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Reliability Analysis of Photovoltaic Systems for Specific Applications

Laurentiu Fara and Dan Craciunescu

Abstract

This contribution is dedicated to the analysis of a reliable PV system for specific applications. The reliability study was based on: (1) the RAMS (Reliability, Availability, Maintenance, and Safety) model applied to a PV system by using a simulation SYNTHESIS platform developed by ReliaSoft, and (2) the simulation of the PV system using the SYNTHESIS platform and TM-21 Calculator software developed by ENERGY STAR. The objective of this analysis was to obtain a more stable and long-lasting operation of a PV system regarding reliability, maintainability, availability and degradation of the system.

Keywords: reliability, maintainability, availability, degradation, PV system, simulation tools, RBD

1. Introduction

Due to various incentive programs and local market conditions in several European countries, as well as around the world, the PV systems represent a widespread solution for residential houses and other autonomous applications. This approach raises new and important issues related to the efficiency, reliability and safety of the PV systems, either autonomous or integrated in the electrical grid [1, 2].

In the case of grid-connected PV systems, the occurrence of system failures may affect the operation of other interconnected systems, that is why a thorough reliability analysis of such systems should be carried out [3–5]. The reliability analysis also makes it possible to establish an acceptable maintenance plan for both the user and the system as efficiently as possible [6, 7]. However, a reliability analysis is often missing from the feasibility study of photovoltaic systems or is treated superficially due to an incomplete methodological approach or lack of specific simulation tools [8, 9]. A PV system for LED lighting applications has been analyzed [10, 11]. To overcome the reported inconveniences, it is envisaged the reliability analysis, using RAMS (Reliability, Availability, Maintainability, and Safety) statistical models through accelerated testing and application of stress levels [12–15]. Starting from ground studies, the failures of PV systems have shown that manufacturers do not correctly perform reliability analysis of their PV modules' lifetime. For this reason, a small part of the PV modules fails before the lifetime specified by the manufacturer [16]. Reliability analysis applies to both PV systems, and simple systems, such as LED-based lighting lamps [17].

The authors proposed and carried out the reliability analysis of solar cells for specific meteorological conditions [16, 18, 20, 21]. To assess the reliability of the

integrated PV system with LED lighting applications, its operating characteristics have been used for a time period [19], and in the case of the simple LED lighting system there were used thermal characteristics of the studied LED lamp [22, 23].

The most relevant analyzes proposed by the authors in this paper are based on reliability block diagrams (RBDs) required for development of RAMS for studied PV systems. RBD diagrams have been developed for: (1) definition of PV systems, (2) description of interdependence between components, (3) identification of how they degrade/fail, and (4) appreciation of how the PV system reliability is influenced.

2. Background, state of the art and simulation tools

2.1 Background

The reliability of a product can be defined as the probability of performing its tasks without incidents within a specified time, under previously established conditions. On this basis, the quality of a product is determined, the reliability concept being applied in almost all areas of engineering, in the preventive maintenance of systems and their components. It is envisaged the modeling of the product's lifetime, represented by the time it has worked successfully or its time until the moment of failure. For the purpose of accurately determining the lifetime, it has been proposed an accelerate product testing (qualitatively or quantitatively during its lifetime) [25, 29].

Qualitative accelerated testing only provides information about system malfunctions or ways of failure. Qualitative tests do not quantify the system's life (or reliability) characteristics under normal conditions of utilization, but provide valuable information on the type and level of demands to use during a later quantitative test. In qualitative accelerated testing, the expected result consists in identifying deficiencies and ways of failure without predicting the life of the product under normal conditions of utilization [2, 24, 26].

Accelerated quantitative testing involves the estimation of product lifetime characteristics, obtained under normal conditions of utilization after an accelerated test. High accelerated life test (HALT) provides various information about the product and its failure mechanisms. Accelerated quantitative testing consists of tests designed to quantify the life characteristics of a product, component or system under normal conditions of utilization, and to provide information on determining the reliability of the system (probability of system failure under various conditions, life expectancy, average lifetime). It can be used to carry out risk assessments or for comparison of different design methods [9].

Two acceleration methods were designed [9] for use of: (1) acceleration rate and (2) stress acceleration, in order to obtain time data on product failure at an accelerated rate. For products where use of acceleration rate is impractical, a second method can be applied, in which the normal stress level of a product is exceeded.

2.2 State of the art

The reliability of photovoltaic systems and their components/elements (solar cells, PV modules, electrical storage systems, inverters, regulators, etc.) are the key issues in manufacturing performance and financially competitive photovoltaic installations. For this purpose, a number of methods for testing and improving the reliability of PV products have been studied [13, 15], such as: (1) the accelerated test method for solar cells [27]; (2) analysis of defect detection and degradation

mechanisms detection for solar cells [14], as well as PV systems and their components [28]; (3) energy production forecasting based on the rate of failure and degradation of PV systems and their applications [12].

In this paper the authors proposed to integrate some of these methods by using a specialized complex simulation platform, namely SYNTHESIS, which allows a physical and statistical approach for PV products; it is envisaged the development of a highly useful RAMS methodology, both in research and in the efficient design of PV systems and their applications [29–31].

