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INVESTIGATING CRYSTALLINE SILICON CELL-BASED SOLAR PHOTOVOLTAIC MODULE DEGRADATION IN THE MALTESE CLIMATE

C. Fenech[1], C. Yousif[1] and C. Caruana[2]
[1]Institute for Sustainable Energy, University of Malta, Triq il-Barrakki, Marsaxlokk MXK 1531, Malta,
Tel: (+356) 21650675, (+356) 21652249, Fax: (+356) 21650615
Corresponding Author E-mail: charles.yousif@um.edu.mt
[2] Industrial Electrical Power Conversion, Faculty of Engineering, Room 224, Engineering Building, University of Malta, Msida, Tel: (+356) 23402438

ABSTRACT

Photovoltaic (PV) modules may experience degradation as soon as they are exposed to outdoor weathering conditions. This occurs from the early stages of installation up to the decommissioning stage. PV degradation exists in many forms, some of which occur during the first few months of exposure, while others depend on the materials' susceptibility to continuous weathering. The Maltese climate is characterised by high levels of solar radiation, humidity and temperatures. These three factors together with coastal region conditions may affect the performance of the PV module during its lifetime. The aim of this research was to gain an understanding of the visual degradation modes together with the rate of loss in maximum power over a number of years of operation. PV modules operating over a range of one to twenty-eight years were analysed. This would provide a clear picture to the installers and investors on the expected degradation in power per year for warranty and energy yield purposes. The results showed that modules with more than eighteen years of operation experienced a greater degradation rate per year in maximum power, when compared to those up to fourteen years operating under Maltese climatic conditions. This implies that the newer modules use improved materials such as UV-stabilised encapsulation, protection against humidity ingress, among others.

Keywords: photovoltaics, degradation, encapsulant, discoloration, delamination, cracks, Maltese climate.

1 INTRODUCTION

The global drive towards a reduction in greenhouse gas emissions, price reductions and fiscal incentives resulted in an exponential increase in photovoltaic installations [1]. PV installations accounted for over 182 GWp of global renewable energy generation by end of year 2014 [2] [3].

Photovoltaics are regarded as a sound investment in Malta, because such systems experience stable solar climate with very low annual variance, high system reliability together with ease of installation and very low maintenance, as well as a high return on investment. This proven technology is backed by the manufacturer's warranty of over 20 years, together with a guaranteed feed-in tariff for a number of years.

Photovoltaic module power degradation occurs from the time of installation as soon as they are exposed to sunlight up to the end of life, which is the decommissioning stage. Degradations are classified by their types, which occur at different stages throughout the module lifetime. While mitigation measures can be adopted to reduce this negative effect on the energy yield, some degradation types are intrinsic properties of the materials themselves.

The Institute for Sustainable Energy has installed or used a number of photovoltaic (PV) systems over the last three decades. These PV modules have been exposed to the Maltese climate.

The Maltese Islands have lately experienced a large increase in PV installations in a relatively short time span, and this is expected to remain so for the years to come, provided that the right incentives are made available. As shown in Figure 1 the cumulative installed capacity in Malta at the end of year 2015 reached 73.4 MWp, up from 54.8 MWp in year 2014. By the end of year 2011, a total of only 5.3 MWp were installed. This means that the total PV installations in 2015 represent a fourteen-fold increase [4].

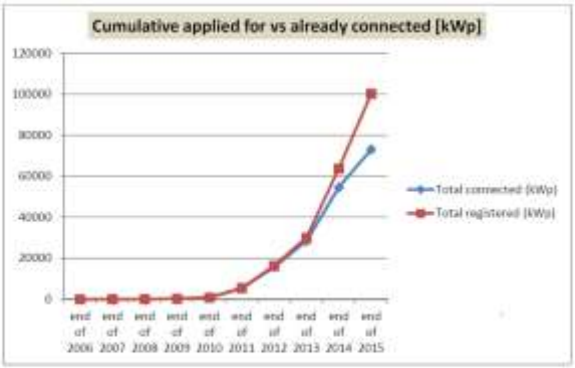

Figure 1: Cumulative PV installations in Malta [4]

The PV modules are certified according to IEC standards. IEC 61215 standard covers module testing regarding the quality and the behaviour of certain materials under laboratory testing conditions. However the standard does not address the reliability nor the performance over the module's lifetime.

