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Review on degradation of EVA encapsulated PV Module by UV ageing

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Solar energy is considered to be one of the prime sources of renewable energy for the generation of electrical energy, which is gaining the importance in recent time in India and there is a plan to generate 200GW of solar energy by 2024. Solar energy is absorbed by Photo-Voltaic (PV) cells and converted into electrical energy. Such PV cells are connected in series and parallel combination to generate required output power. Hence, Photo-Voltaic (PV) modules must be in operation for long time without any reduction in output and efficiency. In recent times, to achieve this, both surfaces of PV module are encapsulated by Ethylene-Vinyl-Acetate (EVA) polymer, but UV radiations leads to degradation of EVA polymer, which results in deterioration of PV module, thus overall efficiency and output of module reduces. Various UV accelerated ageing studies and investigations have predicted service time of module. The objective of this investigation is to review the available literature with respect to types of PV cells & encapsulant used, UV ageing parameters & instruments employed and envision a way forward in employing EVA with nano additives as an encapsulant to improve its performance.

Keywords: *Solar energy; Photovoltaics; Ethylene-Vinyl-Acetate polymer;Encapsulation; Accelerated UV ageing*

1.0 INTRODUCTION

With moderate increase and continuing threat of global warming and devastation of existing fossil fuel reserves, sustainable green energy sources are the only alternative solutions to the crisis. Solar energy is considered to be the most Renewable energy potential to meet energy demand. Solar PV module consists of interconnected PV cells, from which electrical energy is generated when module is irradiated by solar rays. The solar energy reaching the surface of earth has typical power density of 500-1000W/m^2 [1], so to collect this amount of energy from sunlight, large collection areas are required. The main problem is not the collection of solar energy, but collecting it in an inexpensive manner. To cut down cost, multilayered stacks of thin films like mirrors, PV systems, flat plate collectors etc. are used [2].

Literature survey indicates a few ageing studies carried out on degradation of PV module encapsulated by EVA polymer. The factors that affect degradation are weather conditions, temperature, moisture (relative humidity, %RH) and Ultraviolet radiations [3]. At times premature ageing of EVA has led to degradation of PV modules.

The most used encapsulant materials contain UV absorbers, which protect the PV module and polymer layer from UV radiations. But these absorb radiations below wavelength of 360nm and thus preventing UV from reaching PV cells [4]. So overall efficiency gain from these polymers was not attained. To overcome this disadvantage, new encapsulate material which does not contain UV absorber and allows UV radiation (300nm-360nm) on the module, is

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introduced. Such encapsulates are named as blue light encapsulant. Such commercially available encapsulates are EVA and ionomer film. Because of various advantages like good transmittance and elasticity, low processing temperature, good adhesive property, low cost etc., EVA is chosen compared to different acknowledged polymers with higher properties [5].

The process of degradation of PV module with EVA encapsulant is done by accelerated UV ageing. Mainly there are two types of accelerated UV chambers, UV ageing using Xenon Arc lamps and UV ageing using fluorescent lamps. The studies, in refernce [6], narrates about the reduction in transmittance and the characteristic effects of gel content and chemistry EVA encapsulate. The references [5,6] proves that the process of degradation of EVA is due to interactions and incompatibilities between formulation of additives. In the current scenario authors emphasise the need for investigation on EVA as an encapsulant material.

2.0 PHOTOVOLTAIC SYSTEM

2.1. Photovoltaics

PV is a system which consists of PV cells, that produces electricity when irradiated by sunlight and generate electrical energy [7]. Solar PV cells are made of semiconductor material, such as silicon that produces current by photovoltaic effect. When photon of light falls on PV cells, their energy is transferred to the charge carriers. Thus, electrical energy is extracted from PV cell [8].

Usually the voltage able to generate from single PV cell is in the range of 0.3V-0.7V, which is very low [9]. So number of PV cells are connected in series (for operational voltage) and in parallel (for operational current) to obtain desired electrical output.

2.2. Types of PV cells

Mainly there are two types of PV cells: Crystalline and thin film. Crystalline cells are further classified into Mono Crystalline and Poly crystalline [8]. The types of available PV cells has both merits and demerits and are as follows.

