A Review for Assessment on Solar Panel Degradation

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Abstract

The installation of solar panels is now being carrying out not only in cities, but also in rural and backward regions all over the world, especially in India. The aim is to achieve rural electrification in a self-contained manner in remote areas, which may or may not have access to the grid. In this context, it becomes very important to ensure that the installed solar panels last for the number of years they have been designing for, typically 25 to 30 years. For solar panel technology to be an economically viable alternative for conventional electricity, it is essential that they last at least this long. However, inclement weather, pollution, unevenly distributed illumination, high humidity and widely varying temperatures can all have a deleterious effect on solar cells. In this paper, solar panel degradation and its causes are discussed, as it is the important topic of interest.

Introduction

The solar power industry is seeing a massive expansion in India. The amount of power generated from solar increased from 2,650 MW during the middle of 2014 to over 22 GW as on by the end of 2018, which is an eightfold increase in four years. In fact, India has achieved the 20 GW mark in 2018, four years ahead of the originally envisaged plan. [1], [2] Two of the reasons for this is that the efficiency of solar cells has seen major improvement, their mass production capacities have been enhanced and therefore solar cell technology has become much more cost effective.

Solar technology has evolved over the last 3 decades, and *laboratory based* degradation analysis reports for the early solar panels are available from the 1970s. However, the first large scale PV solar modules were only installed approximately 25 years ago. Therefore, there are relatively fewer publications on field modules and their degradation patterns over the *complete lifetime* of the solar cells. This, coupled with the different types of solar cell technologies coming up in the market, makes it rather difficult to come up with an estimate of the best technological choice, vis a vis longevity and performance. However, this article is an attempt to present to even the lay readers the different solar cell technologies available, followed by the parameters, which should be keep in mind, when investing in solar cell technology. It is important to note that we are seeing an exponential growth in solar cell R & D, and therefore, many of the issues highlighted in this article may be resolved in the next few years, as the technology matures further.

The solar panel performance is acceptable if the solar panel is giving at least 80 % of the rated output. If the output falls below this, it is considered to be degraded, and most warranties from the solar cell companies will cover the period of 25 years of operation at 80 % output. However, according to an US report, reclaiming warranties in the event of solar panel failure has proved to be tricky in the past, because many of the small-scale solar panel manufacturers were not able to sustain their business and filed for bankruptcy between 2007 and 2012. Naturally, it becomes almost impossible to reclaim damages from a company after liquidation. Therefore, it is recommended to install solar panels from reputed companies. Luckily, present field based studies on crystalline solar cells have shown that more than 70 % of the solar panels last their full lifetime.

The solar cells, which were install three decades earlier, were based on crystalline silicon. Silicon was the original material used to manufacture solar panels. In the last three decades, many other materials based on the photoelectric effect have been develop for solar cell technology. The table 1 [3] gives an overview of the various solar cell technologies being researched at present. Along with the type of the technologies, it also shows the typical values of their yields. The highest efficiency is that of the monocrystalline solar cells. Silicon mono-crystals are grown by the Czochralski process, and sliced into thin wafers. They are then chemically etched, subjected to diffusion, metal contact deposition and given antireflection coatings. These cells, despite having the highest yields, are much more difficult to manufacture in bulk, and hence the polycrystalline solar cells are used in most solar panels today. The polycrystalline silicon cells consist of multiple small silicon crystals. It is obtained by solidifying a large block of molten silicon to orient crystals in a fixed direction. This block is then sliced into wafers and used to create the solar cells. Their yield is 4 to 5 % lower than monocrystalline solar cells, but the ease of manufacture offsets this demerit. Amorphous silicon material, used in thin film solar cells, has a disordered structure and even though the manufacturing processes are cheap, their efficiency, as shown in table 1, is much lower than crystalline silicon. This material can only be used as thin films.

The Cadmium Telluride (CdTe) thin film solar cells are cheaper and easier to manufacture than silicon cells, and have a high conversion efficiency of around 20 %, but are restricted by their toxicity and the resultant need for responsible disposal. Cadmium is a suspected carcinogen and moderately poisonous for humans and animals. Commercially, the 20% conversion efficiency of CdTe cells is possible because they have an ideal band gap of 1.45 eV. However, grain boundary defects in the thin films can affect the movement of minority charge carriers and decrease the efficiency of the solar cells.

