

Fig. 2. Small flame: (a) test 14; (b) test 1 (upper area) and test 17 (lower area) end of test backsheet; (c) test 1 (upper area) and test 17 (lower area) end of test front (courtesy of Politecnico di Milano).

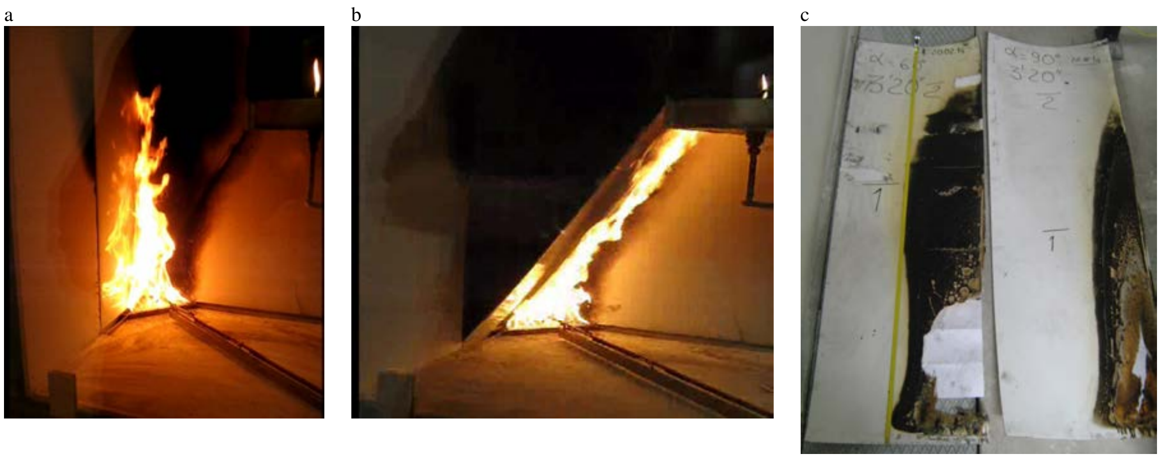

Fig. 3. SBI: (a) test 4; (b) test 5; (c) test 4 (right) and test 5 (left) end of test backsheets (courtesy of Politecnico di Milano).

4. Conclusions

The test program allowed to check the behavior to fire (in particular the characteristics of fire reaction) of some samples from PV modules in accordance with the test protocols for the European construction products and variants of the same. It also allowed the identification of some shortcomings of same protocols to identify the features mentioned above, mainly due to the peculiarities of the outdoor installation of PV modules, such as inclination of the modules, the presence of initial degradation in some areas of the same, primer particularly aggressive (e.g. initial flame for more power and the size and / or of longer duration).

It was evident that the backsheet (mainly of polyester) has good fire reaction characteristics, while EVA (Ethylene Vinyl Acetate) content, having the function to keep backsheet assembled with cells and tempered glass, appears to be a rapidly combustible material releasing gaseous fuels (with some hydrocarbons) once degraded thermally (i.e. exposed to flame impingement as a result of partial backsheet destruction) [9]. Such behavior of EVA is clear in the test performed referring to both standards SBI and Small flame.

In general the test program carried out highlighted the influence on fire behavior of PV modules of following variables:

- Inclination of sample,
- Power and size of initial flame.

About the angle between sample and horizontal floor, it is evident that a greater inclination (small angle) of the sample is causing damage much greater and more rapidly than vertical position configuration. Furthermore, it is evident that a flame with greater HRR and size produce damage with increased size and more rapidly. About that, also impingement time appears having a primary role in the damaging of sample.

(On the basis of the tests carried out, the most likely classification of PV module used in complying with European harmonized standards is D-s2, ref. D.M. 25.10.2007).

Acknowledgements

The experimental program was carried out in collaboration with Politecnico di Milano (Dept. of Energy, FireLab, Milan, Italy) where the test were made; Brandoni Solare S.p.A. (Castelfidardo - AN), which provided samples of PV modules used; Istituto Giordano S.p.A. (Fire Reaction and Electronics labs, Gatteo - FC), which provided support for maintenance and testing activities.

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