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Experimental Study on the Flammability of Photovoltaic Module Backsheets

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Abstract— Non-conventional energies are going to be the main alternative to fossil fuels in the coming years for their clean and renewable nature. Indian government expanded its solar plans, targeting 100 GW of solar capacity including 40 GW from solar rooftop power plant by 2022. Recently, the number of PV modules installed on the rooftop of residential houses has been rapidly increasing in India. Photovoltaic power plants are often installed without considering fire propagation and fire spread hence it can cause or contribute to fires arising due to the presence of cables and electrical boards. The backsheet is the key material for protecting the module from outdoor stresses like environmental heat, fire spread etc. This paper shows a proposal for a method to evaluate the reaction to fire characteristics of a Photovoltaic module backsheet materials. The main aim of this paper is to study and understand flammability of three different types of commercially available backsheet. Backsheet no.1 was a PVDF/PET/PVDF three-layer sheet (300 μm), Backsheet no.2 was two-layer composed FEVE/PET (275 μm), Backsheet no.3 was PVF/PET/PVF three-layer sheet (325 μm). Test results show that the choice of a three-layer for Backsheet no.3 represents the best solution among the ones tested. This paper concludes that the thickness of the backsheet has good impact on time required to burn. Moreover, the approach reported in this paper could represent a useful reference to be used as a baseline for developing an Indian Standard/International standard.

Index Terms— Backsheet material, Durability, Photovoltaic module, Fire safety, Fire flammability test, PV backsheet

1 Introduction

Indian government expanded solar plans, targeting 6385 billion in investment and 100 GW of solar capacity by 2022. India's goal of 100 GW of solar energy by 2022 is an ambitious target since the world's installed solar-power capacity in 2017 is expected to be 303 GW [20]. Photovoltaics is the process of converting sunlight directly into electricity using solar cells. Today it is a rapidly growing and increasingly important renewable alternative to conventional fossil fuel electricity generation, but compared to other electricity generating technologies, it is a relative newcomer, with the first practical photovoltaic devices demonstrated in the 1950s.

The photovoltaic modules exposed to the sunlight under typical field conditions experience much higher temperatures than the ambient temperatures [21].

The main component used for Photovoltaic module are Anti reflecting coating glass, Solar cells, EVA sheet and Backing material. Backsheet plays a vital role in reliability, durability and safety of PV module. One of the critical materials used in the construction of a PV module is the backsheet [2]. The backsheet is considered the only insulation that can be relied upon on the back side of the module [9].

In the PV industry, the guidelines on choosing the backsheet foils are usually the ones set out in the IEC standards. The critical aspects introduced by the backsheet foils to PV modules are clearly shown in the IEC retest guidelines [9]. During its entire lifetime, a PV module is exposed to various different environmental and electrical stresses. These harmful effects may influence the module's electrical performance and lifetime [16]. Being one of the most outer part of a PV module, the backsheet has to withstand environmental stresses, heat, fire spread etc.

Regarding the electrical safety of a PV module, the backsheet has to guarantee its insulation capacity over the module's lifetime in the field [13]. The presence of photovoltaic plant on buildings could contribute to the pre-existing level of fire risk because the PV plant components could influence the propagation of fire outside or inside the building, interfere with the smoke and venting system of the combustion products, hinder fire-fighting operations or even introduce electrical shock hazards for firefighters and rescue operators due to energized circuit items [8,22].

Photovoltaic systems are subject to electrical faults like any electrical installation such as arc faults, short circuits, ground faults and reverse currents [6]. These faults and other failures of the system, including cable insulation breakdowns, rupture of a module, and faulty connections, can result in hot spots that can ignite combustible material in their vicinity. Wrongly installed or defect DC/ AC inverters have been the reason of several photovoltaic fires as well [3].

