Performance and Validation Study of TPO base Encapsulant PV Module

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Abstract - In the solar module, the encapsulant material is used to protect the solar cell from critical environmental conditions. Market of encapsulant material growing rapidly due to Superior properties and cost competitiveness. Most photovoltaic (PV) module manufacturers prefercross-linked ethylene vinyl acetate (EVA) as an encapsulant material for PV module. Some of growing encapsulant material like a non-cross-linked thermoplastic polyolefin (TPO) can be an alternative of EVA. Properties like high-volume resistivity, low leakage current, high dielectric strength and low lamination time makes TPO better than EVA. To ensure the long-term performance of encapsulant material, optical and adhesion properties have been tested. The optical properties represents transmission and absorbance of laminated TPO sample which is measured by using ultraviolet-visible spectrophotometer. Peel test helps to find adhesion Property of TPO material. Thepotential induced degradation (PID) is a major problem facing by PV industry at the module level. The encapsulant material plays an important role to reduce module level PID. To ensure the performance of PV module with TPO Encapsulant, PID test has been performed. This paper try to understand how the performed tests can help to validate the TPO based PV module.

Keywords –Encapsulant, Potential Induced Degradation (PID), PV Module, Thermoplastic polyolefin (TPO)

I. INTRODUCTION

In the past and untilrecently, the PV technology has made huge change in the development of module design and module components. The primary components of the solar module are the glass, encapsulant, solar cells, backsheet, etc.By changing the properties of the components of solar module the power generation, electrical efficiency, reliability, and module life has been enhanced. The encapsulants are critical in nature for the protection and long-term functionality of solar cells in PV modules. The role of the encapsulant is to provide adhesion in between PV cell to glass and PV cell to backsheet. The encapsulant materials have properties like optical transmittance, electrical insulation, stability under UV and weather condition and low thermal resistance.

In the Recent years, Different types of materials like EVA, thermoplastic silicone elastomer (TPSE),TPO, polyvinyl butyral (PVB),and ionomer have been used as an encapsulant material in the solar module. (Michele Carvalho de Oliveira, 2017) EVA has attracted most of the PV Module manufacturers due to its' cost benefit and suitable propertiesBut, there are some few drawbacks like acetic acid formation and delamination of module components (causes corrosion of metallization at High temperature and humidity),discoloration (reduce the light Transmittance) and bubbles formation in the EVA. (Baloji Adothu, 2019)

Commerciallydifferent types of material available as an alternative of EVA, but most often they are either very expensive or not performing well in long term-stability.At the similar cost price TPO is a good competitor for PV encapsulation and has superior properties which overcome the problems like a discoloration, absorption of water vapor or moisture and acetic acid formation. (Baloji Adothu, 2019)TPO does not need to a peroxide agent to ensure stable laminates during the PV module lamination. Also, TPO material provides non-crosslinking which keeps away all the side effects associated with peroxide assisted crosslink lamination process. (S.H. Schulze, 2010)

In this research paper, ultraviolet-visible spectrophotometer used for measuring the transmittance and absorbance of the TPO base laminated sample and peel testing machine used for measuring the adhesion strength. TPO encapsulant base glassglass bifacial module use for the PID test to understand which type of PID is more affected in the module either PID-(S) or PID-(P).

II. PROPERTIES OF ENCAPSULANT MATERIALS

Primary Properties ofTPO & EVA encapsulant material for long-term stability of PV module are shown in Fig. 1. EVA and TPO have similar transparency and UV durability for the cause of the discoloration in the PV module. The TPO shows good flexibility due to its low stiffness which helps the solar cells in thermal expansion and contraction. (Michele Carvalho de Oliveira, 2017)

The EVA has a tendency of formation of acid due to the amount of vinyl acetate (VA) present, but TPO does not cause any acid formation. Moreover, TPO has low water absorption property, which leads to eliminate problem of moisture ingression and metal corrosion in the PV module.TPOs' higher volume resistivity helps to resist Na+ in the PV module. (Cornelia Wiesmeier, 2013)

III. DURABILITY STUDY OF TPO ENCAPSULANT MATERIAL

A. Peel Test :

Expected lifetime of PV module needs to withstand from extreme weather conditions without suffering any degradation in PV module performance.

