Study on appearance and electrical properties of reused solar modules

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Abstract. A test platform for reused solar modules was established in Wuhan in order to study the appearance changes, aging problems and degradation rate in electrical properties of the reused modules. The photovoltaic modules were mono-Si modules produced by Siemens in 1996. It was found that there was moisture at the edge of the modules. The aging of tin-coated copper strip was obvious, and there was blackening phenomenon. There were many white spots on the solar cells around the tin-coated strip, and the solar cells turned blue locally. The average annual power attenuation rate of different modules varied greatly, but it was mainly related to the increase of series resistance of modules. The integrated average annual power attenuation of PV modules was about 3.59% during 4 years.

1. Introduction

Photovoltaic power generation is one of the most promising new energy sources. The life and electrical properties of solar modules are important factors that affect the life cycle and power generation of PV system. Many researchers have studied the performance of various types of solar modules in the use, and found that with the extension of working time, the appearance and power generation performance of the modules have some changes [1-3]. Degradation of solar modules generally occurs gradually with the increase of time and is related to various factors such as outdoor use conditions, climate conditions, environmental conditions and product quality [4-6]. In the literature [7], it is mentioned that the average power degradation rate of c-Si modules is 0.8% ~ 0.9%, and the median annual power attenuation rate is 0.5% ~ 0.6%. The Solar Energy Research Institute of Sun Yat-sen University in Shunde conducted a long-term study on the power generation performance of different modules. After 12 years of outdoor operation, HIT solar modules, CIGS thin-film solar modules and CdTe thin-film solar modules were found to have an average annual power attenuation rate of 0.32%, 0.84% and 1.72%, respectively [8]. Inner Mongolia University of Technology studied the dust accumulation characteristics and attenuation law of solar modules in Hohhot area, and found that the average daily total transmission attenuation rate caused by dust accumulation was 1.29%, 3.42% and 4.71%, respectively [9]. Hunan Red Sun New Energy Technology Co., Ltd. analyzed the mono-Si solar modules used outdoors in Changsha for 9 years, and found that the frequent appearance defects such
as glass erosion, backboard yellowing, the oxidation of gate line and anti-reflection layer could lead to performance attenuation, and the total power decreased by 7.8% in 9 years[10].

In this paper, we built a photovoltaic(PV) power generation system in Wuhan area with old solar modules, and tracked the changes of photovoltaic modules' appearance and electrical performance.

2. The experimental platform

The 30kWp PV grid-connected system for reused module test was built in Wuhan city in 2016. The solar modules were produced by Siemens in 1996 with black mono-Si solar cells and put into use in 1997 at the seaside of Shenzhen city for about 20 years, as shown in Figure 1. Eleven modules (No.1-10) were selected for observation and study, and the electrical performance of the modules was tested by the Meyer Burger PASAN-IV tester.

Fig. 1 PV grid-connected system for old module test  Fig. 2 Meyer Burger PASAN-IV tester

3. Results and discussion

3.1. Appearance of the modules

As shown in Figure 3(a), the appearance of the modules was checked before installation. It was found that the appearance of the modules was in good condition totally. There was no discoloration or delamination in EVA, but there was mist along the edges of some modules. A few solar cells in the modules turned blue locally, and there were some white spots of contaminants on the solar cells around the tin-coated strip. The wire and junction box were in good condition. The back panel of photovoltaic modules is intact without damage and bubbling. The salt-mist corrosion phenomenon existed on the aluminum frame, which made one side of all modules became blurred and the glass surface had stains that were difficult to clean. After 4 years of outdoor operation in Wuhan, it was found that the overall appearance of the modules was intact without obvious changes, but the internal tin-coated strip was blackened, and the white spots on the cells increased, and more solar cells turned blue locally, as shown in Figure 3(b).