2.3 Methodology

In order to perform a fairly accurate reliability analysis of the PV systems and their components, the authors of this paper have chosen to use the SYNTHESIS simulation platform developed by **ReliaSoft** [33]. The simulation methodology is intended to explain how the simulation platform modules work. On this basis the obtained results regarding: (1) solar cell, (2) PV system, including its components, and (3) integrated PV system can be understood. The following modules of the simulation platform were used in the analysis:

- a. The **Weibull++ software tool** is the industry standard in life data analysis (Weibull analysis) for many companies around the world. This software performs life data analysis using multiple lifetime distributions with a clear and concise, reliability-oriented interface. The features of Weibull++ provide the most comprehensive set of tools available for life data reliability analysis. The software supports all types of data and all distributions commonly used throughout the product's lifetime.
- b. The **ALTA software tool** provides an intuitive way of complex and powerful mathematical models for quantitative analysis of accelerated life tests. Accelerated lifetime testing techniques, combined with powerful data analysis methodologies, reduce testing time for the product, thus providing faster product launch times, lower product development costs, as well as lower warranty costs.
- c. The **BlockSim software tool** provides a comprehensive platform for the reliability, availability, maintenance and related products analyzes. The software provides a graphical interface that allows modeling of both simple and complex systems and processes using reliability block diagrams (RBDs), failure tree analyzes (FTAs), or combinations of both approaches. Using accurate calculations and/or discrete events simulation, BlockSim facilitates a wide range of analyzes: (1) system reliability analysis, (2) identification of critical components (important for reliability), (3) optimal allocation of reliability, (4) system maintenance analysis (determining the optimal intervals for preventive maintenance), (5) analyzing the availability of the system (determining the operating time, availability/unavailability), (6) performing calculations for obstacle identification, production capacity estimation, etc., (7) estimating the cost of the life cycle.
- d. The **RENO software tool** is a platform that allows complex analyzes for any probabilistic or deterministic scenario. Chart models can be created for complex reliability analyzes, risk and safety analyzes, decision making, or maintenance planning. The Monte Carlo simulation methods offer a number of definitions and constructions that allow modeling of the examined situations. Simulation results can be applied to estimate/optimize risk analysis, complex modeling of reliability and maintenance planning.

- e. The **RGA software tool** allows the application of reliability enhancement models for data analysis from both development tests and on-site repair systems. In the development phase, the software allows to quantify the increase in reliability achieved for each product prototype and also provides advanced design, planning, and reliability enhancement management methods. The software also offers opportunities for ground-based system analysis, including a test utility for system reliability.

3. Modeling and numerical simulation of PV system components using RAMS analysis: discussion of the results

3.1 Basic concepts

The studied integrated PV system is defined as a PV application, which uses a consumer for a specific application (see **Figure 1**). The implementation of the RAMS analysis of the PV system was performed using the modeling and simulation SYNTHESIS platform for system reliability [32]. When it is analyzed the reliability of studied solar cells, the simulation module used in the SYNTHESIS platform was Weibull/ALTA. This module statistically addresses reliability issues through statistical repartitions and together with the ALTA module contributes to the accelerated life tests. For the analysis of the PV system studied in the paper, the BlockSim simulation module was used within the same platform. The simulation of the PV systems is based on the RBD diagram, as well as on the component types and the way they are arranged in the system.

For a rigorous understanding of the RAMS analysis for the PV integrated system, it was analyzed the highlighting of solar cell degradation. By performing a statistical analysis based on the Weibull, Exponential and Normal repartitions, it was possible to estimate the most frequent events (characterized by main meteorological parameters: solar irradiance, temperature and humidity) that contribute to the most probable degradation of solar cells during their lifetime. The statistical approach was correlated with the accelerating lifetime method by stressing solar cells using different meteorological parameters (**Figure 2**). The present study considered only the three meteorological parameters mentioned above, which have an essential role in cell degradation.

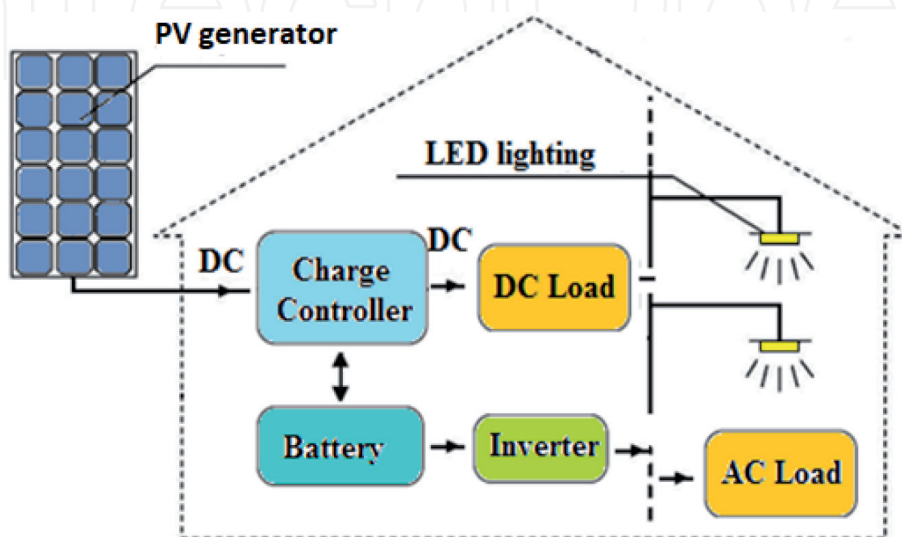


Figure 1.
PV integrated system concept.

