

Physical deterioration of encapsulation and electrical insulation properties of PV modules after long-term operation in Thailand

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ABSTRACT

Cumulative installed PV wattage in Thailand since the 1980s was over 30 MW. A typical module would have a structure of glass–EVA–cell–EVA–tedlar back-sheet. During the hot season, temperature can be over 40 °C coupled with the humidity of over 90% in the monsoon season. Apparent physical deteriorations of modules under long term field-exposure have been observed. In this paper, we report results of visual physical deteriorations of 39 x-Si modules with more than 15 years of operation. We compare these with insulation measurement based on the IEC 61215 Standard. It is found that even with severe delamination of the top EVA sheet from cells, the insulation resistance of all degraded modules is still within a limit of the prescribed IEC standard, which is 102.67 MΩ m² for a module area of 0.3949 m². We further note that degradation of modules resulting in large decrease insulation resistance is peeling of tedlar back-sheet and edge sealant.

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1. Introduction

An insulation material for PV module encapsulation has not only good optical transmission, mechanical support and low water absorption ratio to protect a solar cell from corrosion, but also good electric insulation with highly sufficient electrical resistivity [1]. Consequently, a PV module is fabricated by a manufacturer that is also required to perform qualification and type approval of PV module with the hope of eventually predicting long-term PV module service lifetimes in the field [2]. The module satisfies the requirements, if the module passes all the following criteria: (i) the maximum power output (P_{\max}) of the measured module must not degrade by more than 8% of the initial power after each test sequence; (ii) there should be no open circuit, short circuit or ground to frame; (iii) there is no visual evidence of a major defect or physical deterioration in both solar cells in the module and PV module encapsulation; and (iv) the insulation test requirements are met after the tests [3].

In Thailand, the first nation-wide PV applications occurred around the 1970s [4]. The weather in Thailand is tropical and humid. The temperature can reach over 40 °C in summer period and maximum relative humidity is nearly 90% in monsoonals. Under 15-year field-exposure of PV modules in Thailand, the deteriorations of 39 single-crystalline silicon (x-Si) PV modules made from local PV panel assemblers have collected at CES,

KMUTT. The maximum power outputs of these PV modules are 47 and 60 W. The 47 W module has got 35 modules and the 60 W module has got 4 modules. The encapsulation structure of degradation modules consists of glass, EVA, and backsheets.

Prior to this work, some severely degraded PV modules were characterized. EVA samples taken from the front of degraded modules, continuously exposed to light and higher temperature, become opaque. Their mechanical properties are greatly changed, such as reduced elongation compared with EVA samples taken from the back, not directly exposed to light and were at lower temperature than the front side. It was surmised that cells in modules having large series resistance, or other defects that produced hot spots, could locally heat EVA leading to severe delamination [5]. However, electrical insulations of the modules have no investigation although the testing standard criteria are required to test them.

Therefore, the main purpose of this paper is to determine the physical deterioration of encapsulation and electrical insulation properties of PV modules after long-term operation under Thailand weather by visual inspection and electrical insulation testing for each degradation PV module according to IEC 61215 [6].

2. Experimental setup

2.1. Physical visual inspection

The main objective of the physical visual inspection was to detect the major defects after long-term use in the field under an

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illumination of not less than 1000 Lx according to the International Standard IEC 61215 [6]. In addition, we took photographs at the positions, which had defects such as bubble, delamination, corrosion, and other conditions that may worsen and adversely affect the electric insulation properties of the module in subsequent tests.

2.2. DC dielectric insulation test

The purpose of the insulation test is to determine whether or not the modules are sufficiently well insulated between current carrying parts that are close to the edge of the module and the frame. The DC dielectric insulation test in this paper comprises DC dielectric withstand-voltage test and DC dielectric resistance measurement. Both tests used the DC insulation tester of Chroma Hipot Tester, Model 19052. The ambient temperature was 25 °C, and the relative humidity not exceed 75% according to the International Standard IEC 61215. Before the test, we must short circuit the output terminals of the module and the frame for discharging the residual charge from the module. Eventually, positive terminal of the DC insulation tester connected to the shorted output terminals of the module and negative terminal of the tester to the Al frame of the module is shown in Fig. 1.