This paper presents the degradation both in visual and electrical characteristics of PV installations covering three decades of operation. This information will provide investors with the expected performance over the lifetime of the system and will also provide a clear picture to manufacturers and installers on the warranty expectations. Moreover, it will give a clear indication on the expected performance degradation in PV power production and therefore enable authorities to forecast the real contribution of PV electrical generation to the renewable energy target for year 2020. In doing so, extra efforts may be taken to complement any expected drop in energy production by fresh installations, so that the best outcome is achieved for the 2020 target.

2 METHODOLOGY

This paper focused on extracting module electrical characteristics which consists of the current versus voltage (I-V) curve, from which the module's maximum power output and fill-factor will be investigated to assess the extent of module degradation, when compared to the nameplate specifications. A detailed visual inspection for degradation signs such as encapsulant browning and delamination together with junction box failures has been carried out. The results are presented according to the age of the modules, whilst in operation under the Maltese climate.

Solar modules carry a nameplate with electrical characteristics such as maximum power, open circuit voltage and short circuit current among others. These parameters are measured under standard test conditions (STC), which are specified at a temperature of 25°C, an irradiance of 1000 W/m2 and an air mass (AM) of 1.5.

The I-V curves of the aged modules have been measured outdoors under natural sunlight, where control over cell temperature and irradiance levels would not be possible as in a laboratory setup. The extracted I-V curves will have different conditions than those specified at STC. Therefore various parameters such as temperature and irradiance values were recorded. The current and voltage STC values could then be found using correction factors as specified in existing methodologies of relevant IEC standards [5] [6]. Detailed calculations may be found in a separate publication [7]. The calculated degradation rate was used to quantify the loss in power production of PV systems on a national level due to aging. Statistical data on PV installations was then used to quantify the amount of added PV capacity required to bring the full potential of installed PV power in Malta back to its original capacity by 2020.

The modules were also subjected to other tests such as an electrical insulation test as specified in IEC 61215, to determine the state of the encapsulant. A PV module encapsulant acts as electrical isolation between the current carrying conductors and the outside world. Failing the insulation test would mean that the module has become a safety hazard.

3 RESULTS

The results of a number of analysed photovoltaic (PV) modules operating under the Maltese climate from one year up to twenty-eight years are presented in this section. A short description of the visual defects, including encapsulant browning and delamination is included.

The current versus voltage (I-V) curves, normalised to standard test conditions (STC), are then presented for the electrical analysis, together with an average value for the percentage degradation in power per year assuming a linear degradation over the years.

3.1 TWENTY-EIGHT YEAR MODULES – ARCO SOLAR M55

- Visual Inspection

Encapsulant discoloration is evident on all of the examined mono-crystalline ARCO Solar M55 PV panels covering over 80% of the cell area. EVA cell browning appears to be less next to the aluminium frame and increases towards the centre of the module. The cell area in the middle row experienced over 90% EVA browning. Encapsulant delamination is evident on all of the modules cells. Delamination at the busbars is also evident on all of the cells. On the rest of the cells area this phenomenon is not homogenous. Delamination on the cells located at the module edge seems to increase towards the centre of the PV panel. Figure 2 shows the front of the PV module.

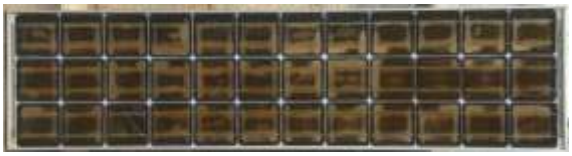

Figure 2: ARCO Solar M55 Module

Figure 3 shows two cells where cracks are visible due to the lack of encapsulant browning along these lines. Micro-cracks not visible to the naked eye could be present in PV cells. They occur during the soldering process or while handling the PV module and the crack increases during the module's lifetime [8].