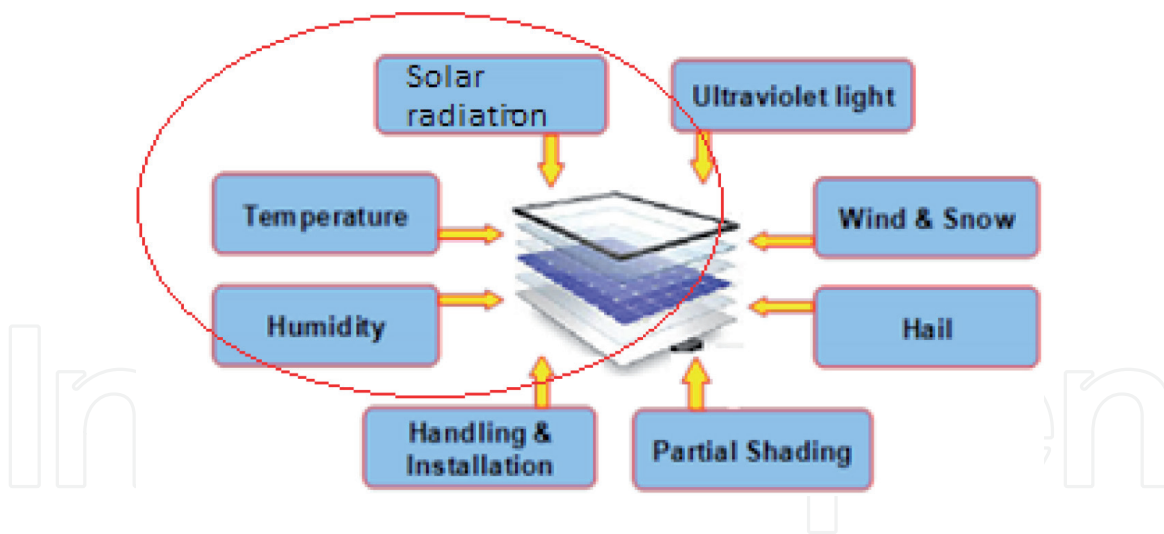


Figure 2.
Accelerated stress test diagram.

3.2 Reliability analysis of solar cells

Reliability analysis of solar cells has been developed based on the accelerated testing method, which has certain advantages: (1) avoiding testing in real and more severe conditions that can lead to cell degradation/failure, (2) determining the frequent reasons that determine cell failure. Highly accelerated stress screening (HASS) aimed at identifying defects in as short time as possible compared to the standard method (based on cell monitoring and results analysis), which may take several months/years. Accelerated testing (HASS) can be performed with either a weather parameter (e.g., temperature/solar irradiance) or combined with few weather parameters (such as, temperature, humidity and solar irradiance). Within this paper the HASS analysis was implemented in the version of the three key meteorological parameters.

The authors' study also looked at establishing the best statistical repartition used to make the most accurate predictions of the of solar cells life time. Three types of statistical repartitions, namely Weibull, Exponential and Normal, were evaluated using the SYNTHESIS software, and based on the correlation cause (determined by one of the three main meteorological parameters)—occurrence (characterized by the degradation degree of the solar cell) it was possible to obtain the probabilities for the three repartitions (the black curve defines the Weibull repartition, the green one defines the normal repartition, and the purple one defines the exponential repartition), using the HASS test. In **Figure 3a** the curves of the mentioned statistical repartitions were obtained. It can be seen that Weibull repartition is the closest to the values of the three main meteorological parameters. The accelerated test has highlighted that the most influential meteorological parameter in solar cell degradation (characterized by most occurrences) is temperature, followed by humidity and further by solar irradiance. **Figure 3b** shows the temporal evolution (in hours) of the degradation level of solar cells for two operating modes: under stress conditions (purple continuous curve) and in standard conditions (blue continuous curve).

Under standard operating conditions, a major degradation level (about 70%) is achieved over a time interval of 2500 h, while under stress conditions the same level of degradation of 70% is achieved over a time interval of 1600 h (see **Figure 3b**).

Using the stress results of the HASS test (purple curve in **Figure 3b**), it was possible to determine by numerical simulation in the SYNTHESIS platform, the limit value of the cell operating time in normal conditions, respectively 1600 h, according to the curve in **Figure 4a**. The accelerated test also enabled the probable number of

