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Features of photovoltaic cell degradation of solar power plants in Hong Kong and Saint Petersburg

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Abstract. This work investigates the degradation characteristics of PV modules in two different climates, Hong Kong and St. Petersburg, in order to better understand the coupling effects of temperature, thermal cycling, UV exposure, relative humidity and other environmental factors on the performance of PV systems. The solar development potential of Hong Kong and St. Petersburg are compared. Different optimization recommendations are given based on the different climates of Hong Kong and St. Petersburg.

Keywords: Photovoltaic Models, Solar Panels, degradation, damp-heat climate, humid continental climate, electroluminescence

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Особенности деградации фотоэлектрических элементов солнечных электростанций в Гонконге и Санкт-Петербурге

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Аннотация. В данной работе исследуются характеристики деградации фотоэлектрических модулей в двух различных климатических условиях, Гонконге и Санкт-Петербурге, чтобы лучше понять влияние температуры, термоциклирования, ультрафиолетового облучения, относительной влажности и других факторов окружающей среды на производительность фотоэлектрических систем. Сравнивается потенциал развития солнечной энергетики Гонконга и Санкт-Петербурга. Даются различные рекомендации по оптимизации, основанные на различных климатических условиях Гонконга и Санкт-Петербурга.

Ключевые слова: фотоэлектрические модели, солнечные панели, деградация, влажный жаркий климат, влажный континентальный климат, электролюминесценция

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Introduction

In the 21st century, the three major problems of energy shortage, environmental pollution and the greenhouse effect have spurred the development of renewable and clean energy sources. Solar energy, as a representative of clean energy, is being utilized in an ever-expanding range. Photovoltaic power plants are emblematic of the use of solar energy. Photovoltaic modules are the core components of photovoltaic power plants, and with the increase in use time, the performance decline is significant [1–6].

The performance deterioration of PV modules is divided into two main categories, one is internal factors, such as defects in the material itself or inadequate manufacturing processes. The other category is external environmental factors, which are greatly influenced by climate. Currently, there is a lack of research into the coupled effects of temperature, thermal cycling, UV exposure, relative humidity and other factors on PV systems [7–9]. There is therefore a need for a global database to determine the factors and characteristics of PV module degradation under different climatic conditions [10]. This thesis compares the degradation characteristics of PV modules in Hong Kong and St. Petersburg. Different optimization suggestions are given according to the climate characteristics of Hong Kong and St. Petersburg.

Materials and optimization methods for degradation of PV modules in Hong Kong and St. Petersburg

Hong Kong is located in southern China and has a humid subtropical climate, with average maximum temperatures above 30 °C from June to September, rainfall greater than 300 mm and an average annual relative humidity of 78%, so the main problem facing PV modules in Hong Kong is the damp-heat climate.

Han et al. [11] carried out an analytical study of a PV module in a hot and humid region and Fig. 1 shows an EL image of this PV module. Three of the more obvious disadvantages can

a)
b)
c)

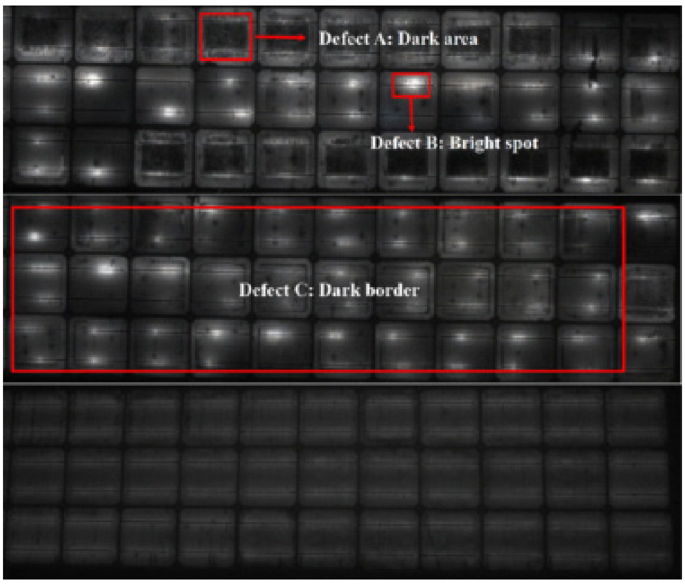

Fig. 1. EL (electroluminescence) image of photovoltaic module [11]: PV module exposed in the field (*a*); PV module exposed in the field (*b*); PV module stored indoors (*c*)

be observed in Fig. 1. Defect A there is a distinct dark area between the busbars in the middle of the cell. defect B, there is a bright spot in the busbars of the cell. Defect C, there is a black border in the cell. By comparing Fig. 1, *a*, *b* and Fig. 1,*c*, it can be seen that the defects in the PV modules were caused by prolonged exposure to the field. Cracking of the solder interconnects (defect B) and corrosion of the silver metallization (defects A and C) have been caused by the hot and humid climate.

