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A Reliability Study of Photovoltaics Energy Systems in DC Microgrid

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Abstract

In this paper, a lifetime of Photovoltaics PV is studied based on the evaluation of the reliability of the DC microgrid. The analysis has a comprehensive consideration of the elements of the inverter and converter composed of a renewable energy system and its process during bad weather as a supplementary measure for the intermittent output of renewable energy sources connected to the DC microgrid. A battery and a boost converter for the battery were used to keep the voltage constant. The output of the battery varies according to the output fluctuation of the renewable energy source. At this time, the life analysis result of the switching devices that are used in the boost converter is introduced. To prevent system downtime and increase maintenance costs due to converter failures connected to the battery, a converter life analysis is required. Considering that the main failure mechanism of switching devices used in converters is thermal stress, and power loss due to thermal stress. Based on the above, the lifetime characteristics of semiconductor devices are analyzed. The main contribution of this work is conducting the lifetime analysis of solar energy system that is used in the DC microgrid with different weather conditions.

Keywords: DC microgrid, physics of failure (POF), reliability, Lifetime of Photovoltaics

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1. Introduction

To improve the reliability of the DC microgrid based on the renewable system, it is necessary to analyze the lifespan of the elements used in the circuit to make it possible to predict long-term operation and maintenance periods. To cope with the output variability of new and renewable energy sources, the voltage is kept constant by using a battery or an energy storage system (ESS). In the case of controlling the DC link single voltage using a battery and a converter, the reliability of the switching device is closely related to the reliability of the system. The main failure mechanism of the converter switching element is thermal stress, and based on this, an analysis of the life span of the switching element is required using power loss [1]. To improve the reliability of a system based on a renewable energy source, Research related to the lifespan analysis of the system is being conducted, and representative researches include the effect of power electronic devices of a photovoltaic system on the lifespan of the system [2], and a study analyzing the lifespan characteristics of inverters in grid-connected photovoltaic systems [3]. In this paper, the lifetime characteristics of power semiconductor devices in a photovoltaic system-based renewable energy system were analyzed by applying the physics of failure (POF) technique.

2. Main subject

2.1 Renewable system-based DC microgrid composition

When constructing a DC microgrid based on a photovoltaic power generation system, it is necessary to connect batteries to effectively respond to the variability of solar power output. As shown in Fig. 1, the DC microgrid connected to the battery was constructed using a PV array, a boost converter for the battery, and a battery. In the system, it was assumed that the amount of solar radiation changes periodically and the size of the load was constant, and the research was conducted on the assumption that the battery plays a role in adjusting the DC link single-voltage to a constant level by discharging through a boost converter.

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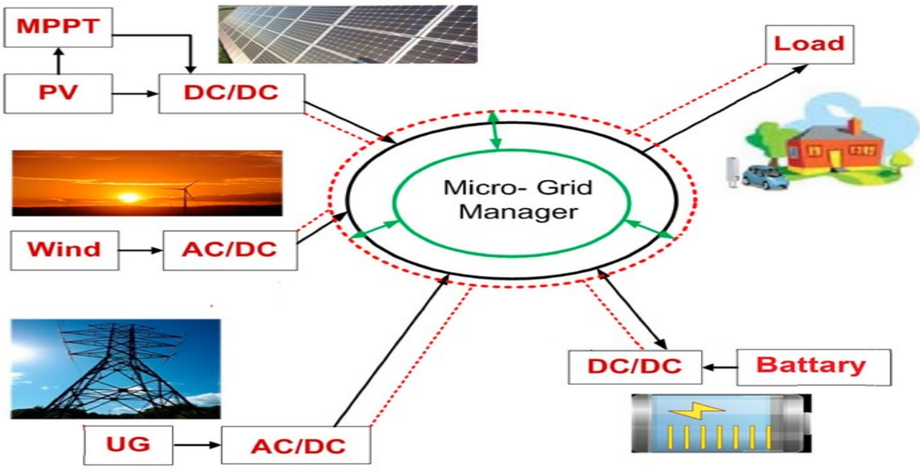

Fig. 1 Composition of a DC microgrid based on a renewable system.

