Field Based Photovoltaic Power Degradation Rates In Oman- Case Study

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***Abstract*— Due to increase in demand for electricity usage all around the GCC there has been emphasizing on the usage of alternative sources of energy i.e. using solar, wind and ocean etc. on the other side accurate prediction of power delivery is crucial for estimating the performance of PV and return on investment. In this paper, a case study was presented on different PV technology under the local climatic influence. Analysis of the case study data indicates that the power degradation of all PV modules is observed to be around 2%/yr. and further emphasizing its effect on PV modules and system size it has been observed smaller modules (<120W$_p$) degrade less than larger modules (>120W$_p$) and with respect to system size smaller systems degrades faster than larger systems. Hot and dry climate installed PV technologies has witnessed higher degradation than the Hot and humid climate region. In conclusion, it has observed that the degradation rates are much high in GCC than any other parts of the globe and thin film PV modules could be an appropriate choice for hot climatic regions whose degradation rates are considerable.**

Keywords- Photovoltaics (PV); Degradation rates; Electroluminesence images (EL); gulf co-operative council (GCC);Mono C-Si (Mono crystalline silicon);Multi C-Si(Multi crystalline silicon).

I. Introduction

Modernization in Oman has led to the development of many world-class projects thereby increasing the standard of living and an active player in the global market. The main interconnected system (MIS) of Oman electricity demand is expected to grow at about 9 % per year, from 5565 MW in 2015 to 9529 MW in 2022[1]. One can see that the energy demand prediction is going to be doubled within next 5 years. The Energy sector in Oman principally depends on natural gas; 97.5% of the installed electricity capacity is fueled by natural gas and the remaining 2.5% by diesel. Though the Oman is abundant in natural gas reserves of about 30 Tcf (according to EIA) [2], it is predicted that there will be a shortage in demand and supply of about 209 Bcf/Year. The deficit of natural gas is not only limited to Oman but also for entire GCC region who face a remarkable challenge in maintaining and enhancing gas production at a level needed to meet demand.

A move towards exploiting Oman's renewable resources on a large scale would contribute to reduced usage of natural gas and oil resources and help in combating the global warming issues. In an initiative to that PAWE (Public authority for water and electricity) of Oman has set a goal of achieving 15% of the energy demand should be generated using renewable energy resources by 2030[2]. The current installation of solar projects in Oman stands at 9280KW in which 26% was installed in the last year. Definitely, the key component of a PV system is the solar panel, which represents more than 50% of the overall cost of the PV system. It is crucial for the stakeholders, manufactures, researcher's etc. to understand the long-term performance of the PV modules in the Oman climate conditions, since the energy production would decide the ROI (return of Investment) and the average lifespan of PV modules. The Climatic conditions of Oman are different when compared with European countries, as generally the country witness clear skies all around the year [3]. However, this elevated solar resource also tends to have a hot climate, especially during summer rising to 55^{0}C.Therefore, it is necessary to estimate degradation of electrical parameters ($P_{max,}$ $V_{oc,}$ I_{sc} and FF) in PV systems under hot climatic conditions of GCC countries. A complete electrical analysis of different PV technologies can be found in previous work [4].

This paper aims to present the power degradation of different PV technologies under the hot climatic influence especially in the GCC countries. This paper is divided into four sections. Section II provides the description of the considered sites in the case study and the different PV technology installed with the adopted methodology. Section III describes the observations and results of the inspected PV modules which include the power degradation of the overall modules and also under the local climatic influence. Finally, in section IV some conclusions are summarized.

II. Case Study Details

A. Site description and PV technology

Generally, Oman experiences two different climates, the coastal area experiences hot and humid climate whereas the central part of Oman has a hot and dry climate. A total of five different standalone sites were surveyed under these two different climate conditions of Oman. Figure 1. Shows the sites (A-E) which include four different technologies of PV modules as mentioned in Table 1.

TABLE I. DESCRIPTION OF MODULES AT FIVE SITES

Photovoltaic Technology	Hot & Dry	Hot & Humid	Age of modules (Yr)	Rated Power
Mono-C-Si	25	10	5	<120 W_p
Multi-C-Si	15	5	3	>120 W_p
Thin a-si	15	10	4	<120 W_p
CdTe	10	10	2	>120 W_p

Figure 1. Five sites (A-E) Considered for a case study.

B. *Methodology*

The main goal of this case study was to understand the degradation of PV modules under Oman climatic conditions. To accomplish the goal the following measurements or observations were carried out in sites.