For DC dielectric withstand-voltage test, these modules have applied a voltage at 500 V. The voltage was increased by the tester at a rate of 500 V/s and the voltage maintained at this level for 1 min. Next, the voltage was reduced to zero and the terminals of the tester short-circuited to discharge the voltage build-up in the module if there was no dielectric breakdown or the leakage current was less than 50 μA. Then, the DC dielectric resistance was measure; the circuit diagram of the experiment was similar to the DC dielectric withstand-voltage test. However, the applied voltage was 500 V for 2 mins before determining the insulation resistance.

3. Results and discussions

3.1. Physical deterioration of encapsulation

The physical deteriorations in front of the module are shown by the photographs in Fig. 2a–i. It is interesting to note that the key defects were discoloration, delamination, and corrosion on the busbar of the cell. The three levels of EVA discoloration were yellowing (Y), browning (B), and dark browning (DB). The dominant delamination formations had four patterns that were bubbles near the busbar (BB), at the center of the cell (CC), around the edge of the cell (EC), and at the corner of the edge on the cell (CE) as shown in Fig. 2a–g. However, corrosion on the busbar of

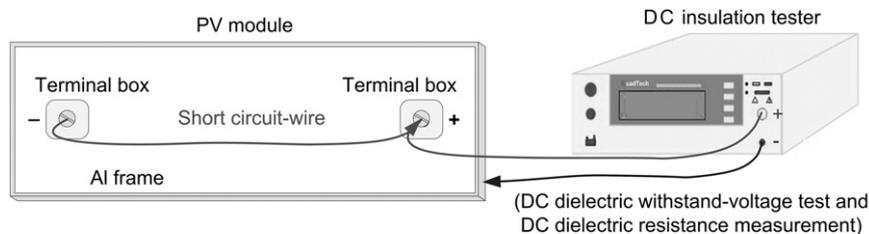


Fig. 1. Wiring diagram between the module and the insulation tester.

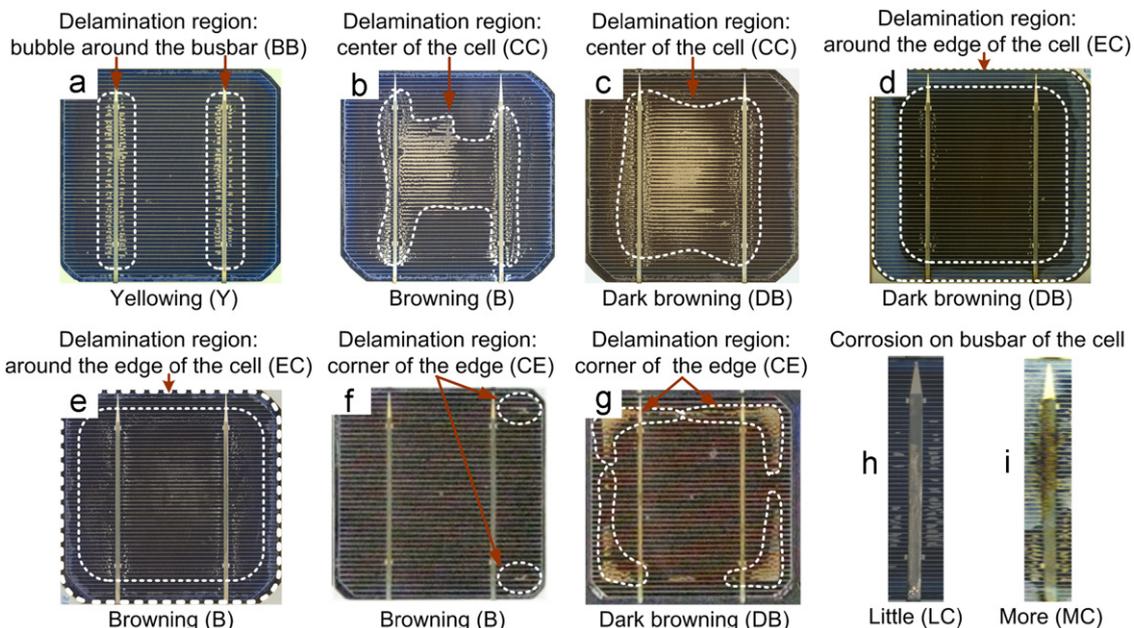


Fig. 2. Photograph of the physical deteriorations in front of the PV modules: (a) Y, BB, (b) B, CC, (c) DB, CC, (d) DB, EC, (e) B, EC, (f) B, CE, (g) DB, CE, (h) LC, and (i) MC.

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