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Experimental investigation of observed defects in crystalline silicon PV modules under outdoor hot dry climatic conditions in Algeria

Ahmed Bouraiou[a,b,*], Messaoud Hamouda[a], Abdelkader Chaker[b], Ammar Neçaibia[a], Mohammed Mostefaoui[a], Nadir Boutasseta[c], Abderrezzaq Ziane[a], Rachid Dabou[a], Nordine Sahouane[a], Salah Lachtar[a]

[a] Unité de Recherche en Energies Renouvelables en Milieu Saharien (URERMS), Centre de Développement des Energies Renouvelables (CDER), 01000 Adrar, Algeria
[b] Laboratoire SCAMRE, Ecole Nationale Polytechnique Oran, Algeria
[c] Research Center in Industrial Technologies CRTI, P.O. Box 64, Cheraga, Algeria

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ABSTRACT

The paper reviews the different detectable failures of mono-crystalline and poly-crystalline silicon in the research unit in renewable energies in Saharan medium (URERMS) fields. This survey is an effort to inspect and assess the defects of PV modules occurring in recent and older installations in a desert environment and under real operating conditions. The analysis and evaluation of 608 PV modules inside the site of URERMS and in a remote located solar installation (Melouka) using the visual inspection test results in the following failures and degradation modes: delamination, discoloration of the encapsulant, corrosion and discoloration of the metallization (gridlines, busbar, cell interconnect ribbon and string interconnect), solar cell cracks, broken glass, deterioration of the antireflection coating, snail trails, junction box failure, soiling. The electrical performance of some tested modules is also performed in order to give the correlation with the visual defects.

1. Introduction

The electricity production using photovoltaic energy has been increased in the last years in Algeria due to the new policy of the Ministry of Energy and Mines which aims to decrease the dependency on fossil fuel and to increase the electrical energy production from renewable sources (Haddad et al., 2017; Saiah and Stambouli, 2017). Within the framework of its strategy of development of the projects of renewable energies in the Saharan regions, Sonelgaz (The National Gas and Electricity Society), created seven power plants in Adrar for the production of electricity from photovoltaic energy. These stations are managed by the group SKTM (Electricity & Renewable Energy Company), their total production is of approximately 53 MW. Electricity produced using photovoltaic power plants can only be profitable if the PV modules operate reliably for 20–25 years under field conditions (Sharma and Chandel, 2013). On the other hand the photovoltaic arrays are a sensitive part of the PV system due to the climatic and environmental conditions influencing the photovoltaic performance and also the degradation after long term exposure under a real operating conditions (Sharma et al., 2014). The reliability of photovoltaic modules can be evaluated by understanding the degradation modes and degradation mechanisms during outdoor field operations (Chandel et al., 2015). Reliability can be affected by various factors such as degradation of packaging materials, semiconductor, solar cell/module interconnects and adhesion losses (Quintana et al., 2002; Rajput et al., 2016). Several research works and field studies have treated the assessment of the photovoltaic module degradation and failure in different locations using various techniques and methodologies like visual inspection, Indoor and Outdoor Power Measurement, Infrared Images (IR) and Luminescence Imaging. Furthermore, the authors in ref (Sánchez-Friera et al., 2011) have given the correlation between visual defects and electrical measurements of crystalline silicon PV modules. They showed that glass weathering, front-side delamination and anti-reflective coating oxidation and the cell metallization grid were the most frequent occurring defects found after 12 years of exposure in Southern Europe (Spain). Degradation analysis of 90 mono-crystalline PV modules was performed after long term of 22-years of operation in the composite climate of India (Rajput et al., 2016). It was reported that the defects in busbars, cell inter-connection ribbon, string inter-connection ribbon and chalking in back-sheet are the most frequent present defects among other observed defects like hot spots in solar cells, burn marks and back-sheet delamination. Analyses of crystalline silicon PV module

* Corresponding author at: Unité de Recherche en Energies Renouvelables en Milieu Saharien (URERMS), Centre de Développement des Energies Renouvelables (CDER), 01000 Adrar, Algeria.
E-mail addresses: bouraiou.ahmed@urerms.dz, bouraiouahmed@gmail.com (A. Bouraiou).