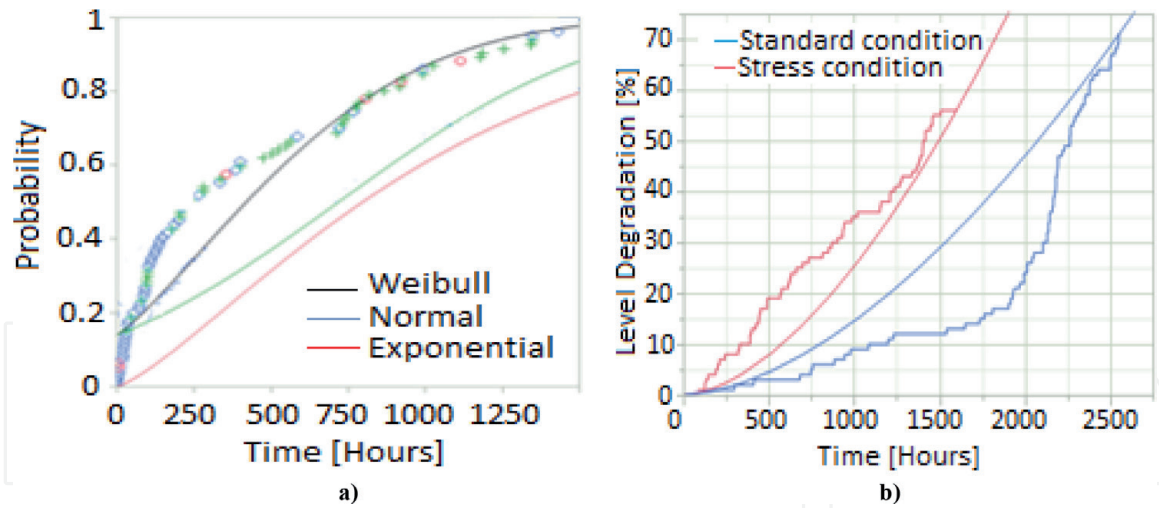


Figure 3. (a) The life distribution of solar cells for three distribution functions, (b) degradation level of solar cells simulation in two modes: standard conditions and stress conditions.

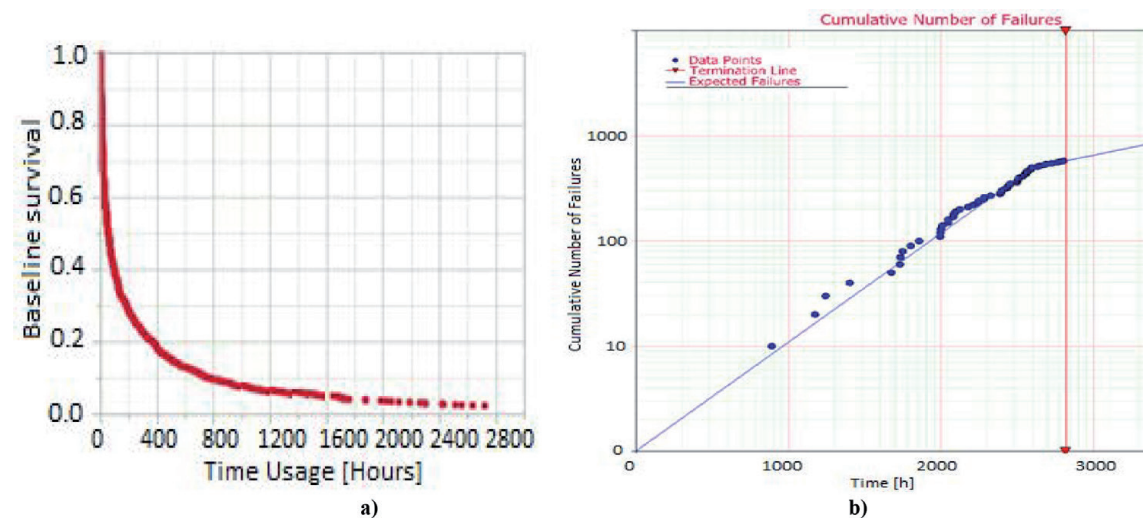


Figure 4. (a) Baseline survival of solar cells module simulation in stress conditions, (b) cumulative number of failures as function of time.

solar cell failures (see **Figure 4b**) within the range of 1000–2800 h, with a higher concentration between 1500 and 2800 h according to the results from **Figure 4a**; the linear dependence defines the expected failures curve based on Weibull repartition.

3.3 RAMS analysis of the PV system

The analyzed PV system consists of a set of components, arranged to achieve the established performance and to provide acceptable reliability. The reliability characteristics of the PV system and its components can be presented in RBD-type diagrams illustrating their possible failures. These failures are due to a facile analysis of the failures risk.

The RAMS analysis for the photovoltaic system aimed to determine how the system and its components worked over a 5000-h period (about 7 months). For this purpose, it was analyzed the time evolution of the PV generator efficiency, as well as of the PV system's battery efficiency. There were noted high fluctuations for the efficiency of PV generator, slower fluctuations in battery efficiency based on fuzzy logic controller (FLC) and maximum power point tracking (MPPT) methods (see **Figure 5**). The specific application (electric consumer) will be discussed further in Section 3.5.