2 Fire Classification of PV Module

UL 1703-Standard for fire performance of Flat-Plate Photovoltaic Modules [23]. Fire Testing of the PV modules are required to be tested once with both the Spread of Flame and Burning Brand on Top of Surface tests [1]. The international safety standard for PV modules currently lists a fire test based on a North American test method for roof-covering materials [15]. While testing Building Integrated Photovoltaics it mandatory to follow the UL 790 test standard requirements [24]. UL 790 Standard are Test Methods for Fire Tests of Roof Coverings [5]. These tests are recommended for the fire resistance performance of roof exposed to develop fire sources originating from the outside of a building [17,18]. UL 790 standard test is introduced as a test method for all the modules incorporated within IEC 61730 [19]. The long-term environmental tests of the IEC 61215 do not cover the aspects of electrical safety adequately [11].

PV system design and installation phases focus on efficiency, reliability, and obtaining the highest possible amount of solar energy that can be converted into electrical energy [7]. In a PV electrical plant, therefore, fire risk is not taken into account by technical designers and, even more, is neglected by PV plant installers [10,14]. The external side of a backsheet has to ensure good weatherability, good bonding to the junction box, moisture protection, UV protection, and protection against mechanical, damage, fire spread and chemical damages [13].

As per IEC 61730 MST 23 Proof according to ANSI/UL790, that the module meets the minimum fire resistance rating of Class C but there are no fire standards for backsheet of Photovoltaic module nor any fire-flammability mandatory for it. However, research about PV fire safety is not enough. In this paper, a test method is introduced to identify the flammability of backsheet materials. The main aim of this paper is to study and understand flammability of different types of commercially available backsheet. By comparing result, a better understanding of failure mechanisms and impact of flammability can be obtained.

3 Materials used and Methodology

In the PV industry, the guidelines on choosing the backsheet foils are usually the ones set out in the IEC standards [9]. The critical aspects introduced by the backsheet foils to PV modules are clearly shown in the IEC retest guidelines [24]. For modifications related to backsheet changing, the retest guidelines advise that the following tests be repeated:

- Damp heat (MST 53 IEC 61730 and 10.13 IEC 61215);
- Wet leakage current test (MST 17 IEC 61730 and 10.15 IEC 61215);
- Dielectric withstand test (MST 16 IEC 61730);
- Cut susceptibility test (MST 12 IEC 61730);
- Impulse voltage test (MST 14 IEC 61730);
- Fire test (MST 23 IEC 61730);
- Temperature test if there is a change in material (MST 21 IEC 61730);
- Partial discharge test (MST 15 IEC 61730);
- UV (10.10 IEC 61215) thermal cycling,
- 50 cycles (10.11 IEC 61215)/humidity freeze (10.12 IEC 61215) sequence and
- Termination Robustness (10.14 IEC 61215)

Some of the common types of backsheet materials available on the market like FEVE, PVDF and PVF backsheets were selected to evaluate and compare the reaction-to fire performances of these products.

Backsheet no.1 (BS1) had three layers (PVDF/PET/PVDF), with these layers having thicknesses of 25 µm, 250 µm and 25 µm, respectively.

Backsheet no.2 (BS2) had two layers (FEVE/PET) with these layers having thicknesses of 25 µm and 250 µm.

Backsheet no.3 (BS3) had three layers (PVF/PET/PVF) with these layers having thicknesses of 25 µm, 275 µm and 25 µm.

Table I Structural setup of backsheet

	BS1	BS2	BS3
Layers	PVDF	FEVE	PVF
	PET	PET	PET
	PVDF	-	PVF
Layers Thickness	25 µm	25 µm	25 µm
	250 µm	250 µm	275 µm
	25 µm	-	25 µm
Total Thickness	300 µm	275 µm	325 µm

As thickness of backsheet material is very thin, selection of test method must satisfy the condition of backsheet materials. The problem that arises with a very thin material is that it may not burn but it will shrink or distort as the flame is directed to the sample, hence UL 94 VTM test is intended to be performed on thin materials [25]. Specified test flame under controlled laboratory conditions classification applies to a particular application depends on factors like size and thickness of part [26].