2.2 Switching element life analysis

As the switching element, IGBT was used as a power semiconductor. To proceed with the lifespan analysis of the device, the lifespan is calculated by applying the system operation profile, lifespan model formula, and algorithms related to the data processing as follows [4]. Parameter values related to thermal impedance can be obtained from the data sheet of the IGBT [4]. The lifetime model of the IGBT module is shown in Equation (1) [5], [6]. In the formula, ΔTj is junction temperature change, Tjm means junction temperature, ton means the junction temperature change time, and the values of the temperature stress parameters are obtained using the rain flow counting method [7]. Results and Discussion should be combined It should end with brief conclusions

$$.N_f = (T2 - T1)^{B1} e^{(B2/(273+T)} t^{B3} \quad (1)$$

Where A, B1, B2, and B3, are constant obtained from the power cycling test result of the module. Using Equation (1), the accumulated damage of the switching element during the one-cycle operation profile can be obtained and the lifespan can be predicted [8]. According to Pamgren-Miner's Rule, when k stresses of different magnitudes are applied and a specific material is exposed to the i-th stress for a separate number of times ni, the damage (D) for the stress is as shown in Equation (2) [8].

$$D_i = \frac{n_i}{N_i} \quad (2)$$

Where no means the number of times the ith stress is applied to the material, and Ni is the number of life cycles Nf when the ith stress is applied, which can be obtained through Equation (1). If k stresses are applied based on the same failure mechanism, the damage accumulated by k stresses is as shown in Equation (3).

$$AD = \sum_{i=1}^{k} \frac{n_i}{N_i} \quad (3)$$

Since Nf is the number of life cycles and ni is the number of stress applications, when the value of AD becomes 1, it is considered that a failure has occurred, and the lifespan of used 4 switching devices can be analyzed.

$$Lifetime(year) = \frac{T_{file}}{T_{operated}(AD)} \frac{1}{365} \quad (4)$$

In equation (4), Tprofile is the time of the one-cycle driving profile, and Corporation is the operating time per day of the switching device, During the time of the one-cycle driving profile. It refers to accumulated damage.

3. DC microgrid technology overview

3.1 Power Converter

Most of the distributed power sources, distributed storage devices, and loads that make up the DC microgrid are connected through a power converter.

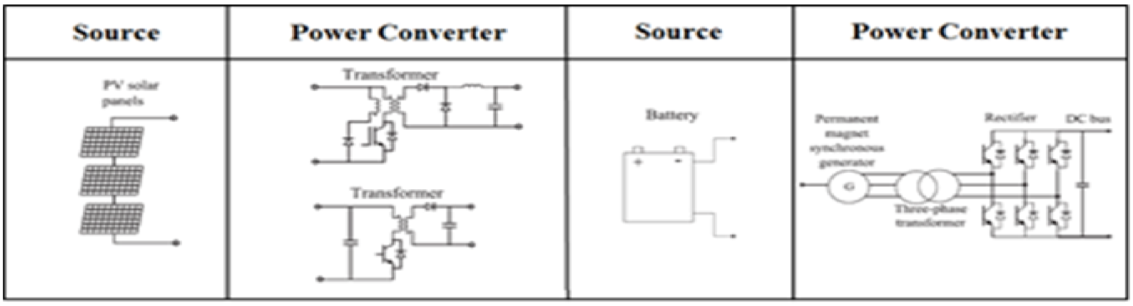

Fig. 2 Converter Topology Depending on Power Source

According to the type of power source shown in Fig. 2, the power supplies of output DC have unidirectional characteristics, such as PV, use unidirectional DC/DC converters, and DC power supplies that have bidirectional characteristics, such as power storage devices that can be charged/discharged, use bidirectional DC/DC converters. In addition, the power output of AC using a rotating machine, such as a wind generator and a microturbine, is connected through an AC/DC converter.