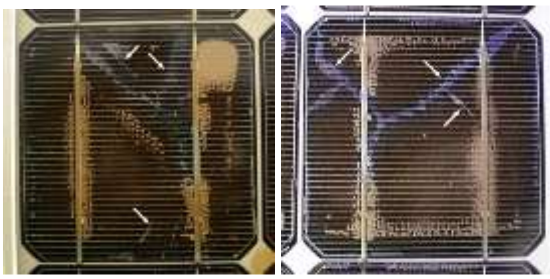

Figure 3: Cell Cracks

Damage to the PV cells which lead to crack propagation across the whole cell was caused during the installation of the PV modules as shown in Figure 4. The round inactive area at the edges of the cells was caused by the drill that was used to make holes in the metal frame and the aluminium structure of the module during installation. It seems that no protective measures were made to avoid the drill bit from damaging the back tedlar layer and consequently the cells themselves. Cracks from these damaged areas seem to spread in different directions towards the cell's edges. The module with this avoidable damage did not result with the lowest maximum power among the six analysed PV panels, as cell cracks may not necessarily cause a significant loss in power.

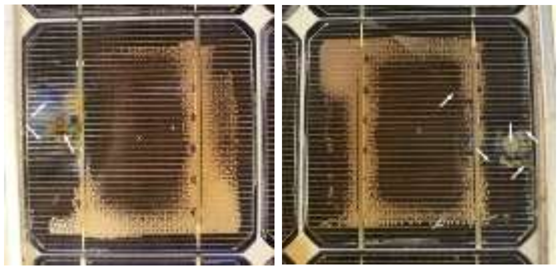

Figure 4: Cell cracks caused during installation

The backsheet of a number of PV modules experienced tearing as shown in Figure 5.

Figure 5: Backsheet tearing

As shown in Figure 6 the junction box's cover experienced substantial damage due to weathering. Humidity ingress and corrosion of the metal contacts are also evident. The bypass diodes inside the junction boxes were all functional.

Figure 6: Junction boxes

- Electrical Analysis

Figure 7 presents the current versus voltage (I-V) curves for the six ARCO Solar modules under STC conditions, ‘PV1’ to ‘PV6’. The curve with the title ‘I’ is the I-V curve as specified in the PV module datasheet. The short circuit current ranged from 2.57 A to 2.71 A with an average of 2.66 A. This represents a 20.6% degradation from the nameplate value of 3.35 A. The open circuit voltage values varied between 21.45 V and 22.03 V with an average of 21.58 V, which is 0.55% lower than the nameplate value of 21.7 V.

The fill factor (FF) range was between 0.54 and 0.57; this experienced a degradation of 23.8% with a nameplate value of 0.73 and a measured average value of 0.56.

The range of maximum power (PMAX) was between 30.31 W and 32.96 W, with an average value of (31.93 ± 1.77) W, which is a 39.8% drop from the nameplate value of 53 W. Hence, the percentage power loss per year over a twenty-eight year period was calculated as (1.42 ± 0.08) %/yr.

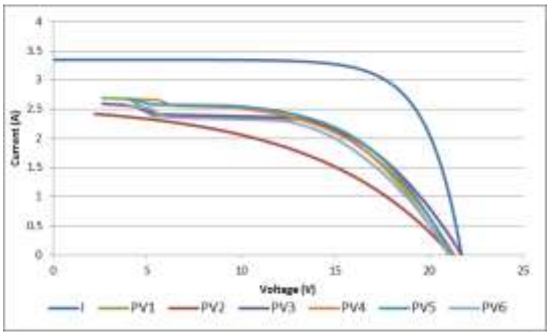

Figure 7: ARCO Solar M55 I-V Curves

3.2 EIGHTEEN-YEAR MODULES – PHOTOWATT BPX 47500

- Visual Inspection

The multi-crystalline Photowatt BPX 47500 PV modules suffered no encapsulant discoloration. EVA delamination is not evident in any part of the cells area. The BPX 47500 PV module uses full glass encapsulation. A number of modules suffered from glass substrate shattering, probably due to excessive expansion due to heat caused by solar radiation. Figure 8 shows the front side of a Photowatt BPX47500 module.