In this experiment, flammability rating is not determined. Flammability of PV backsheets material had determined as per total burning time (sec) when directed to fire. At a certain level, most of this experimental work satisfy condition as per UL 94 VTM. UL 94 VTM Vertical Thin Material method is used to determine the UL 94 VTM0, VTM-1 and VTM-2 flammability of thin materials. These requirements cover tests for flammability of polymeric materials used for parts in devices and appliances. They are intended to serve as a preliminary indication of their acceptability with respect to flammability for a particular application

The test evaluates both the burning and afterglow times and dripping of the burning test specimen [25]. The experiment setup is arranged according to UL 94 VTM to understand flammability of PV backsheet also follows certain conditions. UL 94 VTM test setup is shown in Fig 1 also attempt have made to design same setup

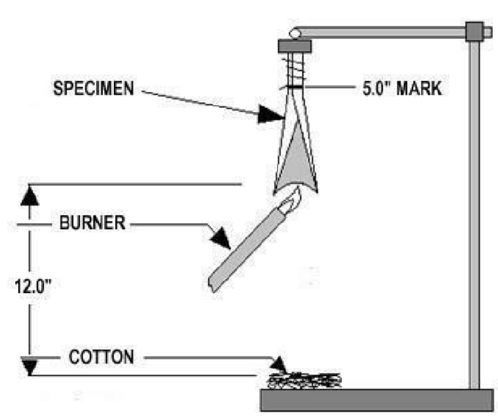

Fig 1 Vertical burning test as per UL 94 VTM classifications

The specimen (cone) is supported in a vertical position and a flame is applied to the bottom of the specimen as shown in fig1. Flame application is directed two times lasting 3 sec each as per UL 94 VTM standard divided in two stages. The flame is applied and then removed until flaming stops at which time the flame is reapplied and then removed. The second flame application time begins as soon as the first burning time ends [26].

4 Experimental Design

The goal of this work is to design a Setup as per UL 94 VTM, a process to observe and characterize backsheet behavior. The required materials for experiment setup are retort stand, Bunsen burner, surgical cotton and burner support 45^0 angle stand. According to UL 94 VTM test, burner must be inclined at angle of 45^0 with the length of 31 cm from the base. The specimen length must be 12.7 cm and specimens are suspended such a way that it must be fixed at height of 43 cm from the base.

Retort stand with total 60 cm in length have taken and fix the holder at 43 cm according to test requirement. Also taken a sheet 15 cm X 15 cm and form a cone with it to perform the flammability test (see Fig 2) one set of three materials are taken.

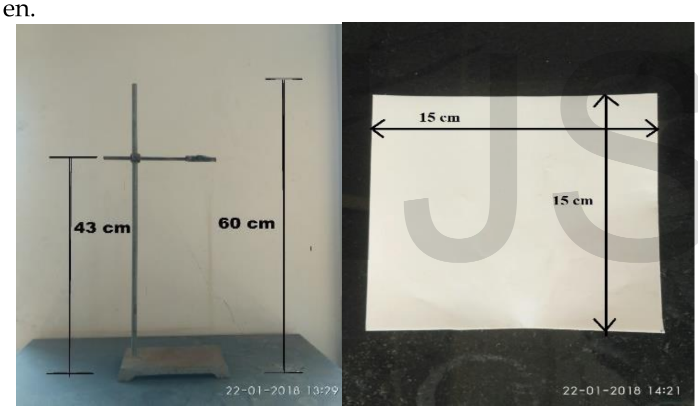

Fig 2 Retort stand arrangement and specimen sample

As all backsheet are white in colour. To identify the particular type is difficult so backsheets have given colour band. Red colour indicates PVDF/PET/PVDF, Yellow colour indicates FEVE/PET and finally Green colour indicate PVF/PET/PVF. The colour band is fixed at 12.7 cm from the base as per test condition (see Fig 3). With the help of metal strips, 45^0 inclined stand have designed with Bunsen burner holder which is 31 cm in height from the bottom (see Fig 4)