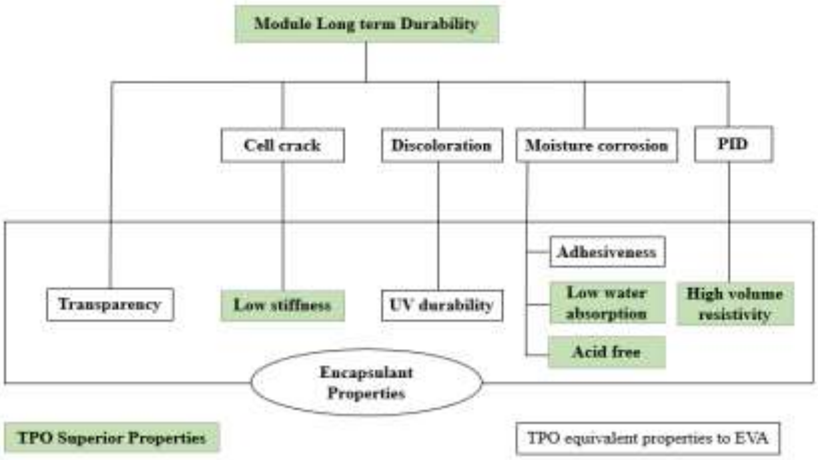

Fig. 1 Properties of TPO & EVA encapsulant materials

There are a number of tests available in the industry to verify the strength of multi-layered laminate PV Structure.Peel testing is used to qualify the adhesion between the encapsulant/glass and encapsulant/back sheet.

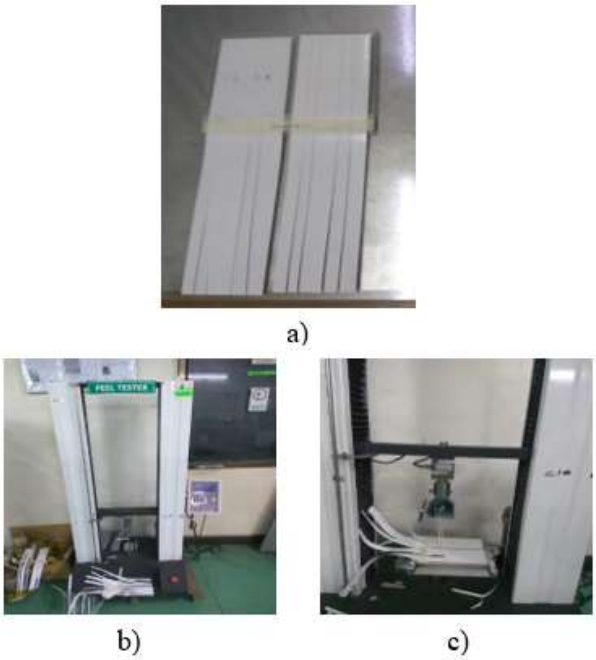

Fig. 2 Peel test a) laminated sample & b) and c) Equipment setup

We used glass, TPO and back sheet as a laminated structure of the module for the peel test. The lamination has been done at 145 °C and 100 kPa in several stages which take approximately 12.5 min.The peel testequipment setup shown in Fig. 2(b) and Fig. 2(c).TPO laminating structure sample is shown in Fig. 2(a).Theadhesion strength value between encapsulant to glass and encapsulant to back sheet are shown in Table I.

Sr. No	Peel Strength	Require strength (N/cm)	Measured Value force (N/cm)	Measured Value force (N/cm)	Measured Value force (N/cm)
1.	TPO to glass	70	163	165	168
Total Average			165 N/cm		
2.	TPO to Backsheet	80	112	117	113
Total Average			114 N/cm		

Average adhesion strength for encapsulant to glass and encapsulant to back sheet should be equal or more than Passing value. Peel test results shows Adhesion strength between layers are good for long term performance.

B. Ultraviolet–Visible Spectroscopy:

UV-Visible spectroscopy is used to determine the absorbance and transmittance of the different material. We take the (2.5*2.5) mm^2 size quarts glass and TPO material. Then laminating these two components using laminator.Teflon Sheet is made of fiberglass with high quality, has super nonstick surface and resist to high temperature. Teflon sheet has also resisted encapsulant outgassing. The lamination has been done at 145 °C in several stages like pins up (180 s) evacuation (210 s), pressure buildup (150 s) and pressure holding (210 s) times, for the TPO encapsulant material which shown in Fig. 3.

