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The fire risk in photovoltaic installations - Test protocols for fire behavior of PV modules

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Abstract

The fire risk in the photovoltaic systems has emerged over the years as not negligible, setting in motion a process, which involves various organizations (control Authorities, standardization bodies, modules manufacturers, etc.) for achieving the codification of construction, design and installation of these systems and their components to minimize fire risk. Currently, European standards focused specifically on fire behavior of PV modules don't exist yet, so test protocols focused on other equipment are used to test PV modules reaction to fire. About that, a research program was carried out to do a short analysis of PV systems fire events, to analyze the current test protocols and for identifying their criticalities and possible improvements. In particular, some variants of these protocols have been developed basing on some of the existing test protocols in standard harmonized at European level about reaction to fire of construction products. These variants have been designed for being specific test tools for determination of reaction to fire features of PV modules with main attention to important peculiarities such as: modules inclination, initial fire particularly aggressive.

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Keywords: PV modules; Reaction to fire; Test protocols.

1. Introduction

Number of photovoltaic installations is increasingin many countries, including Italy, due to the increasing sensitivity of the population and the institutions to environmental issues and to economic

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incentivisation policy made in recent years (e.g. 2014, Italy: +0.65GWp, total installed power 18.45GWp, 650,000 systems in operation).

Nomenclature

lxh	width and height of sample(s) [m]
Small flame tests (EN ISO 11925-2:2010)	
l_f	ignition (external) flame length [cm]
Δt_f	time during which the ignition (external) flame is in contact with sample [s]
α	angle between sample and horizontal floor
SBI tests (EN 13823:2010)	
α	angle between sample and horizontal floor
Δt_f	time during which the ignition (external) flame is in contact with sample [s]
HRR_f	Heat Release Rate of ignition (external) flame [kW]
HRR	Heat Release Rate of sample fire (without ignition flame)[kW]

The diffusion of photovoltaic systems 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]).

Because of that a research program was carried out by RSE S.p.A. as part of the research for the Italian Electrical System[†] performing, initially, a brief analysis of the PV systems fire cases (PV on buildings, no BIPV systems) and a study of existing legislation and technical standards. Finally, a program of experimental tests, based on some of the existing standard test protocols, was performed for evaluating the fire behavior of some PV modules and new test protocols were developed and perfected. In particular, because of the existing standards are not focused on PV modules, the later ones could allow a better assessment of certain typical aspects of the reaction to fire performance of those modules, mainly due to outdoor installation [3, 4] (inclination of the modules, presence of initial degradation in some areas of module, presence of ventilation, aggressive ignition events: initial flame with enhanced power and size and / or with longer duration).Mainly, the new tests revealed the significant influence on the behavior of the modules of sample inclination and of initial / ignition flame (power, size, duration).

Because of the ongoing development of standard projects on that topic, some of the results obtained were also discussed in CEI TC 82 “Systems of photovoltaic conversion of solar energy” (WG11 “The fire risk in photovoltaic plants”) and in CENELEC TC 82 “Solar photovoltaic energy systems” (WG01 “Wafers, cells and modules”).

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:

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- Note prot. n. 1324 on 07 February 2012 - Subject: "Guide for the installation of photovoltaic systems – 2012 Edition" (it refers to the harmonized European standards for construction products);
- Note prot. n. 6334 of 4 May 2012 - Subject: "Clarification on the Guide for the installation of photovoltaic systems - 2012 Edition" (it refers to national technical standards used before the implementation of the Construction Products Directive 89/106/EEC, later replaced by Regulation no. 305/2011).

About the technical regulation, it refers mainly to the following standards:

- IEC 61730-2:2004 "Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing" ;
- UL 1703:2015 "Standard for Flat-Plate Photovoltaic Modules and Panels";
- UL 790:2014 "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+A1:2014 "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";
- 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);
- FprEN 50583:2015 "Photovoltaics in buildings - Part 1: BIPV modules / Part 2: BIPV systems" (CENELEC project);
- prEN 50XXX:2014 “External fire exposure to roofs in combination with photovoltaic (PV) arrays – Test method(s)” (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” (Combustionproductslikely to be hit by flame on one side only – Reaction to fire by applying of 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);
- UNI 9177:1987 “Classificazione di reazione al fuoco dei prodotti combustibili” (Reaction to fire: combustible products classification).

It is, therefore, clear that, particularly for European countries standards, there are not still technical rules suitable for allowing a complete assessment of PV modules fire behavior.