CIS and CIGS also belong to the category of thin film technologies, and show a lot of promise. They are also reported to be more robust than many other thin film technologies, and do not degrade easily. However, the presence of the element Indium, which is hard to find, may restrict the mass production of these material. Further, the robustness and resistance to degradation of thin film technologies when subject to the elements are still a matter of research.

Gallium Arsenide solar cells have a structure similar to silicon, and are lightweight. They have a direct band gap as opposed to the indirect band gap of silicon, which enables efficiency in light absorption and emission. They also have better tolerance towards high temperatures, and are expected to replace silicon technology in concentrated solar power applications. However, they are more expensive to manufacture. It is envisaged that this might be an excellent material for space application where, performance, not cost is the criteria.

Organic solar cells are bio-degradable and an interesting option, however the current low efficiencies prohibit their use in commercial solar panels. Nano wires based solar cell technology is still very much in the research domain, yet it is touted as the solar panel choice of the future. This is because the theoretical limits to a silicon solar cell efficiency is around 28 %, and as can be seen from table one, the solar technology of today is already hovering around 25 %. It is expected that nanomaterials would push the boundaries of the maximum solar cell efficiency further. However, until this happens, it is clear that silicon based solar technology, which currently account for more than 80 % of the solar infrastructure today, will continue to be the first choice of consumers.

Table 1. Various Solar Cells and its efficiency [3].

Solar Cell Type	Commercial Conversion efficiency %
Monocrystalline silicon cells	25 ± 0.5
Polycrystalline silicon cells	20.4 ± 0.5
Amorphous silicon cells	10.1 ± 0.3
Cadmium Telluride cells (CdTe)	18.3 ± 0.5
Gallium Arsenide (GaAs)	
Copper, Selenium and Indium cells (CIS)	19.3
Copper Indium, Gallium and Selenium cells (CIGS)	19.6 ± 0.6
Organic solar cells (thin-film)	10.±0.3
Nanowires based solar cells	13.8

The basic structure of the solar panel is shown in Figure 1. It consists of the solar cells covered by a polymer encapsulated. The front is covered by tempered glass bordered by a frame, and the back has a back sheet connected to a junction box. The solar cells consist of photovoltaic cells and diodes with interconnects in series or parallel. The encapsulated is usually ethylene vinyl acetate (EVA) or a clear silicone. The back sheet is usually composed of a stiff material such as Tedlar. The glass front cover is often coated with Transparent Conductive Oxides (TCOs) to enhance the solar ray's absorption onto the cell. Each of these components are subject to the various environmental stresses, primarily UV radiation, humidity, mechanical erosion and temperature. Listed below are the most common forms of degradation of the solar panel. The defects generated due to degradation tend to result in reduced module output, safety issues and sometimes result in complete failure before the full lifetime of the solar cell.

The various types of degradation for solar cell modules are broadly listed as [5] :

Degradation due to moisture intrusion

Moisture intrusion into solar panels can cause a host of issues. It can lead to chemical reaction with the EVA encapsulated under UV light and high temperatures, leading to the formation of acetic acid. The acetic acid can cause the discoloration of the encapsulated. The color changes to yellow and finally brown. The uneven distribution of this discoloration leads to partial shading of the solar cells. This can be potentially hazardous because it can cause the cell under the shaded region to go into reverse bias, creating a high resistance region. The dissipation of heat here gives rise to hot spots, which can damage the functioning of the cell. The acetic acid itself can also corrode the solar cell material. Many manufacturers, in their haste to reduce the cost of the solar cell unit, tend to use cheap polymers, which tend to absorb moisture easily, and lead to higher risk of long-term failure. It has been reported that the only way to reduce moisture intrusion is to have a layer of desiccants at the interface between the glass and the frame. Some papers have reported better results when EVA is replaced by clear silicone, which also has the bonus of having better spectrum of light transmission.[6]