- To analyze and evaluate the performance characteristics of PV modules (P_{max}, I_{sc}, V_{oc}), I-V curves of different PV modules are measured using a portable curve tracer, irradiance meter and module temperature sensor. The measured values are translated to the STC for estimating the best exact degradation of PV modules. More about this test bench setup is available in our previous work [4].
- Observation of Visual degradation (such as delamination, corrosion of interconnects, discolouration of encapsulating) and recording these in the checklist [5].
- Electroluminescent image of PV modules is inspected to identify the cracks in PV modules using InGaAs short-wave infrared (SWIR) camera.

III. OBSERVATIONS AND RESULTS

A. *Power Degradation (P_{max})*

The KPI parameter for the PV modules is its output power (1,412 KWh/Yr.). The figure shows the histogram of the inspected 100 modules with different PV technologies. It is observed that the degradation rate seems to be higher than the other European countries. The average degradation rate of PV modules is estimated to be 2.052%/year. This raises concerns about the quality and environmental conditions of the PV modules installed in Oman.

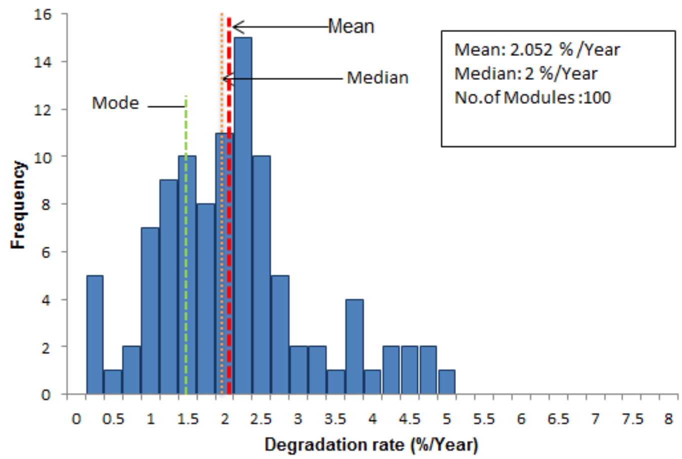

Figure 2. All modules P_{max} degradation histogram.

To understand the distribution better, the degradation rates are plotted separately for different sites with the corresponding module manufactures under the climatic influence. In this figure, the x-axis represents different sites (A-E) and the different manufacturers (1-6) of PV modules installed at these different sites. Further, data is colour-coded to represent the different climatic zones where PV modules are installed. One can notice that the degradation of ($_{max}$) under hot and dry climate was much higher (>6%/year) and also has the higher dispersion rate. On the other hand, the (P_{max}) degradation under the two other climatic conditions was less than that of earlier one and also shows tightly bound degradation rates.

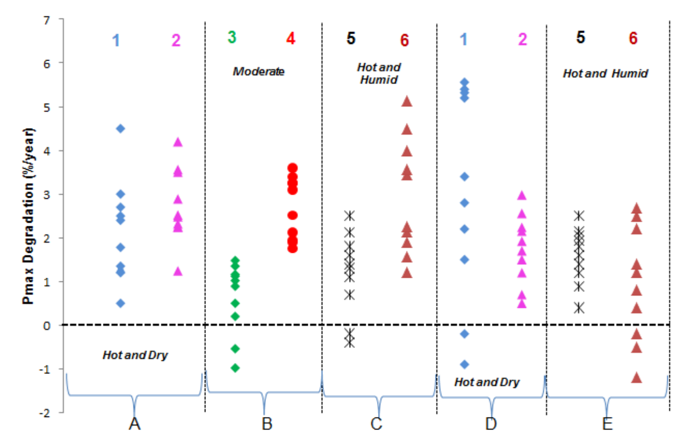

Figure 3. Site-wise, Manufacturer and climate-wise (Hot and dry, Hot and humid and Moderate) P_{max} degradation rates. 1 through 6 are different manufacturers with different colour representations

B. PV Module size, PV system size and installation variation

To understand factors affecting the power degradation it is necessary to observe the electroluminescence (EL) images seen on site. Based on PV technology a sample of EL images is shown in figure 4. The EL images show cracks on the PV modules. The cracks in a PV module can be classified into three types (Mode A, Mode B, mode C) with the detailed explanation given in [6]. The table shows the type of crack statistics for the 22 modules (contains 616 cells) based on PV technology. Crystalline group (mono & multi) has observed with a large number of cracks when compared with thin film technology. This is likely due to age, visual defects such as discolouration of encapsulating, and delamination and metallization of cell interconnects and bus bars. From figure .4. One can observe that the yellow circle indicates hairline cracks, the red indicates single broken fingers and the green indicates the discolouration of encapsulating.

TABLE II. DIFFERENT TYPES OF CRACKS IN PERCENTAGE OBSERVED IN DIFFERENT PV TECHNOLOGIES.