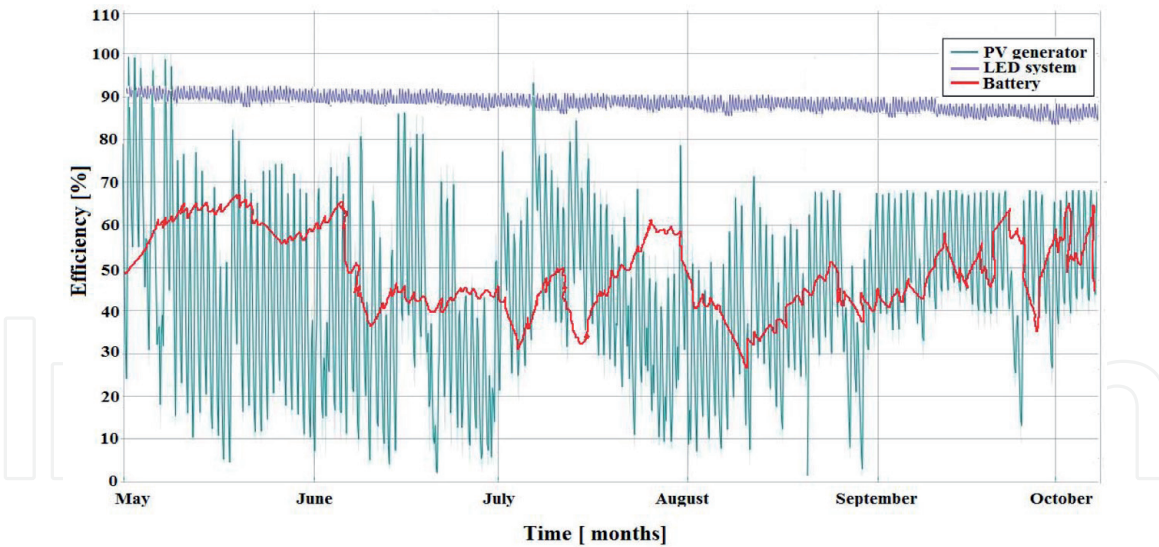


Figure 5.
 Efficiency and functionality of a PV system for its main three components: (1) PV generator, (2) battery and (3) electrical load.

Using the results obtained in **Figure 6a** we could establish the availability diagram of the PV system giving the operation time and unavailability periods (when the PV system is not working). The unavailability periods are usually small; after 3000 h of operation there is a 500-h period when the PV system has to be repaired due to different failures. In **Figure 6a** there are also analyzed the main components of the PV system (PV modules, battery and load) to be maintained. The complex analysis of defect risks and preventive planned maintenance of the components aims at avoiding spontaneous malfunctions and premature degradation of the PV system.

In **Figure 6b** the level of degradation for each component of the PV system is presented. Although, excepting the inverter, all other components exceed the critical threshold to the end of the test (3500–4500 hours); however, two components, respectively the PV modules and the storage system, are the most vulnerable to failure (exceeding the critical level much earlier). The simulation tools allowed to obtain the efficiency degradation analysis of the PV system (see **Figure 7a**). A good PV system is characterized by small fluctuations of the time evolution of efficiency, determining a usual degradation based on normal operation requirements for the analyzed simulation period (5000 hours).

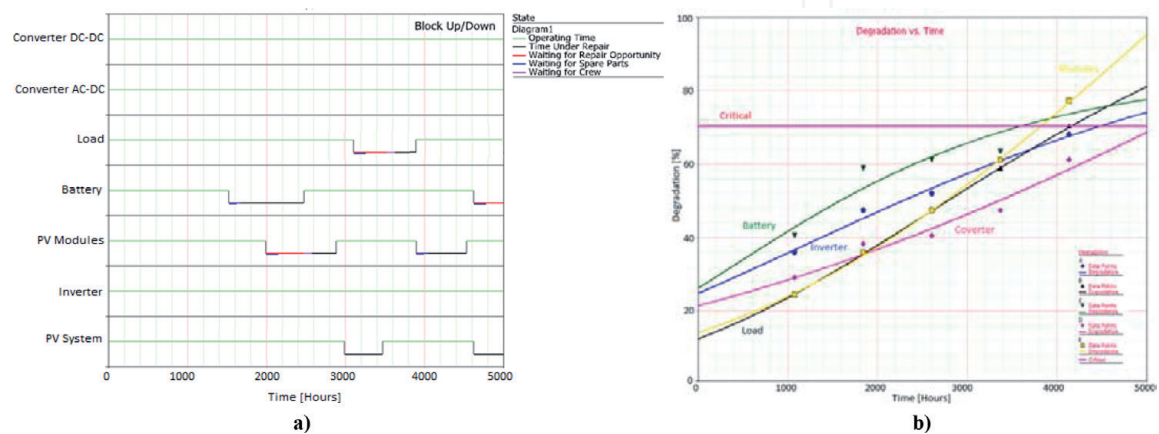


Figure 6.
 (a) PV system availability/unavailability diagram, (b) degradation of system components based on availability/unavailability diagram.