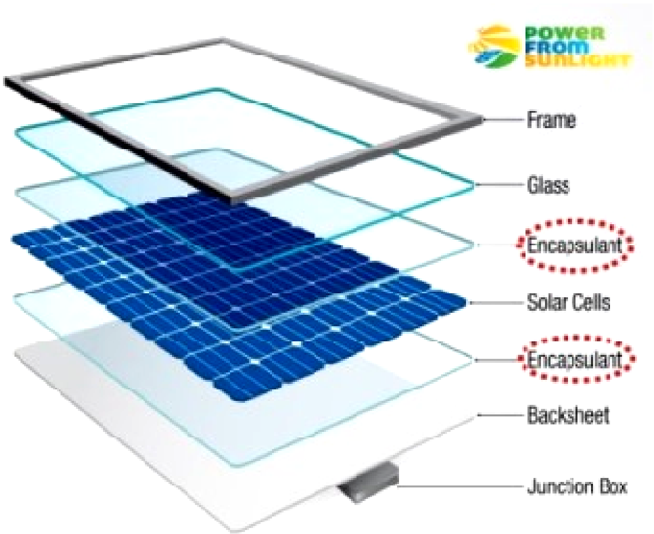

Figure 1. Components of the solar panel [4].

Degradation of packaging materials

Cracks in the glass can occur, especially during transportation and setting up of the solar panel. The back sheet, made of TEDLAR, has a possibility of getting warped and discolored. However, these are comparatively rare occurrences as compared to the encapsulated browning. While buying units, do check if the glass covering of the solar cell panel is made of tempered glass. Tempered glass is more likely to be able to withstand harsh weather conditions for long periods without damage, and is highly recommended.

Loss of adhesion of the solar panel encapsulant

Loss of adhesion or delamination of the encapsulated introduces air pockets within the structure. This has two-fold effect; it helps moisture entry into the panel, and creates a change in the refractive index, which reduces the amount of light into the solar cell, thus affecting the electrical performance and electrical safety of the solar panel. A report on the degradation modes of a set of solar panels from China listed delamination as the single most important cause of degradation. However, well-manufactured solar panels attend to the lamination aspect, and silicone technology is one, which can be layered on top of the solar cell, leading to better adhesion.

Degradation of cell/module interconnects because of thermo-mechanical fatigue

Solar cell assemblies have silver bus bars connected to copper strips, via various automated or semi- automated soldering technologies. These solders act as mechanical supports, heat dissipation path and electrical interconnects on the solar panel. Some amount of residual stress remains in the soldiering joint due to the manufacturing processes, and further stress can occur due to thermal cycling tests carried out on the module, as well as high temperature regions. The coefficient of thermal expansion of the silicon substrate is different from those of the metals, and hence when these panels are subjected to wide changes in temperatures, thermo-mechanical induced non-linear deformation of these interconnects is possible, which over time can build up cumulatively, causing failure.

Degradation of semiconductor device

The photovoltaic cell itself is least likely to fail due to manufacturing defects, as this is the part of the panel which manufacturers are most concerned about. However, many of the solar cells, which were installed 20+ years ago, had thicker semiconductor. Enhancement in efficiencies have made manufacturers cut down on the thickness of the crystalline solar cells. The resistance of thin film solar cells under adverse atmospheric conditions are still a matter of research. It is expected that materials such as gallium arsenide, which has more improved material properties as compared to silicon, may perform well in thin film form as well. Field studies after some more years are expected to shed light on the particular challenges of thin film solar cell technology. Another form of degradation related to the semiconductor device is Potential Induced Degradation (PID), which actually affects the encapsulated. This is caused due to the voltage difference between the series solar cells, which creates electric stress across the encapsulated material. Once again, it is important to use an encapsulated, which can withstand long-term low level of electric stress.