2.2.1. *Monocrystalline Solar Cells:*

In mono crystalline, by using a single cylindrical crystal of silicon the cells are made as shown in Fig 1[6]. The characteristics are:

- Efficiency is high and is in the range of 15-20%, for panels that are made using high grade silicon.
- These are space- efficient, as they are made using highest grade silicon, thus they require less space compared to polycrystalline silicon panels [10].
- Monocrystalline panels produce four times more output power as compared to thin-film solar panels.
- Life time of monocrystalline panels is high compared to polycrystalline and thin-film panel.
- More chances of circuit breakdown are possible if the panel is covered with dirt, snow or shade.

Demerits of monocrystalline cells are:

- These are more vulnerable in hot weather, as performance efficiency decrease at higher temperature.
- During manufacturing process, more silicon is wasted.
- These panels are expensive.

2.2.2. *Polycrystalline Solar Cells:*

In this, the cells are extracted by using wafers of recrystallized silicon as shown in Fig1 [6]. The salient features are:

- Manufacturing process of polycrystalline silicon is simpler and less expensive.
- Amount of silicon wasted is less compared to monocrystalline silicon [8].

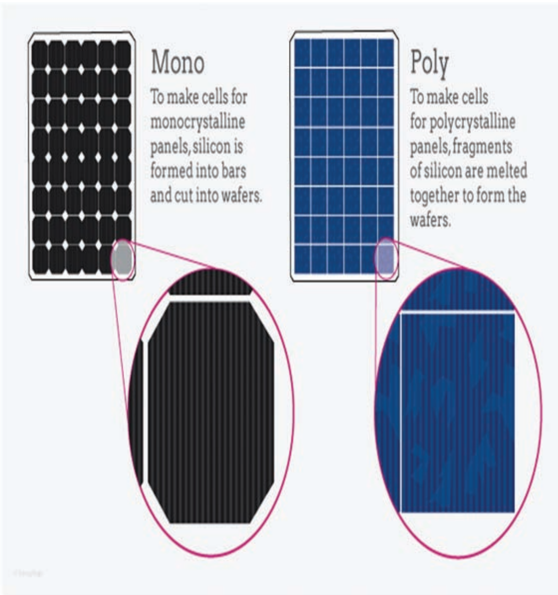

FIG 1: STRUCTURE OF MONOCRYSTALLINE AND POLYCRYSTALLINE SILICON SOLAR CELL

Some of the short comings are:

- Exhibits low heat tolerance, which affects performance of solar panels and hence life time.
- Efficiency is quite less, in the range of 13-16%.
- Lower space - efficiency, as it has to cover large surface for specified output[9].

Monocrystalline and thin-film solar panels tend to be more aesthetic because of uniform pattern of crystalline material[10].

2.2.3. *Thin- Film Solar Cells:*

In Thin-film type, by using ultra-thin layer of photovoltaic material deposition onto silicon substance cells are extracted as shown in Figure. 2. Based on different material depositions on a silicon substrate, they are further classified as [11],

i. Amorphous Silicon (a-si)

ii. Cadmium Telluride (CdTe)

iii. Copper indium gallium selenide (CIS/CIGS)

iv. Organic photovoltaic cells (OPC)

The salient features are:

- Efficiency ranges between 7-13%.
- Mass production is simple and low cost.
- High temperatures and shading impact on panels is less.
- Pattern of silicon is uniform which makes them look more appealing.

Some of the demirits are:

- Low space efficiency.
- Rate of degradation of panel is high compared to mono and polycrystalline solar panels [12,13].

FIG 2: STRUCTURE OF THIN-FILM SOLAR CELLS

3.0. ENCAPSULANT

To protect PV cells, from UV radiations encapsulation is needed as dicuseed in reference [14]. The glass cover is the top most layer of PV module and which may or may not consist of UV screen. Thus beneath the glass cover encapsulation is provided which acts as encapsulant/pottant and blocks UVA (315nm - 400nm) and UVB (

280nm - 315nm) radiations. Typical solar PV module is shown in Fig 3. The pottant in almost all monocrystalline (c-si), polycrystalline (pc-si) systems used is EVA [15]. Thus, PV module consists of several layers and have back sheet. Another layer of EVA that is not exposed to UV radiations and the supporting substrate complete the module encapsulation .

