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A novel study for determining early life degradation of multi-crystalline-silicon photovoltaic modules observed in western Himalayan Indian climatic conditions

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Abstract

The results of a first time study are reported on the degradation of a roof mounted multi-crystalline-silicon photovoltaic system after 2.5 years of outdoor exposure in a western Himalayan location in India. The main objective of the study is to identify frequently occurring defects in modules to study the change in electrical performance parameters and correlate these with identified defects under Indian climatic conditions. A comprehensive test campaign is conducted by visual inspection, thermal imaging and current–voltage characteristic measurements. Early degradation and recently reported defect: snail trails are observed in all modules along with non-uniform single cell browning and junction box failure. Thermal imaging analysis is carried out which shows that three modules developed serious defects like hotspots, disconnected cells and string interconnect ribbons and a significant result that all solar cells located directly on top of junction boxes were 3–8 °C hotter than other cells indicating higher thermal degradation rate of these cells than others. Peak power degradation of modules is quantified by measuring performance parameters under standard test conditions as a function of field exposure time, using class-A sun-simulator. Three modules showed 50% degradation while remaining seven modules showed 0.6–2.5% degradation in peak power after 2.5 years. PV modules certified as per International Electro-technical Commission (IEC) standards have shown considerable degradation indicating the need to enforce quality control and review qualification standards for Indian climatic conditions if modules have to perform reliably for more than 20 years under field conditions. The outcome of the study will be of importance to enhance the knowledge of climate specific field PV degradation mechanism and to provide inputs to Indian/IEC standards, the improvements of which are being considered currently.

Keywords: Photovoltaics; PV degradation; Multi-crystalline silicon; Snail trails

1. Introduction

Solar photovoltaic (PV) modules convert Sun's energy into electricity thus providing a non-exhaustible energy conversion alternative. With decrease in price of solar panels and increase in conversion efficiencies, a large number of rooftop PV systems and PV plants are being installed worldwide. The cost of PV modules ranges from 40% to 60% or 30% to 50% of the total cost depending on whether it is a stand alone or grid interactive PV system respectively (IRENA, 2015). The advancement in PV technology has led to decline in the cost of PV modules from \$3.3/W_p during early nineties to \$0.6/W_p during 2014 (REN21, 2014) and is expected to decline further to \$0.45/W_p or less. The change in module design, manufacturing processes and development of new low cost materials after 2004 has led to this reduction in cost (Zielnik, 2013). The current

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module designs include thinner silicon (Si) wafer (~120 μm), less encapsulant layers, thin sized n-type wafers and all back contact technologies to increase efficiency and counter the Potential Induced Degradation (PID) effects. In monolithic thin film modules, frameless designs, alternative back-sheet materials and modified cell interconnect are incorporated to improve reliability and to resist impact due to leakage currents under high temperature, humidity and high voltage environment. However, it is still not clear whether these changes have affected durability and reliability as compared to earlier designs and require in depth studies.

All these issues related to long term reliability of PV modules are gaining more importance. The qualification standards developed by International Electro-technical Commission (IEC), such as IEC61215 (wafer based crystalline Si modules) and IEC 61646 (thin film modules) and IEC61730 have helped to ensure long term reliability of PV modules to some extent (IEC 61730, 2004; IEC 61215, 2005; IEC 61646, 2008). Ideally, it is considered, that these standards are devised to simulate severities which PV modules experience under actual field conditions during a span of 20–25 years. However, qualifying IEC standards, does not guarantee long-term performance or service lifetime (Osterwald and McMahon, 2009). There are number of reports which show that PV modules have survived in field for more than 20 years along with reports where qualified modules have failed in the field before completing the required service lifetime. Thus, it is now broadly believed that these IEC standards are not adequately addressing the real outdoor conditions.

During the outdoor operation, noticeable changes/defects are observed in appearance and performance of the PV modules which indicate that these modules may have degraded resulting in the decrease in the output power of the PV modules. So, it is important to understand the generation of defects and how these defects result in decrease in power output of PV modules with time in order to make technology commercially acceptable. Generation of defects and their growth resulting in degradation is mainly due to environmental stresses such as: temperature, humidity, UV radiation etc. experienced by PV module during the outdoor operation as such generation of defects and degradation are likely to depend on the local climate and climatic zone (Jordan et al., 2012).

Therefore the information on field performance and degradation of PV modules from various climatic zones is required, so that enough details are available to provide quantitative predictions of field performance and service life. Also a reliable database on outdoor weathering is required for developing realistic and effective procedures for accelerated testing to simulate 25 years of operation.

Keeping in view these aspects, results of degradation of PV modules in the western Himalayan region are reported for the first time. The results presented in this study are of significance in the context of quality and problems faced in field installed PV modules. Also such degradation studies have not been carried out at present in detail in different parts of India except at the National Institute of Solar Energy, Gurgaon location.

In the present study degradation analysis of 1 kW_p multi-crystalline silicon (m-C-Si) PV system after 2.5 years of outdoor exposure in the cold climatic conditions of western Himalayan region is carried out. The main objective of the study is to identify frequently occurring defects in the modules to study the change in the electrical performance parameters and correlate these with identified defects under Indian climatic conditions. The main defects observed in the studied modules are junction failure, surface browning, hotspots and snail trails. Some defects reported may be caused due to climatic conditions in the western Himalayan location but other defects are due to poor quality of materials used during manufacturing. The outcome of the study will be helpful to quantify the PV modules degradation and review the accelerated aging qualification tests depending upon the dominant field degradation mechanisms.

The paper is organized as follows: a brief overview of research studies on degradation and defects occurring in photovoltaic panels are presented in Section 2. Details of experimental PV setup are given in Section 3. In Section 4 degradation analysis methodology followed in the present study is described. The results and discussion are presented in Section 5. The conclusions are given in Section 6.

2. Brief overview of degradation in photovoltaic modules

Modules degrade slowly, but some defects can reduce the module performance significantly. A brief overview of main degradation research studies and types of defects are presented in this section.

2.1. Research highlights

Various methods to study PV degradation are discussed in a detailed review by Ndiaye et al. (2013). The modules in countries with higher ambient temperatures are found to show enhanced "yellowing" of the encapsulant (Palmblad et al., 2009). PV modules need to be tested to identify the defects using different methods like visual inspection and thermal imaging (Munoz et al., 2011). Djordjevic et al. (2014) studied various defects in PV modules after an exposure of test modules to environmental conditions up to ten years and compared with reported defects to identify defects specific to Western Australia (WA). However, no new defect specific to WA conditions were found. Paul et al. (2011) investigated the degradation mechanism in a 2 kW_p PV installation after 12 years of outdoor operation using visual inspection, thermal imaging and electrical performance measurement. Glass weathering, delamination at the cell–EVA interface and oxidation of the antireflective coating and the cell metallization grid were found to be the most frequently occurring defects. The degradation in peak power of the installation was found to be 11.5%