PV Tech	**Percentage of cells affected by Type of Cracks**			
	Mode A Cracks	***Mode B Cracks***	***Mode C Cracks***	***Total Cells***
Mono-C-Si	26.2%	38.9%	16.4%	216
Multi-C-Si	20.8%	35.4%	15.2%	124
Thin a-si	5.6%	12.2%	4.5%	154
CdTe	3.4%	7.2%	1.8%	122

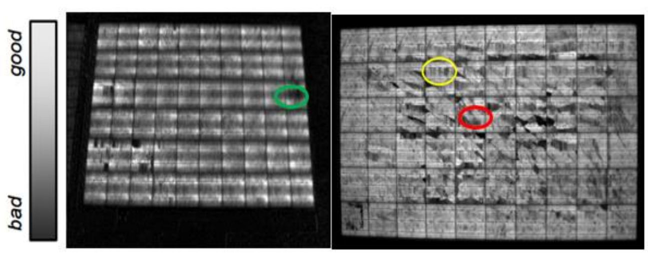

Figure 4. Electroluminescence images of some samples taken in the field.

The capacity of the inspected modules ranges between 10 W_p to 220 W_p. The smaller size modules (<120 W_p) are predominately old, and larger size modules (>120 W_p) seen in recent deployments. Figure. 5. Shows the power degradation based on modules size. Each data point refers to an individual module, the red and blue bar in the middle represents the average degradation value. One can observe from the figure .5. That the modules with size < 120W_p shows less degradation than that of modules > 120 $W_{p.}$ The reason could be related to installation site as most of them are serving for pilot projects which are not facing the same impact of irradiance and temperature as outdoor based installations.

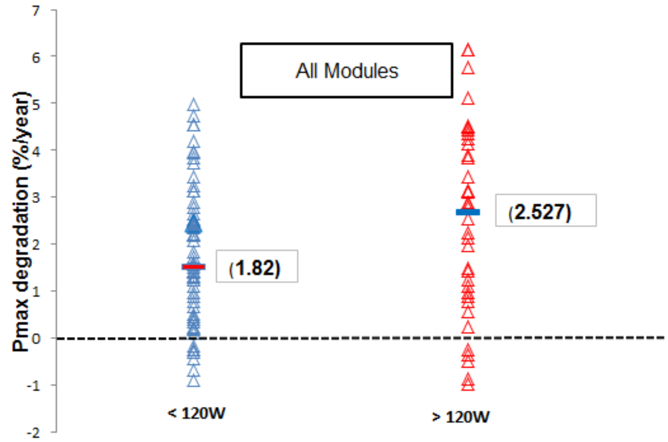

Figure 5. Effect of PV module size on P_{max} degradation of all modules.

To comprehend the result of the system size (different from module size) on the degradation rate, the surveyed sites have been classified into two groups 1. Small/medium system size (<120KW_p) and 2. Large system size (> 120KW_p). Figure. 6. Shows the results of degradation rates due to system size. The large systems show smaller degradation rates than the counterpart which is unexpected. The reason for this can be attributed to more emphasis on best installation practices adopted in larger systems which might be lacking in smaller systems. Finally, a comparison of the degradation rates based on the installation type is also made. One can observe from figure 7. That the roof mounted installations showed significant impact on degradation rates. The reason could be due to lack of proper concentrated effort on part of small PV system installers and owners which might result in usage of lower grade materials and also roof-mounted PV systems are subjected to more hot conditions that the ground-based installations.

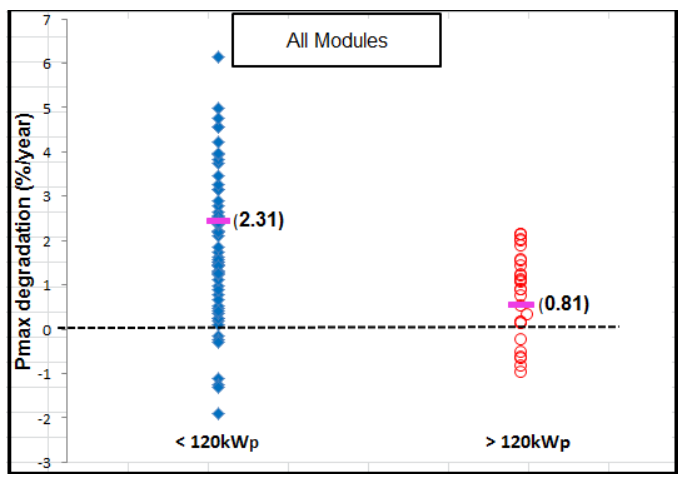

Figure 6. Effect of PV system size on P_{max} degradation of all modules.