2. Research activity

The research activity carried out was mainly based on an experimental program performing tests according to harmonized European standards for building products (EN 13823:2010 "Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item", i.e. “SBI”; 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", i.e. “Small flame”), which were initially listed as references by national legislation (ref. Note 1324/ 2012, Ministry of Internal Affairs), and, later, according to some “variants” of previous test protocols designed for assessing the influence of: sample inclination, HRR and size of ignition flame, sample exposure time to ignition flame and presence of sample initial degradation(21 tests according to EN ISO 11925-2 and 5 tests according to EN 13823– original and variants tests – were performed) [3], [4].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. The performing of tests with the modified protocols (variants) needs the same equipment already utilized in the current version and it requires only minimal additional resources to be carried out. These protocols were developed by introducing variations mainly about different values of: sample inclination (α), ignition flame *HRR* and size (l_f), sample exposure time to the ignition flame (Δt_f). The samples used in new protocols are totally identical (same type of materials [5], same production recipe and same dimensions) to those used in the original protocols regard to the test derived from the EN ISO 11925-2 (Fig. 1), while about EN 13823 the variant needs only one of the two samples of the original test(Fig. 2).

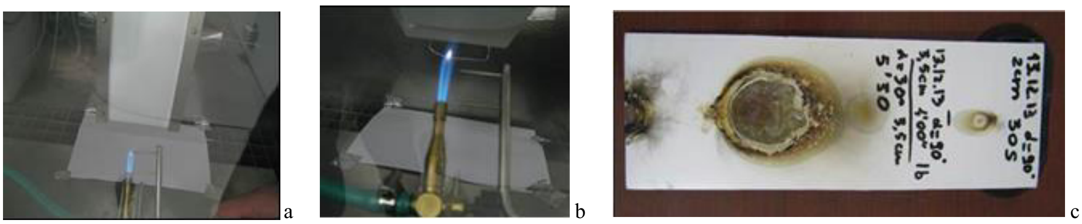

Fig. 1. (a) Sample (0.09x0.25 m) carrying out test according to EN 11925-2 (original version); (b) Sample (0.09x0.25 m) carrying out test according to EN 11925-2 (variant version); (c) Sample with fire deteriorations by original (dx) and variant tests (sx, edge).

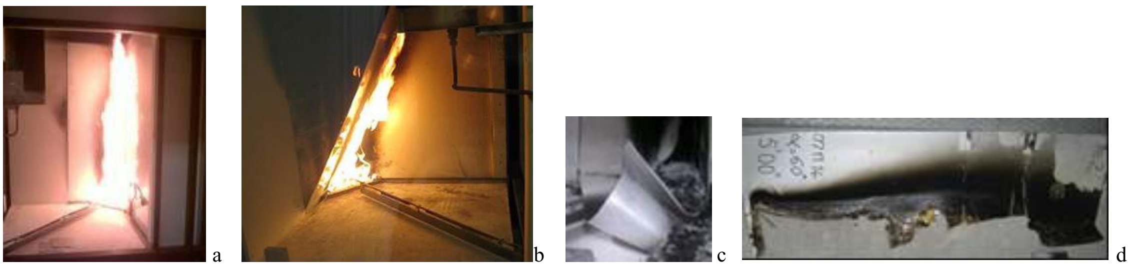

Fig. 2. (a) Samples (0.5x1.5 m and 1x1.5 m) carrying out test according to EN 13823 (original version); (b) Sample (0.5x1.5 m) carrying out test according to EN 13823 (variant version); (c) Original test sample; (d) Variant test sample.

3. Main results

The two new test protocols are similar to original ones, but the differences between them are quite promising as regards the possibility of characterizing equipment with very special features likePV modules.

Table 1. Main features of tests according to EN 11925-2 and EN 13823 (original and variant versions).

Standard test	EN ISO 11925-2 (original test)	EN ISO 11925-2 (variant test)	EN 13823 (original test)	EN 13823 (variant test)
Sample(s) size [m]	0.09x0.25	0.09x0.25	0.5x1.5 1x1.5	0.5x1.5
α	90°	30° ÷ 60°	90°	30° ÷ 60°
l_f[cm]	2	3.5		
HRR_f [kW]			30	30
Δt_f [s]	15 ÷ 30	300 ÷ 330	1200	300 ÷ 330

A possible link between the new protocols reaction to fire gradesand the current grades of the Italian legislation is summarized here below (Tab. 2, [4][‡]).

Table 2. Possible link between reaction to fire grades according to Italian law and grades of EN 11925-2 and EN 13823 variants.