Fig 3 Cone shaped backsheets with different colour band

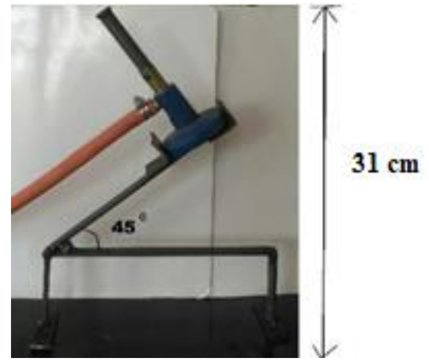

Fig 4 Bunsen burner support stand 45^0 inclined

5 Results and Discussion

In this experiment, the setup according to UL 94 VTM had arranged to understand flammability of PV backsheet also followed certain conditions of UL standard. Three types of backsheet with different thickness described in the previous section were tested according to UL 94 VTM standard in Chemistry laboratory of S.S Jondhle College of Engineering and Technology at Asangaon, Thane. Fig 5 shows one of the material being tested as per UL 94 VTM Standard method. In the case of fire, a high rated flame is propagated hence oxidizing flame (≥ 200^0 C) is directed to backsheet during flammability test. The presented work aims to assay three different commercially available PV backsheet performance in course of fire flammability test.

Fig 5 Reaction to fire on backsheet material

Note - The exact temperature responsible for burning of sheets (fire point) have concluded as per burning flame characteristics and results on total burning time of sheets.

The following is the main discussion on the test results:

BS1 results: - Material was contacted by flame for 3 secs, shrinkage was observed with some burn marks. After the Second flame contacted, material started burning. Combustion was not quick. After 53 sec it started reaching the red colour band area (see fig 6). Total 56 secs took to burn up to red band.

BS2 results: - Burning started as soon as material was contacted by flame for 3 secs. After the first flame, no shrinkage or no burn mark but directly burning was observed. Spreading speed was quick. Within 37 sec most part of material where fully burnt (see fig 7). Total 40 secs took to burn up to yellow colour band.

BS3 results: - After the first flame for 3 sec shrinkage was observed. No burn marks were observed. After the second flame, slowly started burning. The fire spreading speed was slow as compared to first 2 materials (see fig 8). It took total 74 secs to burn up to green colour band.

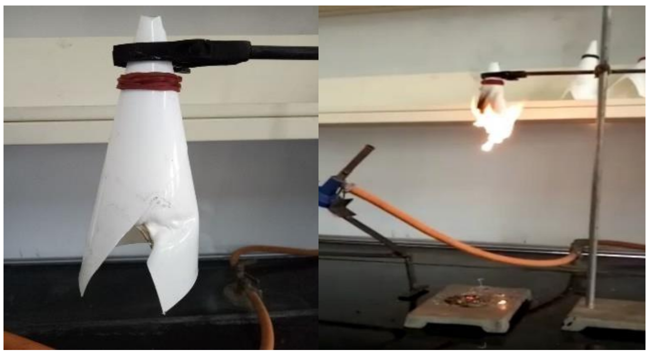

Fig 6 Shrinkage with burn mark after first flame and fire spread after 50 secs (BS1)

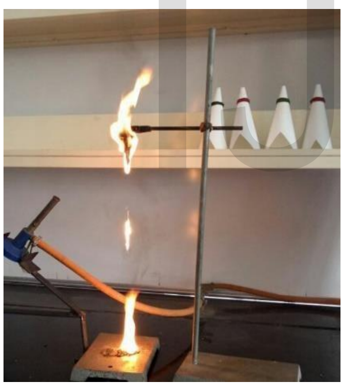

Fig 7 High-speed fire spread (BS2)

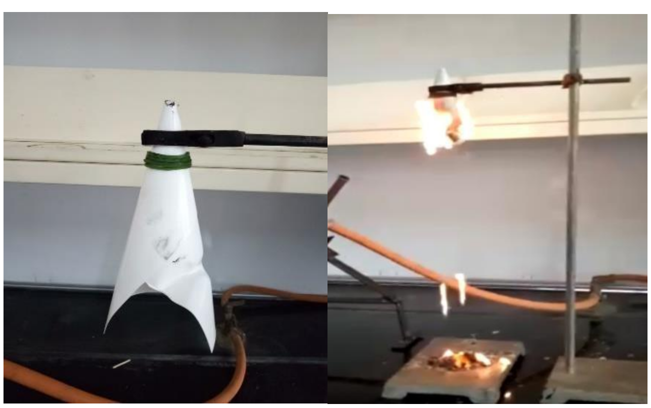

Fig 8 Shrinkage after first flame and fire spread after second flame (BS3)

It can be seen than three-layer backsheet materials have lower fire propagation speed. Fig 9 shows total burning time of all tested materials. Fire spreading speed of two-layer BS2 was quick. BS3 had taken more time to burn up to colour band (i.e. 12.5 cm) as compared to BS1 and BS2.