Fig. 3 Lamination Structure of TPO encapsulant for UV-Visible spectroscopy

Fig. 4 UV-Visible Spectrophotometer

This sample measurement has been conducted by placing them on the UV-Visible spectroscopy (as shown in Fig. 4). The optical transmittance and absorbance (Asma Shamim, 2019)were measured from 200to 1000 nm. Transmittance and absorbance spectrum in the range of 380 to 750 nm shown inFig. 5 (a) and Fig. 5 (b).

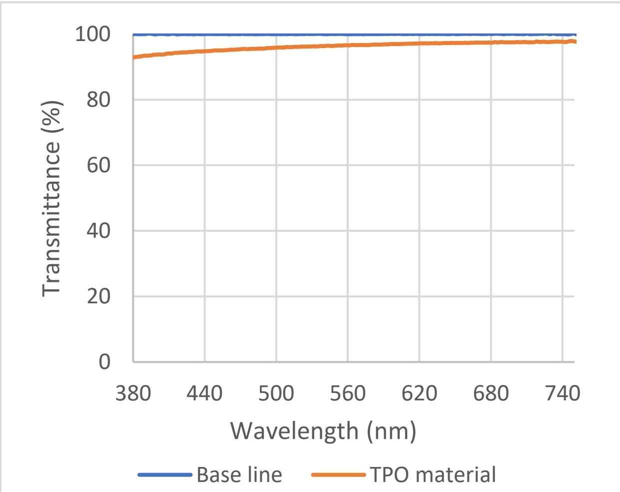

Fig. 5 (a) Transmittance of TPO sample invisible range

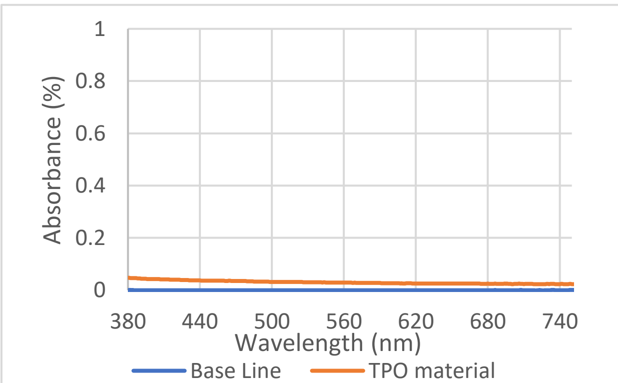

Fig. 5 (b) Absorbance of TPO sample invisible range

Results show that in the visible region we get 93 % transmittance and 0.033 % absorbance. From this we conclude that TPO has fulfilled the requirements of encapsulant and also shows better performance in visible region.

IV. RELIABILITY STUDY OF TPO BASED BIFACIAL PV MODULE

Potential Induced Degradation (PID) is the undesirable effect found in PV modules which reduces the power performance of the PV module. The primary factors for PID includes, high potential difference, heat, and humid conditions. Most of the PV modules experience these factors during their working condition. (Jorne Carolusa, 2019)Solar power plant has a floating (negative or positive) array potential difference with respect to earth which leads to migration of Na+ ions from the grounded frame to the PV cell. PID can be identified in system, module, and cell level. ARC(Anti-Reflective Coating)layer plays a significant role for the cell level PID.Optimum value of refractive index of the PV cell helps to decreasing the effect of PID.At the system level, the grounding of the PV system can be configured in such a way that there is no major Potential difference between system to earth. Moreover, High volume resistivity of encapsulant materials can be useful to reduce module level PID.

TPO is a high volume resistive encapsulant material. To examine the PID effect in bifacial glass glass module with TPO encapsulant PID test have been performed as per IEC 62804-1 standard. PID Test condition shown in Table II. This test results helps to understand how TPO base PV module perform under PID.