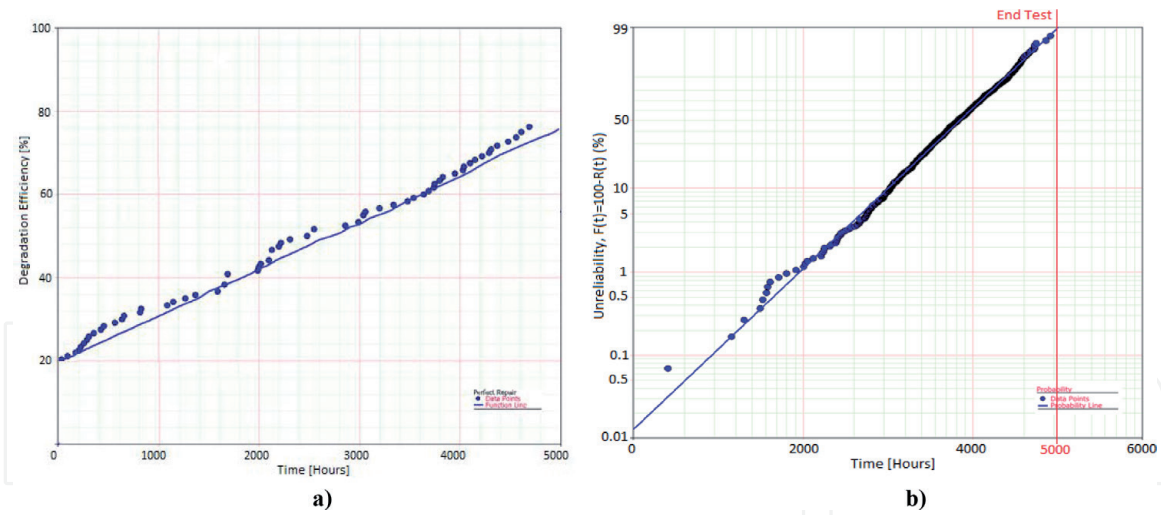


Figure 7.
(a) Time degradation of PV system efficiency, (b) statistical unreliability of the PV system in time.

The probability of non-functioning of the PV system over time is sensitive after 2000 hours of the product use (see **Figure 7b**). It is noted the role played by this diagram in RAMS analysis; when the components of the PV system start to degrade, the number of failures increases, that leads to the need for more frequent interventions (repairs) on the PV system.

The RAMS approach, based on the SYNTHESIS simulation platform, was able to obtain preliminary information on the time behavior of the PV system and its components (from the point of view of its reliability and maintenance) which could be very useful for its proper design.

3.4 RAMS analysis specific to a PV system

A PV system based on specific application has been studied. Analysis of the PV integrated system was possible using the availability/unavailability diagram of its components (**Figure 8**). This diagram describes the interdependence between the

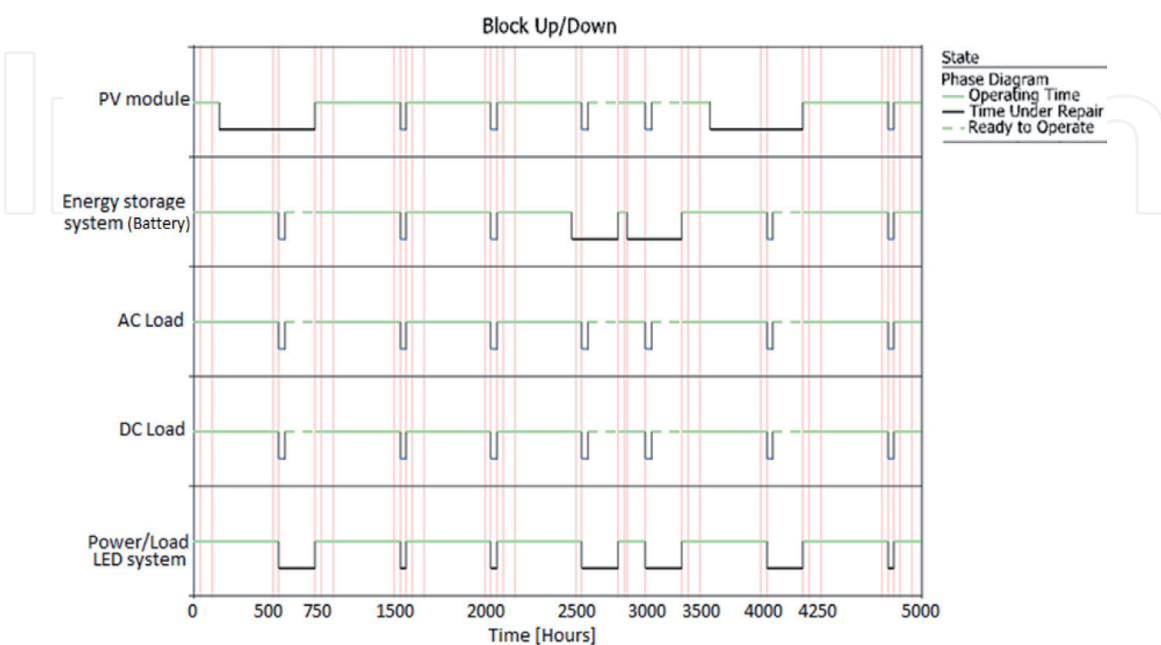


Figure 8.
Diagram of the availability/unavailability (up/down) of the PV integrated system.