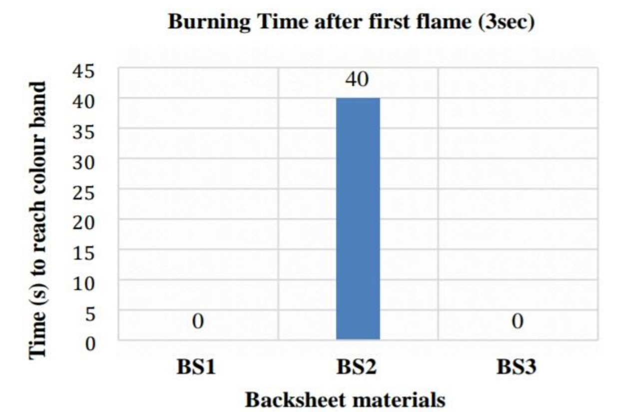

Fig 9 stage-1 Burning time after first flame

Fig 9 shows the burning time after first flame for the three materials evaluated i.e. Stage 1. Two-layer BS2 started burning as soon as flame directed to it whereas BS1 and BS3 resist the flame. Figure 10 shows the burning time after second flame of all the tested specimens.

Completely burnt BS2 is not considered in Stage 2. It can be seen that three-layer backsheets have a lower flame propagation speed compared to two-layer backsheet.

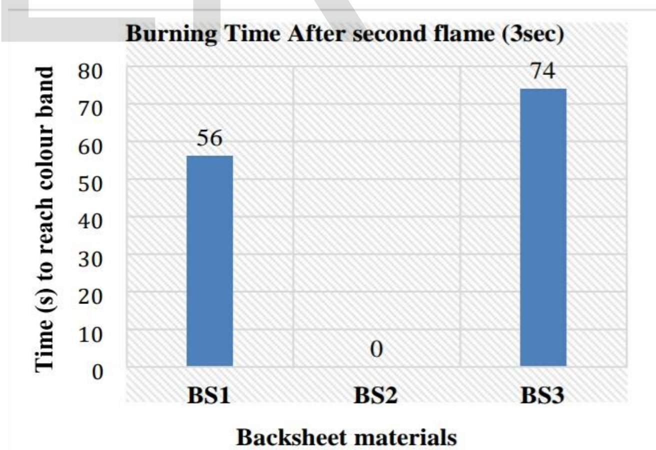

Fig 10 stage-2 Burning time after second flame

6 Conclusion

This paper showed the Fire classification of PV module and how to test PV backsheet under UL 94VTM flammability test. Three different types of backsheet available on market have selected in order to evaluate and compare fire flammability of these products. Backsheet no.1 was a PVDF/PET/PVDF three-layer sheet (300 μm), Backsheet no.2 was composed FEVE/PET (275 μm), Backsheet no.3 was PVF/PET/PVF three-layer sheet (325 μm).

In this study, it has found that three-layer BS3 have taken more time to burn till colour band following BS2 and BS1. The exact temperature responsible for burning of sheets can be ≥ 200^0 for BS1 AND BS3 as during stage-1 no burning has been observed. BS2 has lowest fire point compare to BS1 and BS3 and It can be ≤ 200^0C.

The experiment tests result that the best choice of BS3 i.e. PVF/PET/PVF which was three-layer sheet, represent the best solution among the ones tested. This paper concludes that the thickness of the backsheet has good impact on time required to burn. Even though BS1 was also three-layer sheet like BS3, the PV backsheet production could be critical as regards the fire safety of PV module. In the case of fire, a high rated reaction to fire PV module could drastically reduce the spread of fire and flame propagation. In order to comply this requirement, Photovoltaic module manufacturer should assess the material chosen for building a proper reaction to fire spread. Moreover, the approach reported in this paper could represent a useful reference to be used as a baseline for developing an Indian standard/International standard.

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