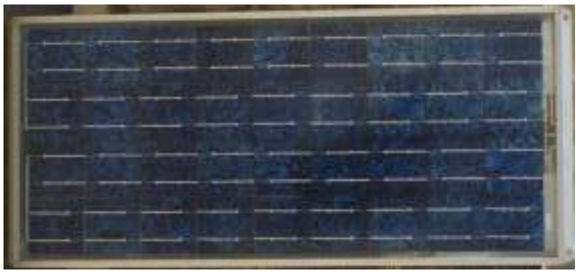

Figure 8: Photowatt BPX 47500 Module

- Electrical Analysis

The average short circuit current (I_{SC}) of the modules with an intact substrate was measured at 2.65 A, which represents a drop of around 13% from the datasheet value of 3.05 A. The average open circuit voltage (V_{OC}) was at 21.13 V, which is 0.33% less than the specified value of 21.2 V. The average maximum power (P_{MAX}) was at (34.88 ± 1.79) W, compared to the datasheet value of 46W this results in a percentage drop per year of (1.34 ± 0.07) %/yr. Figure 9 shows the corrected I-V curves to standard STC for four modules.

The short circuit current of the module with a shattered glass substrate (PV3) was calculated at 2.53 A, which is 17% less than the specified value of 3.05 A. The open circuit voltage was at 20.92 V, which is 1.32% less than the datasheet value of 21.2 V. The maximum power stood at (29.63 ± 1.52) W, which is 35.58% less than the datasheet value of 46 W. This resulted in a further decrease in P_{MAX} of 11.5%.

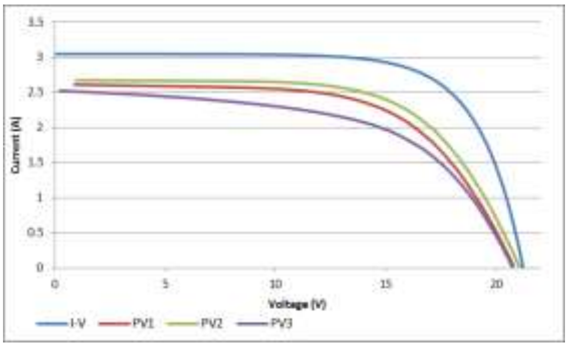

Figure 9: Photowatt Eighteen Year Modules I-V Curves

3.3 TWELVE-YEAR MODULES ANALYSIS – SOLARPOWER LTD SPL 60

The SPL 60 modules were assembled in Malta by the ex-Solar Power Ltd. utilizing 36 mono-crystalline PV cells connected in series achieving a rated power of 60 Watts at 3.7 A. The SPL 60 module experienced encapsulation browning covering most of the cells area. Bubbles in the encapsulation on the front side of the module were visible in small amounts at the cells' edges.

Figure 10 presents the I-V curves of the two analysed PV modules normalised to STC conditions. The short circuit current (I_{SC}) for PV1 was calculated at 3.85 A while PV2 was 3.74 A, averaging at 3.8 A. This represents a drop of 15.6% from the specified value of 4.5 A. The open circuit voltage (V_{OC}) averaged at 20.06 V, which is 0.3% higher than the datasheet voltage of 20 V. The maximum power (P_{MAX}) of PV1 was at 55.2 W while PV2 was at 53.77 W, averaging at (54.48 ± 2.44) W. Over a twelve-year period this represents a percentage loss per year of (0.77 ± 0.03) %/yr.

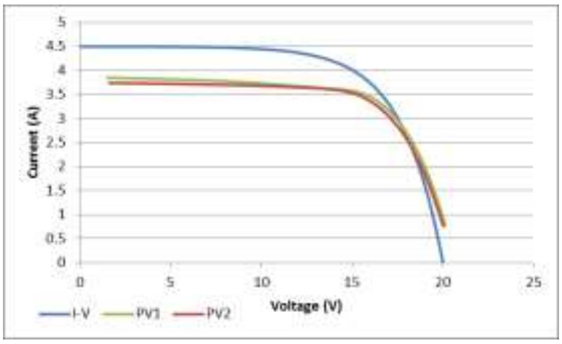

Figure 10: SolarPowerLTD SPL 60 Twelve Year Modules I-V Curves

3.4 SIX-YEAR MODULES ANALYSIS

These relatively new modules utilize 48 multi-crystalline PV cells each 156 mm by 156 mm in size, achieving a maximum power (P_{MAX}) of 180 W at STC conditions. A glass sheet is used as the superstrate. The aluminium frame is silver in colour. The module certifications include IEC 61215 and IEC 61730.