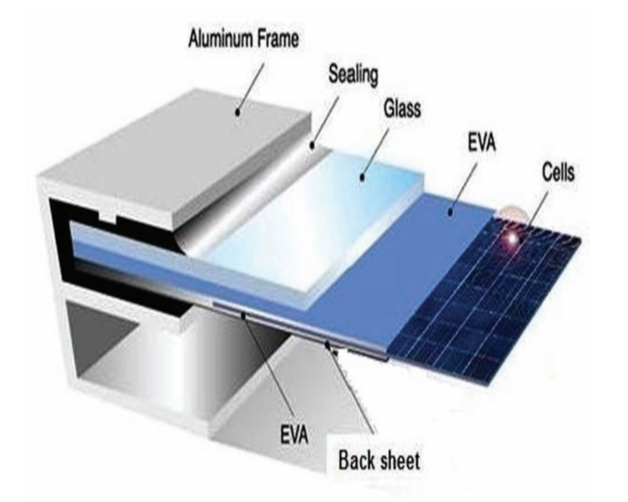

FIG 3: TYPICAL PV MODULE WITH EVA ENCAPSULANT

3.1 Purpose of PV Encapsulation

The main purposes of encapsulation in PV module are:

a) They provide support and positioning for circuit during handling, storage, installation, fabrication and operation in environment.

b) Also to achieve and maintain max optical coupling between PV cell and incident solar irradiance.

c) To provide isolation of PV cells and circuit components from exposure to degrading environmental factors like reactive compounds, hail, salt spray etc.

d) To achieve and maintain proper electrical isolation of circuit elements from operational and safety viewpoints, as potential above ground may exceed 1000V.

e) To provide ancillary electrical circuitry for the PV cells.

These are the main functions of encapsulation, which gives higher service life time and better efficiency of the module [16].

3.2. Properties of EVA used for encapsulation

Mainly mechanical, optical, chemical and electrical properties of EVA play a vital role. These are affected by solar radiation, thermal and humidity cycles and mechanical stresses [17].

- Mechanical properties like tensile & elongation supports design, creep resistance and wind load.
- Toughness or ductility are important in allowing the polymer to sustain thermal expansion or mechanical torsion without brittle failure.
- UV stabilizers movement is based on permeability [18], which affects movement of gases and moisture into the polymer.
- Morphological and structural changes can change optical clarity and absorbency of the polymer.

3.3. Degradation effects on EVA

The effects of UV irradiations on EVA polymer are: chain scission and cross-linking in polymers [19].

By exposing for long duration with moderate irradiation or short duration with highly intensive irradiation, both of these effects will eventually change the mechanical properties of EVA. Chain scission reaction reduces molecular weight, which in turn affects elongation to break as it is sensitive to reduction in molecular weight [20]. The other effect is cross- linking of polymer will increase stiffness which also decreases elongation to break.

3.4. Performance losses due to ageing

Discolorations of various EVA encapsulated PV modules is shown in Fig 4; In hot and dry or hot and humid climates, discoloration are reported that ranges from light yellow to dark brown [21], where maximum performance losses are reported.

From various studies carried out it is clear that discoloration of EVA reduces optical transmission, power output of the module and total service life time of PV module;

FIG 4: EVA DISCOLORATION FROM YELLOW TO DARK BROWN

which leads to corrosion of metallic circuits on solar cells and enhances metal ion-catalyzed photo degradation [22].

4.0. TYPES OF UV AGEING

An investigation as in the reference [23] has been made to compare and evaluate ageing methods for PV-EVA samples. One of the objectives is to choose a method which will reproduce more realistic degradation process by spectral output of sunlight.

UV ageing systems are broadly classified on the basis of light sources and equipment bulbs in specific. They are, Xenon arc systems, Carbon arc systems and Fluorescent systems. These can perform as per ASTM, ISO, DIN, MIL-STD.

4.1. Xenon Arc Systems

A Weather-Ometer uses a xenon arc light source to provide a radiation spectrum that simulates natural sunlight. The spectral irradiance of the filtered xenon lamp is in UV-Visible range (285-800nm). Glass filters around the xenon-arc modify the light spectrum to simulate the appropriate end use conditions. Some typical filters are Quartz, Borosilicate glass, High borate borosilicate, Type – S glass and Soda lime . Moisture is provided by a humidifier and direct spray, and temperature is controlled by heaters. Microprocessors monitor and precisely control the radiation applied to the test samples [24].

No direct correlation can be made between accelerated weathering duration and actual outdoor exposure duration. However, performance comparisons under the controlled conditions of accelerated weathering can be compared to documented performance of materials and coatings that have experienced extended periods of end use exposure.