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Table 1
Summary of recent studies about PV failures (Kumar and Kumar, 2017).

Country	PV technology	Period	Main defects	Evaluation and detection techniques	Refs
India	mono-Si	22 years	– EVA discoloration – Delamination in back-sheet – Hot spot – Corrosion of fingers, bus-bars and interconnects – Junction box corroded	– Visual inspection – IR thermography – Insulation resistance – I-V characteristic	Rajput et al. (2016)
India	multi-Si	2.5 years	– Snail trails – EVA browning – Disconnected cell, interconnect ribbon – Junction box defects – Hot spots	– Visual inspection – IR thermograph – I-V characteristic	Sharma and Chandel (2016)
Italy	multi-Si	3 years	– Snail trails – Micro-cracks in cells – Fingers blackened	– Visual inspection – dielectric withstand – I-V characteristic – Wet Leakage Current – Electroluminescence	Dolara et al. (2016)
India	mono-Si	20 years	– EVA discoloration – Busbar and finger gridlines corrosion	– Visual inspection – Electroluminescence – Dark lock-in thermography	Sinha et al. (2016)
Italy	c-Si	20 years	– EVA discoloration – Junction box rust – Delamination – Front glass defect – Busbar corrosion – Fingers discoloration – Cell interconnect ribbon discoloration	– Visual inspection – I-V characteristic – Electroluminescence – Laser beam-induced current	Pozza and Sample (2016)
India	mono-Si	28 years	– Discoloration of encapsulant – Front grid and antireflective coating oxidation – Delamination – Glass breakage – Bubbles on the back sheet – Hot spots	– Visual inspection – I-V characteristic – Thermal imaging	Chandel et al. (2015)
Algeria	mono-Si	28 years	– Discoloration of encapsulant – Broken – Abrasion of glass, – Delamination – Hot spot – Front grid fingers oxidation	– Visual inspection – I-V characteristic	Bandou et al. (2015)
Algeria	mono-Si multi-Si	11 years	– EVA Discoloration – Corrosion of cell-interconnect busbar – Cracks in cells – Deterioration of anti-reflection coating	– Visual inspection – I-V characteristic	Kahoul et al. (2017)
Algeria	mono-Si	12 years	– EVA discoloration – Delamination, – Busbar corrosion – Cracking of solar cell – Glass breakage – AR coating deterioration – Solder bond degradation	– Visual inspection – I-V characteristic	Bouraiou et al. (2017)

degradations and failure modes were conducted after 20 years of field exposure using electrical tests, electroluminescence, and laser beam-induced current (LBIC) in survey (Pozza and Sample, 2016). Various defects such as discoloration, rust in the junction box, delamination, finger defects, cracks, dark areas, scratches, busbar corrosion were found. Yellowing of encapsulant was the main defect which affected all modules. In the research work of (Chandel et al., 2015) in western Himalayan region of India, an experimental investigation on mono-crystalline-silicon PV modules after 28-year field operation using different techniques like visual inspection, thermal imaging and indoor I-V characteristic measurements was carried out in order to study the impact of PV degradation on solar pump performance, reliability and life-expectancy under field conditions. The EVA discoloration, delamination, front grid fingers and anti-reflective coating oxidation, glass breakage and bubbles in backsheet were the main defects observed in this field study. A summary of recent studies about the PV failures is provided in Table 1. In the desert region of Algeria (Adrar) two studies

Table 2
Monthly average of daily weather parameters (2014).

Months	GHI (KWh/m^2)	T_{min} (°C)	T_{max} (°C)	RH (%)	W_s (m/s)
January	4.35	4.6	26.5	38	2.8
February	5.49	7.1	31.1	26	2.9
March	6.64	7.6	32.7	21	3.2
April	7.73	14	40.6	14	3.6
May	7.8	20	44.1	12	3.6
Jun	8.1	22.3	48	11	3.1
July	7.48	28.7	49.4	8	3
August	6.96	26.5	49	13	3.3
September	6.16	24	45.7	15	5.1
October	5.48	15.2	42.3	18	3.4
November	4.23	8	34.7	35	2.8
December	4.26	2.2	25	43	2.7