3.2 Power Protection

DC microgrid. has a big difference in that zero-crossing does not occur, so it is necessary to develop a protection technology suitable for DC systems. In addition, a fault protection technique using multiple power converters in the system is required. On the other hand, it is known that some protection sheaths used in AC systems can be used in low-voltage DC systems, but to form a DC system of medium voltage or higher, there is a very large difference in the fault current and overcurrent characteristics of the DC system. Technology development is required. A DC bus is used to transmit power from DC power sources such as renewable energy sources and energy storage devices to the DC load side. The DC bus is a monopolar DC link (one cable) or a bipolar DC link depending on the number of lines used.

3. DC microgrid analysis model

Fig. 3 is a single-line diagram of a model that converted the microgrid demonstration into a DC microgrid. The AC microgrid in Figure 1 was designed to have the same configuration of distributed power and load. Unlike the AC microgrid, there is an AC/DC converter on the secondary side of the 22.9kV/380V transformer, so a voltage of 400V DC is delivered to the load. As can be seen in Fig. 42, DC/AC converters such as solar power and batteries can be omitted, so energy loss due to power conversion can be reduced. On the other hand, the AC power supplied by the power company must be converted through an AC/DC converter. In the case of loads, contrary to AC microgrids, DC loads can be connected without a rectifier, while AC loads require DC/AC power conversion inverters. According to a report by Virginia Tech in the US, 80% of total loads in 2010 are supplied with power through power converters, and the proportion of DC loads is expected to increase further in the future with an increase in the failure of the Large Photovoltaic System as similar as DC Series Arc Fault [9].