UV Fluorescence is a relatively new characterization method for photovoltaic solar panels to detect defects such as cracked solar cells [12]. Gilleland [13] observed package delamination after UVF imaging of field exposed modules (Fig. 2,*a*) and Gabor [14] also observed package delamination after UVF imaging of outdoor mounted PV modules (Fig. 2,*b*). This phenomenon may be due to corrosion caused by the degradation of EVA, which is exacerbated by the damp-heat climate. Ways to reduce this hydrothermal degradation can be considered by using solders that do not contain tin or lead or by replacing EVA with new encapsulation materials.

a) *b*)

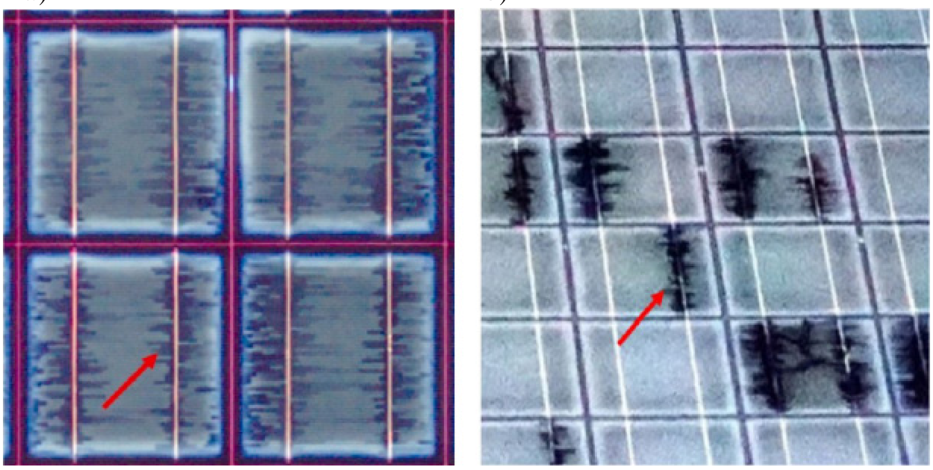

Fig. 2. UVF image showing similar patterns from the busbar for field-exposed modules (*a*); UVF image showing patterns from the busbar for outdoor installed modules (*b*) [13]

St. Petersburg is located at around 60 degrees north latitude and has a humid continental climate. During the summer months, the average daily incident shortwave solar energy is higher in St. Petersburg than in Hong Kong, as shown in Fig. 3.The data is derived from NASA's meteorological model reconstructions(MERRA-2 (nasa.gov)).This may be due to St. Petersburg's higher latitude, and therefore shorter daylight hours in winter and longer daylight hours in summer.

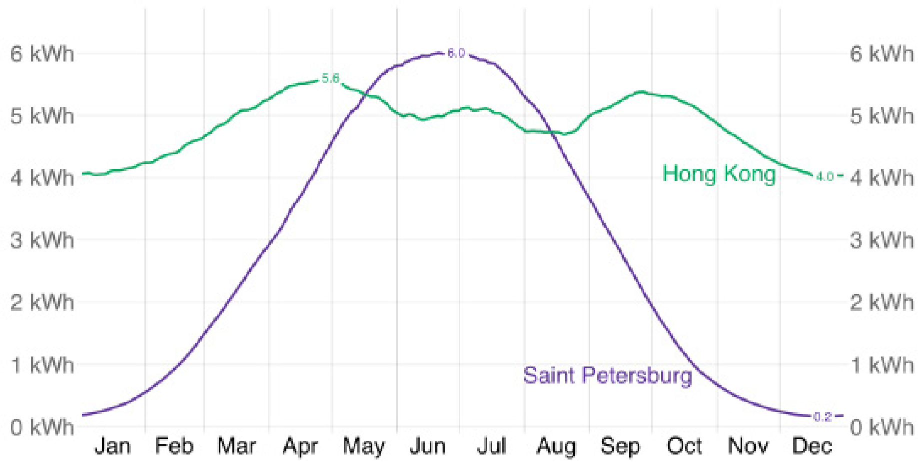

Fig. 3. Average daily incident shortwave solar energy

PVsyst is a widely used simulation software commonly used to evaluate PV energy yield and facilitate system optimization. Fig. 4 shows a comparison of the annual yield of the same PV arrays in Hong Kong and St. Petersburg, simulated using PVsyst. The PV module used for the simulation is the LG 450 N2W-E6 from LG Electronics, which is a high power solar panel with a conversion power of 20.5%. It can be seen that in the summer the same PV system in St. Petersburg yields more electricity than in Hong Kong. The low yield of photovoltaic modules in St. Petersburg from October to April may be due to frequent snowfall resulting in snow, frost and ice.