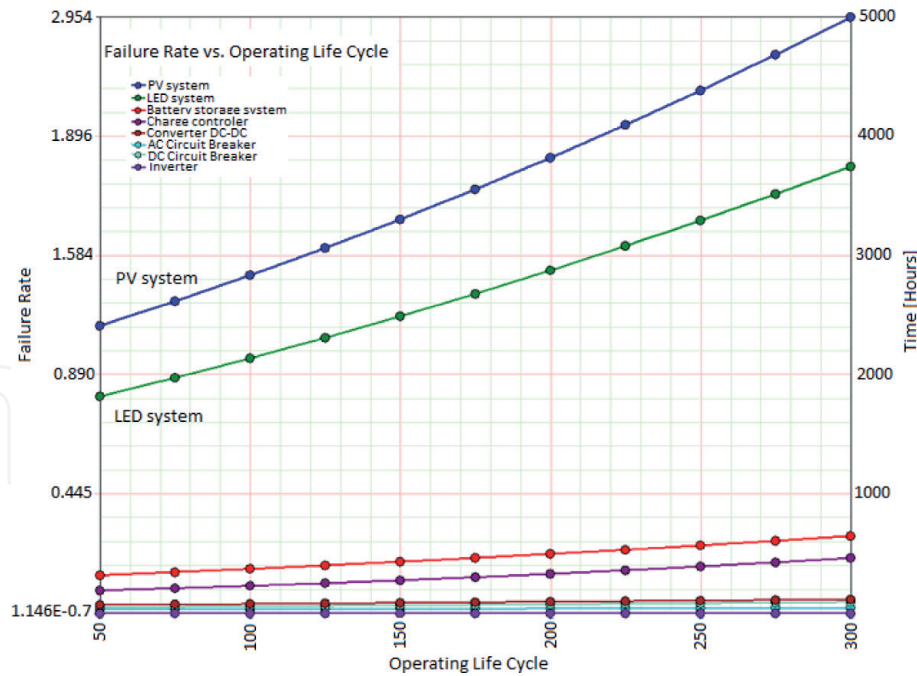


Figure 9. Time evolution (in hours) of components failure rate of the PV system depending on operating life cycle.

components and defines how the system works. An important parameter of the availability/unavailability diagram is the power load of specific application that is influenced by the operating mode (using either serial, parallel or mixed type configurations). Each component of the PV system is characterized by a repairable block, parameterized in the BlockSim simulation module.

A feature of the up/down diagram is the planning of the PV system maintenance; thus, as a result of prompt interventions in order to repair its components, spontaneous or irreversible failures are eliminated, the system thus becoming functional over the entire lifetime.

The failure rate for each component of the PV system was also being studied. The highest failure rate is presented, by the PV modules, according to the results in **Figure 9**. This is due to the specific configurations for these components (series, parallel or mixed) that increase their failure rate compared with other components (battery, inverter, regulator, etc.).

4. Concluding remarks

The authors have proposed the reliability analysis of a PV system for a specific application using a performance SYNTHESIS simulation platform, which allowed the system to function more accurately by identifying probable defects in certain components of the system.

This contribution is based on an original approach of RAMS reliability analysis. It was considered the adaptation of up/down reliability block diagrams (RBD) from *the reliability theory and applications* for a photovoltaic system in order to determine its functionality and availability and to establish its duration of non-functionality (required to implement the PV system maintenance). The obtained results of this study are in good agreement with the reliability published studies from the point of view of the methods used [1, 2, 6, 7, 17, 26, 28].

The main results obtained by the authors in this article could be synthesized as follows:

- The simulation of the solar cells operation on an accelerated test basis (under the influence of three essential meteorological parameters: solar irradiance, temperature and humidity) allowed to put in evidence the normal operating time under normal/stress conditions, defining the initial degradation time of stressed solar cell (determined by a possible degradation of the cell's I-V characteristics). The Weibull most probable statistical repartition has also been identified using a proper solar cells testing; on this basis, the operating duration in which a significant concentration of defects is achieved, was determined.
- The simulation of the PV system operation allowed to obtain information on the availability/unavailability of the system, based on a RBD diagram. Using this diagram, PV components that may exhibit a higher rate of degradation (PV modules, electrical battery) during operation are identified. Also, useful information on degradation of the PV system was obtained (based on the efficiency degradation curve and the non-functional curve).

The results obtained by the authors were partially validated by other authors research studies, regarding the availability and degradation of analyzed systems [34, 35].

In order to increase the reliability of the PV system and its components, it is necessary to develop an elaborated failure management strategy that involves knowing the initial level of reliability and developing efficient solutions for planning and assessing the probable risks of failure. The essential directions for such a strategy could be as follows:

- experimental accelerated testing of the PV system under the influence of possible degradation factors;
- identifying the cause of failure in experimental conditions, that is intended to isolate possible failures occurring in the PV system;
- implementing effective corrective actions to significantly reduce the failures of the PV system.