As for the existence of mist on the edge of the modules. There maybe two reasons. On the one hand, it may be because the sealing of the modules is not enough, leading to the water vapor entering. On the other hand, it may be due to salt spray corrosion running all years at the seaside in Shenzhen. Tin-coated strip Blacking and white spots around the tin-coated strip should be due to the aging of the tin-coated strip, resulting in the surface layer falling off. Turning blue of solar cells may be related to the degradation of the cells themselves.
3.2. Electrical performance of the modules

The electrical performance of eleven modules (No1-No.11) was studied from 2016 to 2020, and the electrical parameters of the modules were tested in September 2016, September 2018 and September 2020 respectively. As shown in Fig. 4, the average annual power degradation rate of the modules is about 3.59%, the power attenuation of 1# and 4# samples is the largest, reaching 5.2% and 5.5%. It was much higher than the reported values in the literature[7], which may be related to the early raw material and encapsulation quality. Viewed from the outside, the tin-coated strips of the samples were blackened, and the white spots of contaminants on the cells around the tin-coated strips increased, and more cells turned blue. Especially for the 1# sample with great power attenuation, there were obvious white smoky spots in the module. However, the appearance of sample 4# is not significantly different from that of other samples. Therefore, there should be other factors that caused the power attenuation.

By analyzing the series resistance and shunt resistance of modules, it was found that the power attenuation trend was related to the increase of series resistance, which led to the decrease of filling factor, as shown in Fig. 5 and 6. The filling factor decreased rapidly in the first two years from 2016 to 2018 and slowed down in the latter two years from 2018 to 2020. The series resistance was mainly affected by the body resistance of semiconductor material, electrode resistance and contact resistance etc. Due to a long time of use, the tin-coated strips of the samples changed significantly, which increased the electrode resistance. At the same time, other factors may also cause increase of series resistance of the modules. This needs to be verified by more detailed experiments. The shunt resistance didn’t change regularly. During the experiment, the shunt resistance may become larger or smaller, but the shunt resistance was far greater than the series resistance.
4. Conclusions
This paper studied the changes of appearance and electrical properties of used photovoltaic modules during 4 years of outdoor operation in Wuhan. The results show that the overall appearance of the modules is good, and the change is not obvious; but the aging of internal tin-coating strips is obvious, and there is blackening phenomenon. The white spots on the solar cells around the tin-coating strips
increase, and more solar cells turn blue from black. The average annual degradation rates of different modules have distinct differences, which should be mainly related to the increase of series resistance of the modules. The integrated average annual power degradation rates of all samples are about 3.59%.

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References
[1] David A.Q, Muyiwa S.A.(2018) Comparative study of performance degradation in poly- and mono-crystalline-Si solar PV modules deployed in different applications. International Journal of Hydrogen Energy,43,6: 3092-3109
[2] David A.Q, Muyiwa S. Adaramola,(2018) Ageing and degradation in solar photovoltaic modules installed in northern Ghana. Solar Energy, 173:834-847
[3] Kumari V, Kumar N, Srivatsa K.M.K, etc. (2020) Estimation of potential induced degradation in solar Mini-modules. Materials Today: Proceedings, 30: 229-233
[4] Wang P, Xie J.J, Ni L, etc. (2018) Reducing the effect of dust deposition on the generating efficiency of solar PV modules by super-hydrophobic films. Solar Energy, 169: 277 – 283
[5] Rin N, Han C.W. (2021) Lifetime prediction method for moisture-induced degradation of glass-to-glass solar cell modules using spatially distributed diode model. Solar Energy Materials and Solar Cells, 225:111052
[6] Phua B, Shen X.W, Hsiao P.C, etc. (2020) Degradation of plated silicon solar module due to copper diffusion: The role of capping layer formation and contact adhesion. Solar Energy Materials and Solar Cells, 215: 110638
[7] Jordan D.C, Kurtz S.R, Vansant K, et al. (2016) Compendium of photovoltaic degradation rates. Progress in photovoltaics: Research and applications, 24(7): 978 - 989
[8] Zhang K, Huang P, Han H.L etc. (2021) Outdoor power generation performance and attenuation analysis of PV modules with different technologies. Solar Energy, 03:25-31
[9] Wang S.J, Tian R, Guo X. (2019) Dust accumulation characteristics and transmission attenuation law of photovoltaic modules. Transactions of the Chinese Society of Agricultural Engineering, 35,22:242-250
[10] Huang Y W, Cao H.X, Liu S etc. (2019) Degradation analysis of monocrystalline silicon PV modules. Chinese Journal of Power Sources, 43,4:641-645