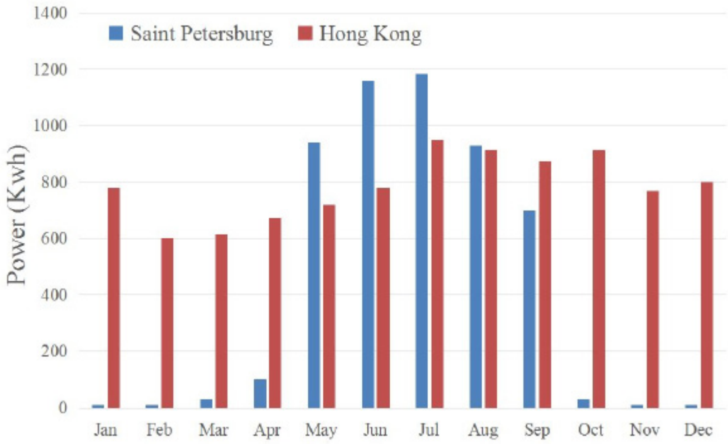

Fig. 4. Comparison of the annual yield of PV array in Hong Kong and St. Petersburg

As shown in Fig. 5, Christopher's [15] study of PV modules in humid continental climates found that moisture infiltration was clearly observed at the edges of the cells adjacent to the module frames and that darkening occurred in the middle of the cells, with an average annual power loss of about 0.6% in the modules. The reason for this phenomenon may be related to the frequent snowfall in northern climates, and as this phenomenon occurs mainly in cells adjacent to the module frame, consideration could be given to improving the durability of the module edge seal and frame structure to reduce the degradation rate. Due to the low yield of photovoltaic modules in St. Petersburg in winter, the degradation of solar cells can also be reduced by removing the solar panels during the frost season [16, 17].

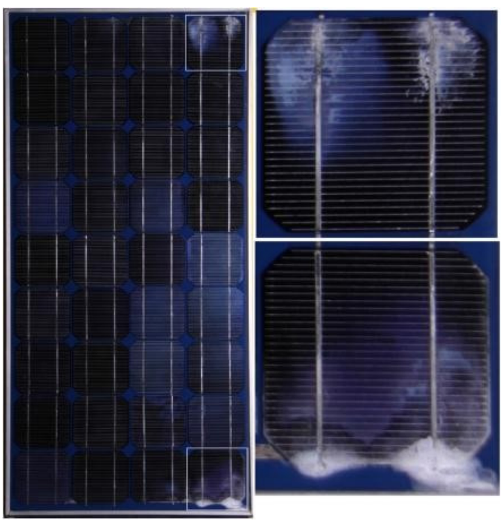

Fig. 5. Module showing moisture ingress at corners.
Two selected cells are shown enlarged [15]

Results and Discussion

Degradation of PV modules in Hong Kong should take into account their hot and humid climate. The use of lead-free solder or thermoplastic polyolefin (TPO) instead of ethylene and vinyl acetate (EVA) reduces the degradation rate of PV modules to 0.3%. Degradation of PV modules in St. Petersburg should take into account frequent snowfall and can be reduced by considering improving the durability of module edge sealing and frame construction or by removing solar panels during the frost season. Data from the Pulkovo Observatory shows that the annual degradation rate of PV modules removed during frost periods is 2.3%, which is much lower than the annual operational degradation rate of 8.19%.

Conclusion

We have analyzed the effects of two climates on PV modules in the Hong Kong region and the St. Petersburg region by examining PV modules from different regions. Different methods should be used to optimise degradation rates depending on the climate of different regions. Especially negatively the degradation of solar panels is affected by the number of temperature transitions through the zero mark. At one point, everything will melt (water appears and it penetrates into all the cracks). Then it freezes and expands. This leads to the destruction of the solar panel starting from the edges. Further cracks can lead to current loss from the panel when it is transferred to the network (part of the photovoltaic cells will lose contact). For a number of regions of Russia, this is the main factor in the degradation of solar panels.

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