Table IIPID test condition

Parameters	Values
Voltage across	negative 1500 V
Temperature	85 ± 5 ˚C
Relative Humidity	85 ± 5 % RH
Exposure Time	96 Hours * 3 cycles

PID effect mainly described in two different types (I) PID-S and (II) PID-P. The PID-S can be identified by measuring shunt resistance of PV cell. The Na+ ion transmits into the stacking faults of the PV cell lattice.Due to this direct shunt path created and causes a significant decrease in the shunt resistance.The loss in shunt resistance affects in the Reduction of fill factor(FF) But, other characteristics like the short circuit current (I_{sc}) and the open-circuit voltage (V_{oc}) are not changed significantly in IV characteristics. (Jorne Carolusa, 2019)

The PID-P is due to polarization of ions at the rear side of PV cells. It is hypothesized that in bifacial PV cells the High resistive AlOx rear passivation layer not allow to pass the electrons,which cause in accumulation of electrons at passivation layer is neutralized by Na+ positive charges which deteriorating the functioning of the passivation layer. (Jorne Carolusa, 2019)PID-P type degradation,affects Series resistance of metal contact which leads to reduce Isc and Voc parameters, while negligible change found into a fill factor (FF).

Table III&TableIV shows the result of TPO based PV module after the PID test. The front side of PV module has power degradation of about 1.86, 3.11 and 5.81% for 96, 192 and 288hr respectively. Moreover, the rear side of PV module has power degradation of about 15.13, 24.84 and 43.30% at 96,192 and 288hr respectively. Results show that V_{oc} and I_{sc} of PV module changes but FF have a negligible change.

Table III PID test Results

Sample	Time (hrs)	P_{max}(W)	Isc (A)	Voc (V)	FF (%)
Glass-Glass (Front)	0	352.67	9.57	48.26	76.36
	96	346.10	9.48	48.3	75.59
	192	341.69	9.48	47.8	75.40
	288	332.18	9.29	47.57	75.17
Glass-Glass (Rear)	0	241.57	6.49	47.4	78.53
	96	205.02	5.6	47.07	77.78
	192	181.49	5.19	45.33	77.14
	288	136.97	3.95	45	77.05

Sample	Time (hrs)	ΔP_{max}(W)	ΔIsc (A)	ΔVoc (V)	ΔFF (%)
Glass-Glass (Front)	0	0.00	0.00	0.00	0.00
	96	-1.86	-0.94	0.08	-1.01
	192	-3.11	-0.94	-0.95	-1.25
	288	-5.81	-2.93	-1.43	-1.56
Glass-Glass (Rear)	0	0.00	0.00	0.00	0.00
	96	-15.13	-13.71	-0.70	-0.95
	192	-24.87	-20.03	-4.37	-1.76
	288	-43.30	-39.14	-5.06	-1.87

However, our aim is to understand the PID effect Over glass glass bifacial PV module which uses a TPO based encapsulation.Aftereach PID test Cycle electroluminescence (EL) test was performed, which helps to understand the degradation and defects due to PID in the glass glass bifacial PV module as shown in Fig.6.

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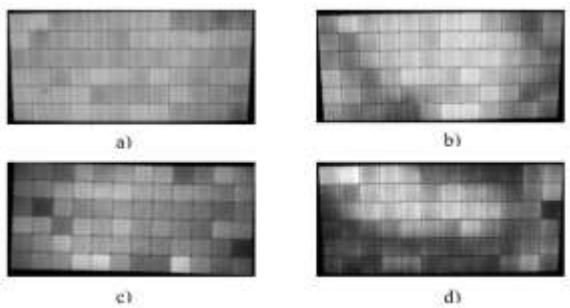

Fig. 6EL Images a) 0 hrs Module, b) 96 hrs Module, c) 192 hrs Module, d) 288 hrs Module

V. CONCLUSION

The reliability study of TPO based encapsulant module has been successfully conducted and it shows lower lamination cycle time of 12.5 min.UV-visible spectroscopy results show that the TPO based encapsulant have 93 % transmittance and 0.033 % absorbance in the visible region.TPO encapsulant gives better peel adhesion strength of about 165 N/cm for the glass-encapsulant and 115 N/cm for the backsheet-encapsulant. The PID test helps to understand the degradation of front side as well as rear side in the glass glass Bifacial PV module. EL images after each PID cycle shows no Visual defects. Results shows that front side degradation is 5.03 % and the rear side degradation is 43.30 %. Severe effect of PID exhibited at rear side attributed to surface polarization effect (PID-P), which cause in reduction in the fill factor at nearly same V_{oc} and I_{sc} parameters. These successive test results validate that the TPO can be an effectiveencapsulant material in PV module.

VI. REFERENCES

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[*****Degradation(%) = ((Reference value – Instant value) / Reference value)*100
Reference value taken as 0 hrs.
Instant value taken as 96,192 and 288 hrs.]