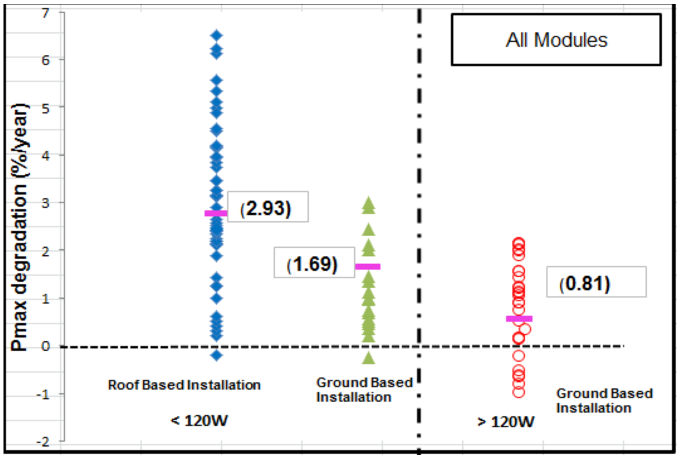

Figure 7. Effect of installation type on P_{max} degradation of all modules.

C. Climate and Technology based variation

The effect of both climate and technology on the power degradation rates is shown in figure 8. Hot and dry climate sites have seen a significant impact on degradation rates i.e. (>2.54%/year) while hot and humid has seen degradation rates about (.1.52%/year). This trend of degradation is likely due to hot temperatures and environmental factors such as dust, delamination and discolouration of encapsulating. Multi C –Si is observed to be degrading quickly than the Mono C -Si followed by other technologies in hot and dry climatic conditions. Whereas in hot and humid climate monocrystalline seems to degrade faster. However definitive conclusion is not possible due to a low number of samples inspected in this region. The best choice in both the climatic conditions is CdTe whose degradation rate is (< 1.0%/year). Which agrees well with the results presented in Jordan et al.[7,8]. They have reported that the average degradation rate for CdTe modules is 0.6%/year, while for amorphous silicon and c-Si is within 1%/year in general. These values are much lower than those seen during our case study which raises concerns about the long-term performance of the PV modules in Oman.

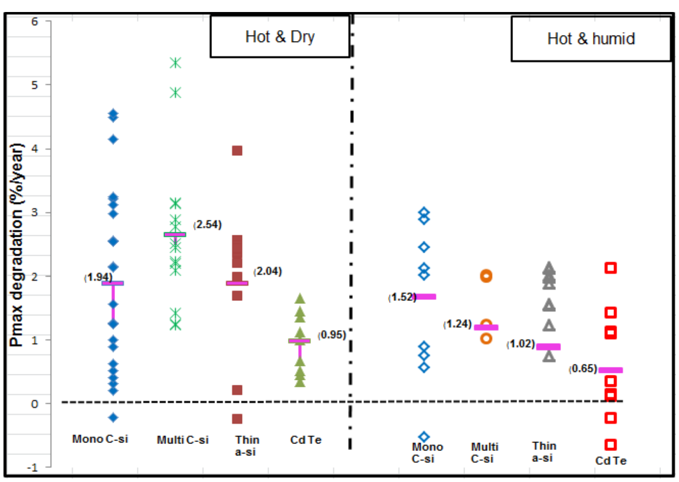

Figure 8. Effect of climate and type of PV technology on P_{max} degradation of all modules.

IV. Conclusion

It is crucial to understand the performance of PV modules in actual field conditions as the power degradation rates have serious implications on return on investments. Analyzing the data obtained during case study has shown that the PV modules installed in hot countries have higher degradation rates (around 2%/yr.) than the other European countries. The mean power degradation based on module size showed that the modules with larger size (2.52%/yr.) degrade faster than the smaller (1.82%/yr.) size. However, the same trend is not observed with regard to system size. The larger system (0.81%/yr.) degradation rates are lower with regard to smaller system size (2.31%/yr.). This suggests that there may be issues with module quality and/or installation process for these sites. This is supported by the observation on PV modules EL images which showed the presence of micro-cracks which tend to degrade faster than PV technology modules in hot climates.

Further investigations based on the type of installation showed that roof based installation (2.93%/yr.) tend to degrade faster than the ground-based installation (0.81%/yr.). The effect of climate on Power degradation rates regard to PV technology is also analyzed; the results showed that the Multi-c-Si (2.54%/yr.) has seen the highest degradation rates in Hot and dry climate while the lowest is CdTe (0.65%/yr.) in hot and humid climate. The results which have become apparent from this case study in Oman provided performance indicator factors for future deployment of PV system in terms of location, climatic influence, technology type and diligence required for module selection and handling during installation.

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