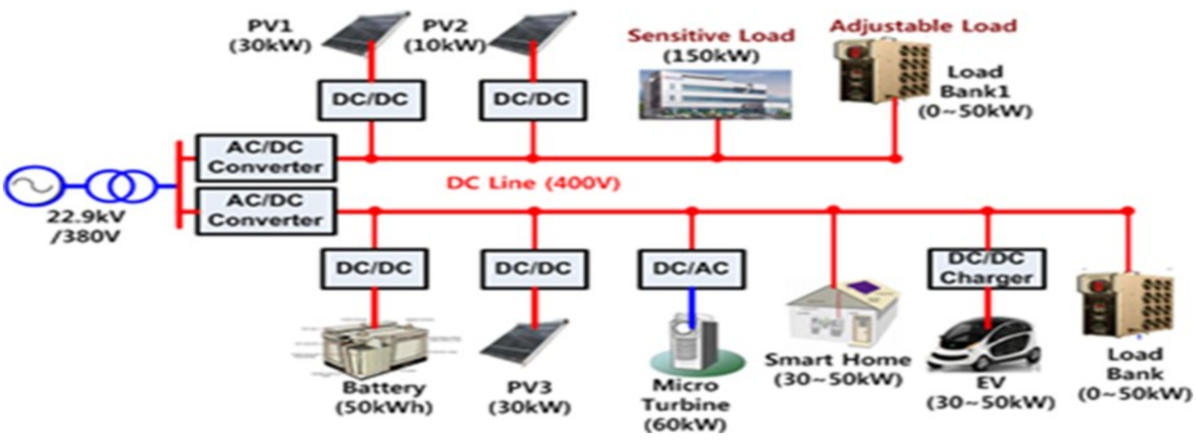

Fig. 3. Configuration of DC microgrid model

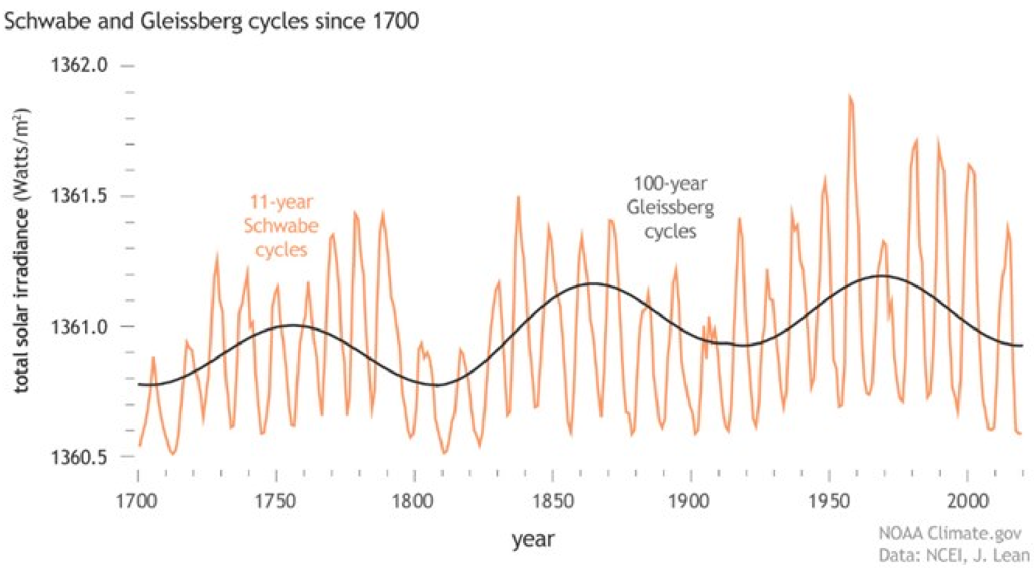

Fig. 4. The Glassberg cycles of 300 years

4. Historical solar cycles

The history of renewals exposes that some solar cycles have extra activity, and that timing isn't completely because it is random. Mostly, 2-3 comparatively strong cycles were heralded and they were followed by 2-3 relatively weak ones [10]. These alternating weak and strong periods tend to be grouped. Figure 4 shows about 300-year periods, a decoration acknowledged as Gleissberg cycles. The Gleissberg cycles: 1700-1810, 1810-1910, and 1910-2021.

5. The Reliability of Photovoltaic

A PV module service life prediction (SLP) reliability model is defined as a time-dependent function that describes the performance evolution of a PV module as the operating period increases. These functions are used to estimate long-term performance degradation from calculated or extracted performance degradation rates. In most cases, the solar community applies a linear regression reliability model of Equation (5) to evaluate long-term performance degradation. However, several researchers reported nonlinearity in the performance (output) deterioration studies of on-site solar modules and systems.

$$.P(t) = P_o\,(1 - K\,.\,t) \qquad (5)$$

Where, $P(t)$ and $P0$ are the evaluation time and initial output, respectively, k is the annual degradation rate [year-1], and t is the time.

Recently, observed polynomial power degradation instead of linear behavior in several PV modules after 35 years of field exposure [11]. Many researchers have proposed a nonlinear output degradation reliability model of Equation (6) with a tunable shape parameter (μ) to optimize these nonlinear various degradation types.

$$.P(t) = P(max)e^{-\left(\frac{\theta}{k.t}\right)^{\mu}} \qquad (6)$$

Where: μ is a shape parameter, and θ is a parameter related to the material. The failure times derived from the linear model is (Equ.5) and the nonlinear model is (Equation 6)

6. The Experimental Results

P where the maximum output of the PV is 30kW, the size of the load is 50 ohm, and the voltage of the battery is 380 V. PV insolation was varied as shown in Fig. 5. Waveform have calculated performed during the rain flow and sunny of the 6 sec operation of the IGBTs used in the boost converter and invertor the lifespan could be calculated based on the standard of using 6 hours a day. It is judged that the lifespan can be predicted..