	Italian grade	Variant tests grades[§]
PV modules	1	NN
	2	(B-s1,d0,1,2,p0,1_d0',1',c0')[**]
	3	(B-s1,d0,1,2,p0,1_d2',c0',1'), (B-s2,3,d0,1,2,p0,1_d0',1',c0'), (B-s2,3,d0,1,2,p0,1_d2',c0',1'), (B-s1,d0,1,2,p0,1_d1',c1'), (B-s2,3,d0,1,2,p0,1_d1',c1'), (C…), (D…),(E)

In fact the differences mentioned above involve:

[‡] Fire reaction grades classification take into account many variables like: sample fire growth, lateral flame spread on sample surface, total heat release, visible smoke production, drops or particles falling from sample, sample combustion after ignition flame stop (post - combustion), combustion of paper under the sample – at the bottom.It is expected to test also samples deteriorated (e.g. humidity - temperature - mechanical stresses).

[§] New fire reaction grades nomenclature: e.g. B-s1,d0,1,2,p0,1_d2',c0',1' means B class; SBI grades: smoke production s1, drops or particles d0 or d1 or d2, post – combustion p0 or p1; Small flame grades: drops or particles d2', bottom paper combustion c0' or c1'.

[**] Because of the "attempt" origin of proposed classification, it is possible that the grade B-s1,d0,p0_d0',c0'may be equivalent to Italian grade 1 (better than grade 2).

- EN 13823 - sample inclination (α): a better likelihood of the test with the recurrent situation having flame attack below the installed tilted module (tilted sample has a more intense and localized fire deterioration)[††];ignition flame time (Δt_f): a value lower than that in the original test allows to avoid the extremely large sample destruction, letting to assess possible differences of samples behavior.
- EN 11925-2 - sample inclination (α):a better likelihood of the test with the recurrent situation having flame attack below the installed tilted module (same as above,EN 13823 α considerations);ignition flame length (l_f): a greater value allows to have significant thermal degradation (which, in the original test, appears to be negligible in many cases);ignition flame time (Δt_f): same as above (l_f considerations).

The new (variant) and original test protocols main features are summarized in the following table.

4. Conclusions

The research carried out by RSE allowed to briefly analyze the main causes of fire in PV systems and the current state of legal measures and technical standards in the field of PV fires. Later experimental activity based on existing test protocols and on new tests (variants specifically developed for FV purposes) permitted to verify the behavior to the fire of some FV modules. This activity also helped to identify some weaknesses of European testing protocols about fire behavior classification, mainly due to special design and outside installation features of PV modules (i.e. module inclination, ignition flame power and time duration, initial deterioration of sample).

It is likely that new test protocols can improve identification of reaction to fire features of modules as more close to real situations and, because of that, also provide some help to new standards development.

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References

[1] Cancelliere P. – Ministero dell'Interno, Dipartimento dei vigili del fuoco, del Soccorso pubblico e della Difesa civile – Direzione centrale per la prevenzione e la sicurezza tecnica, Contenuti della "Guida per installazione impianti FV – Ed. 2012" e circolare 04/05/2012; soluzioni tecniche per conciliare la presenza dei moduli FV e relativi accessori con coperture realizzate in materiali combustibili, Ordine degli Ingegneri della Provincia di Vicenza, 2012.

[2] Kreutzmann A., Uno su diecimila. Passi avanti dei produttori nella prevenzione degli incendi – primi tra tutti gli Stati Uniti, Photon, June 2013.

[3] Manzini G., Analisi delle situazioni di rischio incendio dei moduli FV negli edifici e metodi di prova per la verifica della sicurezza dei moduli in caso d'incendio, RSE RdS Report 14000430, 2014.

[4] Manzini G., Il rischio incendio dei moduli fotovoltaici negli edifici – Protocolli di prova relativi alla sicurezza in caso d'incendio, RSE RdS Report 14009656, 2015.

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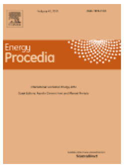
†† Testing PV samples with different angles is possible depending of what will be actually realized during the real case installation.

[5] Cancelliere P., Liciotti C., Fire Behaviour and Performance of Photovoltaic Module Backsheets, Fire Technology 06/2015; DOI:10.1007/s10694-014-0449-7



Biography

Engineering M.S degree and Ph.D. of Politecnico di Milano. He worked on both modelling and experimental activities focused on thermal–fluid–dynamics problems mainly in Fire Safety Engineering area (buildings, tunnels, nuclear power plants). He is researcher at RSE S.p.A. and adjunct professor at Politecnico di Milano (Dept. of Energy).