Erosion of front glass coating

The front glass can be coated with grime and dust, bird droppings etc. It also takes the brunt of storms, rain and atmospheric pollution. All this can cause the Transparent Conductor (TCO) coating to erode. This lowers the efficiency of the solar cell by reducing the amount of light absorbed into the glass. Current solar cell modules have special UV protection enabled glass and encapsulated, which should be checked. Regular cleaning of the glass should be initiated, and special attention should be given to the installation of the panel so that partial shading of the panel due to surrounding structures does not occur. It is important that the frame should also be airtight, so that moisture does not seep in and cause damage.

After becoming familiar with the common causes of degradation, let us look at a couple of the studies, which assess the severity of each of these modes in real life studies. The Figure 3 displays a survey in China, which looks at the percentage of each degradation mode present in the solar cell modules. It shows that delamination and discoloration of the encapsulated together constitute 54 % of the degradation. Another study, which looks at the causes of failure in 1865 solar modules in Arizona, USA, showed that the primary cause of solar panel failure is due to browning of solar panel encapsulation.

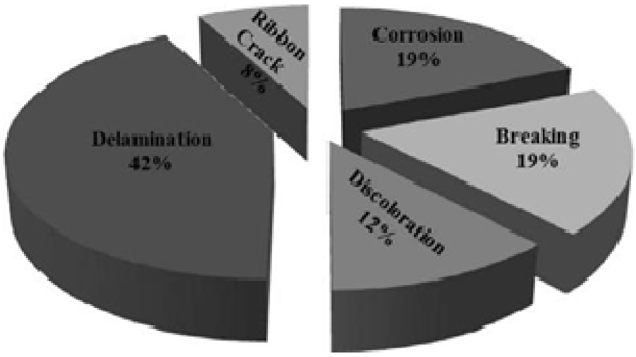

Figure 2. Silicon PV modules: representative of degradation modes in 2012 [5].

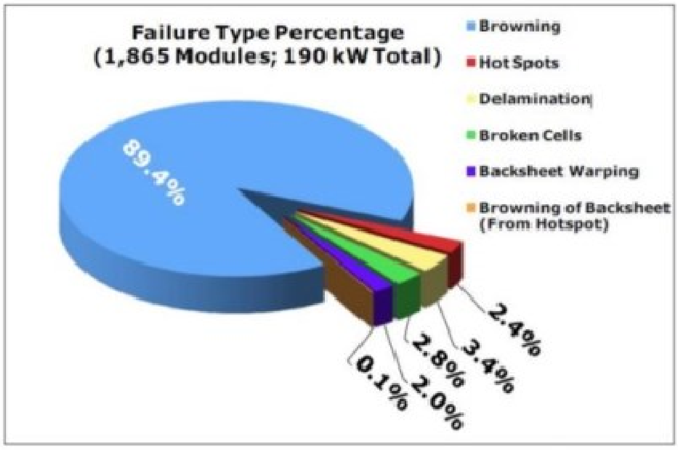

Figure 3. American solar cell degradation modes [7], [8].

Finally, a list of the various modes of solar cell degradation is reported in Figure 4, along with their respective percentages.

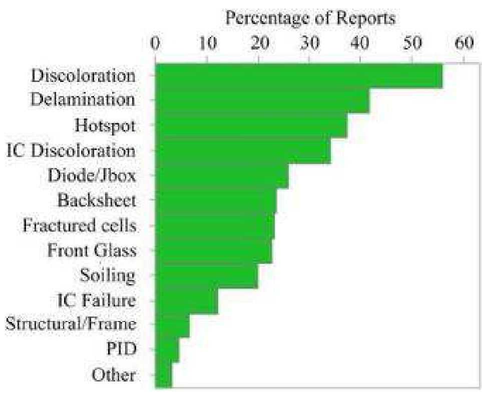

Figure 4. Solar cell degradation reported statistics.

The percentage of various degradation modes reported in literature [3]

Conclusion

From these studies, it can be seen that the technological challenges at present are centered mostly on the encapsulated, which is the cheapest part of the solar panel. Even though EVA is the most prevalent encapsulated in the solar panel market today, it is highly recommended to transition to a silicone based encapsulated. By paying a little attention to the quality of the components of the solar panel system, rather than only their electrical specifications and costs, we can make a more judicious choice for our 25-year investment in free and renewable solar energy.

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