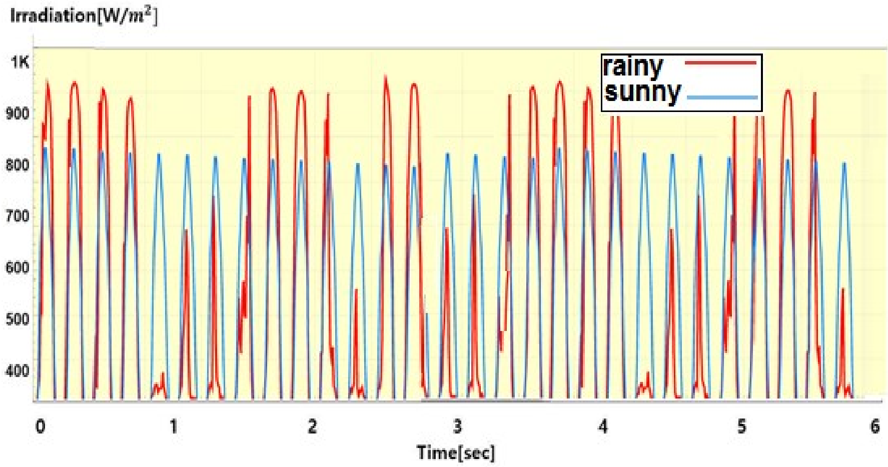

Fig. 5. PV irradiation change graph

7. The Simulation Results and Discussions

The simulation results were observed in Fig. 6. Which shows a lifetime of power obtained from photovoltaics. In addition, Fig.7 demonstrates the energy yield of an evaluated photovoltaic module can be highly dependent on the type of deterioration during the same evaluation time. For long-term performance degradation prediction, the degradation rate (k) can be evaluated either from the physics-based model described above or by fitting the model to performance data after a given period. Figure 8: shows the PV-reliability models in both calibrations linear and nonlinear (Equ. 5 and Equ. 6 respectively). The dotted line represents the long-term performance degradation prediction. Figure 9 Simulate the failure time change with the degradation rate. However, it should be noted that depending on the reliability model used in the calibration process, the estimated or extracted degradation rate may be different for a given degradation data set. For example, in Fig. 8, the linear and nonlinear models are calibrated against PV module performance data after 6 years of field exposure. Using a linear model, a deterioration rate of 1.1% per year is estimated to correspond to a lifetime of 18 years. In comparison, in the nonlinear model, a deterioration rate of 1.2% per year is estimated to correspond to a lifetime of 21 years. From this example, it can be seen that the use of a non-linear model predicts a long lifetime when compared to a linear model, despite a relatively high degradation rate. These differences in degradation rates due to different reliability models require changes in the reporting and interpretation of degradation rates in the photovoltaic community. In practice, the best way to consistently interpret reported degradation rates is to report degradation rates commonly performed by the photovoltaic system and the methods used to extract them. Besides, another concern is using simple extrapolation after a given number of years of field exposure to predict long-term performance.