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References

- [1] Huffman DL, Antelme F. Availability analysis of a solar power system with graceful degradation. In: Proceedings of the Reliability and Maintainability Symposium, Fort Worth, TX; 2009
- [2] De Graaff D, Lacerda R, Campeau Z. Degradation mechanisms in Si module technologies observed in the field; their analysis and statistics. In: Presentation at PV Module Reliability Workshop; NREL. Denver, Golden, USA; 2011
- [3] Kececioglu DB. Reliability Growth, Reliability Engineering Handbook. 4th ed. Vol. 2. Englewood Cliffs, New Jersey: Prentice-Hall; 1991. pp. 415-418
- [4] IEC International Standard. Reliability growth—Statistical test and estimation methods. In: IEC 1164 International Electrotechnical Commission; 1995
- [5] Ishii T, Takashima T, Otani K. Long-term performance degradation of various kinds of photovoltaic modules under moderate climatic conditions. *Progress in Photovoltaics: Research and Applications*. 2011;19:170
- [6] Crow LH. Evaluating the reliability of repairable systems. In: IEEE Proceedings of the Annual Reliability and Maintainability Symposium; 2004. pp. 73-80
- [7] Crow LH. Methods for reducing the cost to maintain a fleet of repairable systems. In: IEEE Proceedings of the Annual Reliability and Maintainability Symposium; 2003. pp. 392-399
- [8] Herrmann W, Bogdanski N, Reil F, Kohl M, Weiss K, Assmus M, Heck M. PV module degradation caused by thermo-mechanical stress: Real impacts of outdoor weathering versus accelerated testing in the laboratory. In: Proc. Vol. 7773, Reliability of Photovoltaic Cells, Modules, Components, and Systems III; 777301; 2010
- [9] Hoffmann S, Koehl M. Effect of humidity and temperature on the potential-induced degradation. *Progress in Photovoltaics: Research and Applications*. 2012;22:173-179
- [10] Sterian A, Sterian P. Mathematical models of dissipative systems in quantum engineering. *Journal of Optoelectronics and Advanced Materials*. 2012;2012. Article ID 347674, 12 pages. DOI: 10.1155/2012/347674
- [11] Power Semiconductor Reliability Handbook, Alpha and Omega Semiconductor. 2010
- [12] Holley W, Agro S, Galica J, Yorgensen R. UV stability and module testing of non-browning experimental PV encapsulant. In: IEEE Photovoltaic Specialists Conference; 1996
- [13] Nelson W. An application of graphical analysis of repair data. *Quality and Reliability Engineering International*. 1998;14:49-52
- [14] Kijima M. Some results for repairable systems with general repair. *Journal of Applied Probability*. 1989;20:851-859
- [15] Mettas A. Reliability allocation and optimization for complex systems. In: Proceedings of the Annual Reliability & Maintainability Symposium; 2000
- [16] Meydbray Y, Wilson K, Brambila E, Terao A, Daroczi S. Solder joint degradation in high efficiency all back contact solar cells. In: IEEE Photovoltaic Specialists Conference; 2008
- [17] Collins E, Miller S, Mundt M, Stein J, Sorensen R, Granata J, Quintana M. A reliability and availability sensitivity study of a

- large photovoltaic system. In: IEEE Photovoltaic Specialists Conference; 2009
- [18] McMahon T. Accelerated testing and failure of thin-film PV modules. *Progress in Photovoltaics: Research and Applications*. 2004;12:235-248
- [19] Wohlgemuth J. Tutorial/short course on reliability: PV cells, modules, and systems. In: IEEE Photovoltaic Specialists Conference. Seattle, WA; 2011
- [20] Aoki Y, Okamoto M, Masuda A, Doi T. Module performance degradation with rapid thermal-cycling. In: *Proceedings of Renewable Energy*; 2010
- [21] Dhere N, Pethe S, Kaul A. Photovoltaic module reliability studies at the Florida Solar Energy Center. In: IEEE International Reliability Physics Symposium; 2010
- [22] Kim SK, Kim SY, Choi YD. In: *Proceedings of 10th Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems*; 2006. pp. 377-379
- [23] Handbook. Lumileds, understanding power led lifetime analysis. Technical report. Philips Lumileds Lighting Company; 2007
- [24] Crow LH. A methodology for managing reliability growth during operational mission profile testing. In: IEEE Proceedings of the Annual Reliability and Maintainability Symposium; 2008. pp. 48-53
- [25] Dhere N. Reliability of PV modules and balance-of-system components. In: IEEE Photovoltaic Specialists Conference; 2005
- [26] Copper JK, Bruce A. Calculation of PV system degradation rates in a hot dry climate. In: Asia Pacific Solar Research Conference; Canberra, Australia; 2016
- [27] Desombre A. Methodology for a reliability study on photovoltaic modules. In: *Proceedings of the third European Commission, PV Solar Energy Conference*. Cannes, France; 1980. pp. 741-745
- [28] Vazquez M, Rey-Stolle I. Photovoltaic module reliability model based on field degradation studies. *Progress in Photovoltaics*. 2008;16:419
- [29] Wohlgemuth J. Long-term photovoltaic module reliability. In: NCPV and Solar Program Review Meeting, NREL/CD-520-33586; 2003. pp. 179-183
- [30] Van Weeran N. Degradation of photovoltaic modules in Alice Springs, Australia [undergraduate thesis]. School of Photovoltaics and Renewable Energy Engineering. The University of New South Wales; 2013
- [31] Granata J, Boyson W, Kratochvil J, Quintana M. Long-term performance and reliability assessment of 8 PV arrays. In: IEEE Photovoltaic Specialists Conference; 2009
- [32] Craciunescu D, Fara L, Sterian P, Bobei A, Dragan F. Optimized management for photovoltaic applications based on LEDs by fuzzy logic control and maximum power point tracking. *Nearly Zero Energy Communities*. Springer Proceedings in Energy. 2017. DOI: 10.1007/978-3-319-63215-5_23
- [33] Synthesis Platform. Available from: <http://www.reliasoft.com/synthesis/downloads.htm> [Accessed October 2017]
- [34] Mahdi I, Chalah S, Nadji B. Reliability study of a system dedicated to renewable energies by using stochastic petri nets: application to photovoltaic (PV) system. In: 4th International Conference on Energy and Environment Research, ICEER 2017.

17-20 July 2017; Porto, Portugal. Energy
Procedia 136; 2017. pp. 513-520

[35] Lavrova O, Flicker J, Johnson J,
Armijo K, Gonzalez S, Schindelholz E,
Sorensen R, Yang B. PV Systems
Reliability: Final Technical Report.
Sandia Report-SAND2015-376607; 2015

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