A typical Xenon arc Weather-O-Meter of Atlas C-series is shown in Fig 5.

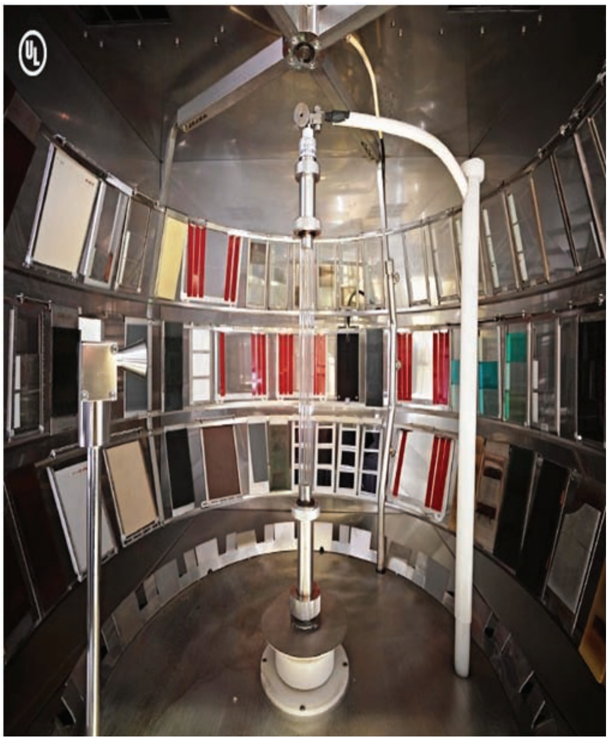

FIG 5: XENON ARC WEATHER-O-METER

4.2. Carbon Arc Systems

Carbon Arc systems provide insights into materials property changes in accelerated weathering conditions such as artificial light, sunlight, moisture and heat[25].

The Carbon Arc Weathering system provides more UV exposure at wavelengths below 300 nm than natural sunlight alone. Open-flame carbon system as in ref [26], tells that the light source tests light fastness durability of materials and coatings utilizing three pairs of carbon rods that emit ultraviolet, visible and infrared radiation when an electric current is passed between them. The Carbon Arc utilizes temperature control with a black panel sensor and sample conditioning water. Typical carbon arc system is shown in Fig 6.

FIG 6: CARBON ARC WEATHERING CHAMBER

4.3. Fluorescent UV Systems

The purposes of Fluorescent UV Systems is to predict the relative durability of materials exposed to outdoor environments [27]. Racks of samples are placed in the fluorescent UV chamber. Rain and dew systems are simulated by pressurized spray and condensation systems while damaging effects of sunlight are simulated by fluorescent UV lamps. The exposure temperature is automatically controlled. Cyclical weather conditions can also be simulated [28].

In reality, natural sunlight contains radiation from many areas of the spectrum. This includes both UVA and UVB, however the UVB radiation is at the lowest end of natural light and is less predominant than UVA. Since it has a shorter wavelength, it also has a higher energy. This makes UVB more damaging not only because it increase chemical reaction kinetics but also because it can initiate chemical reactions to occur which would not normally be possible under natural condition [29]. For this reason, testing using only UVB lamps have been shown to have poor correlation relative to natural weather testing of the same samples.

Accelerated fluorescent chamber is shown in Fig 7. It is speculated that EVA degradation rate is high in range of 285-295nm. Thus UVA or UVB alone doesnot contribute completely in degradation so the effect of combination of UVA and UVB appears to throw more light in degradation.

FIG 7: ACCELERATED FLUORESCENT CHAMBER

5.0 CONCLUSIONS

From the past studies and survey it is seen that EVA encapsulate degrades in the presence of UVA and UVB. This degradation leads to reduction in efficiency of PV module as PV cells output reduces. It is imperative that EVA needs to be evaluated as a material prior to its usage an encapsulant. In every standard 7-8 different exposure cycles are prescribed . However the applicable cycle w.r.t material used needs to be investigated and standardised. Further from the accelerated ageing studies, to arrive at the realistic degradation that would occur during service life or service life itself also forms a topic of research.

A way forward:

The literature survey indicated that, the use of nanofillers and additives to increase the life of EVA polymer is not reported and hence inclusion of nanofillers and additives in EVA is suggested as a way forward, as EVA plays a significant role in retaining the efficiency of PV modules, standardisation of EVA is suggested besides the .

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