- Visual Analysis

All of the analysed PV modules encapsulation experienced discoloration. Browning over the whole module front side area was clearly evident. No encapsulation delamination was visible and neither aluminium frame corrosion.

- Electrical Analysis

Figure 11 shows the I-V curves of the six modules, which had their electrical characteristics analysed. The maximum power varied between 166.45 W and 169.63 W, with an average of (167.97 ± 8.10) W. This represents an average percentage drop per year of (1.11 ± 0.05) %/yr.

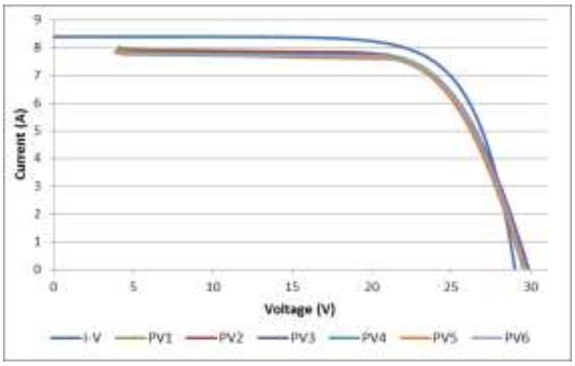

Figure 11: Six Year Modules I-V curves

3.5 EFFECT ON THE EU RENEWABLE ENERGY TARGET

Based on data provided in the NREAP for Malta of 2011 [9] together with the prominence to the contribution of PVs of half the target of 10% renewable energy share [10], the projected year 2020 target of 194.3 MWp was calculated. The percentage degradation per year in maximum power will have an impact on this target; an added capacity beyond the 194.3 MWp will be needed to truly reach the 5% contribution of renewable energy from solar PV systems.

The average degradation rate was calculated considering the modules exposed to the Maltese climate between five and twenty-eight years. This results in a degradation rate of 0.91 %/yr. A loss of 6.45 MWp was calculated as shown in Figure 12. This is equivalent to around 14 football fields.

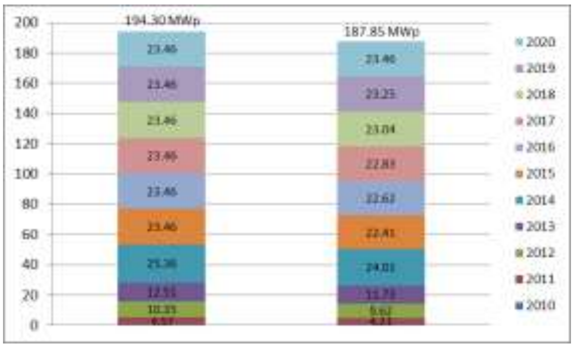

Figure 12: Average Degradation per Year Analysis

4. CONCLUSIONS

Encapsulation discoloration and severe delamination were evident in the twenty-eight year modules, while the two twelve-year systems and the six-year modules had clear signs of encapsulant browning only. Modules between six and fourteen years have experienced an average degradation in power per year less than the older modules showing an improvement in module materials and assembly. The percentage degradation in P_{MAX} per year ranged between (1.42 ± 0.08) %/yr and zero loss in power when compared to the module nameplate value. The average value was found to be (0.91 ± 0.05) %/yr.

Following the determination of degradation rates representing the average scenario expected for a PV module operating under the Maltese climate, the national renewable energy targets for the year 2020 were investigated. A linear increase in newly installed PV systems was assumed up to the target date with a cumulative installation of 194.3 MWp. The degradation rate was applied on the yearly installations from the year 2010 resulting in an overall degradation value which has to be considered in order to reach the EU renewable energy sources target. Hence, in order to reach the declared share of 5% renewable energy from photovoltaics in 2020, a total installed peak power of 194.3 MWp is needed with an additional 6.45 MWp to cater for the expected degradation over the years leading to 2020.

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