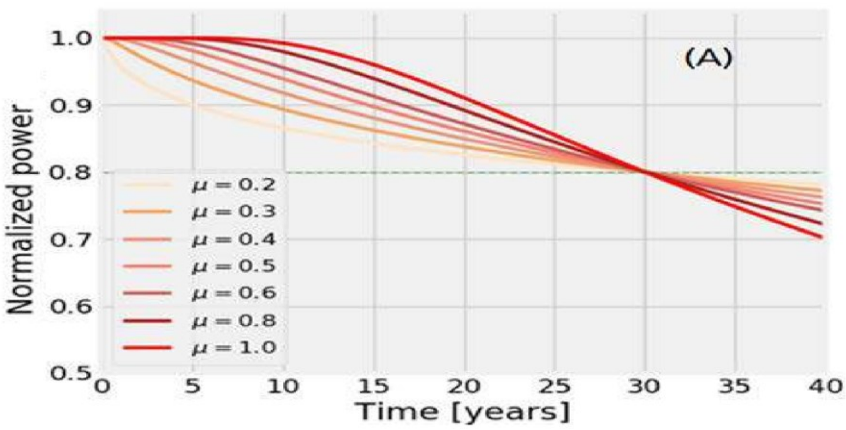

Fig. 6 The lifetime of photovoltaic

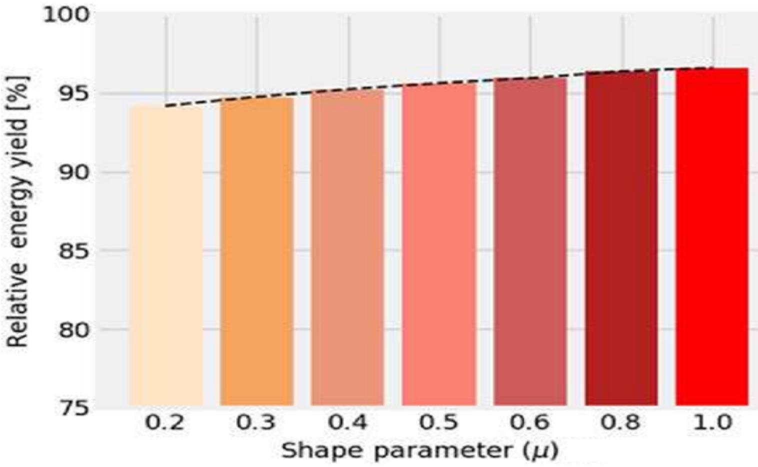

Fig. 7. Dependent on the type of deterioration

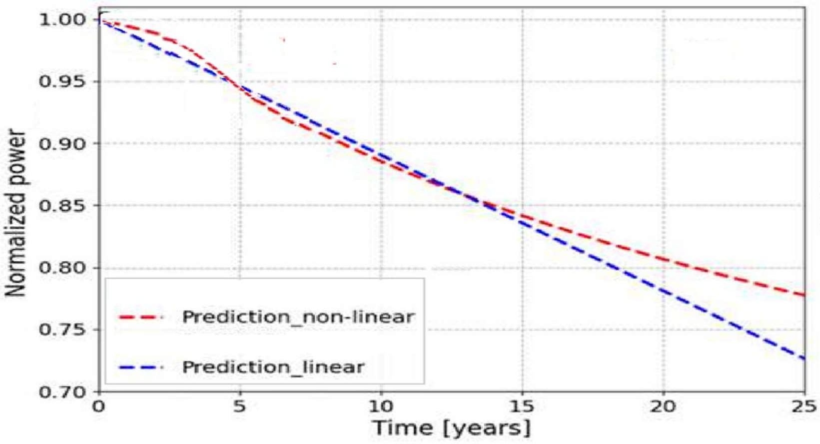

Fig. 8. Calibration of reliability models for outdoor measured PV module performance data

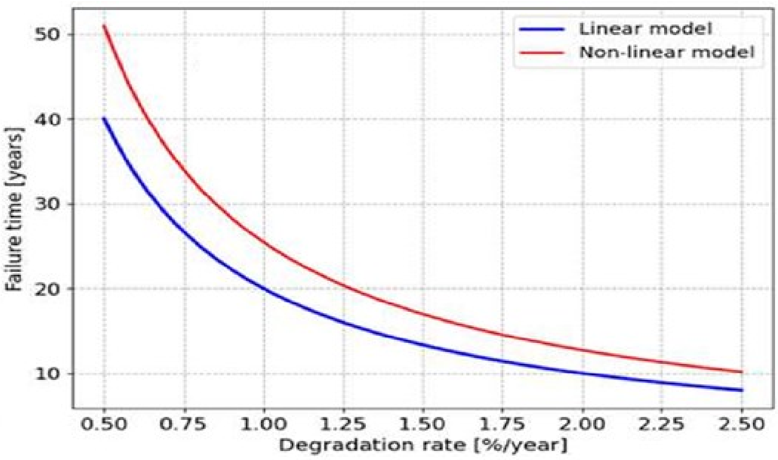

Fig. 9 The long-term performance degradation prediction of the failure time change

Conclusion

This study showed the dangers of this approach and proposed a new approach based on time-dependent degradation rates for more reliable long-term prediction. The conclusions of this paper can be summarized as follows:

1. As shown in Figure 5 we expect the photovoltaic will be more reliable in the next twenty years

2. As shown in Figure 4 the reliability analysis of the renewable system depends on the weather and it must have calculated by considering the actual practice that was conducted through the lifespan analysis. Also, the insolation of PV output changes under the influence of the weather and the surrounding environment.

3. The reliability Based on the lifespan analysis of the device used in the battery converter the IGBT device, the system's lifespan, that is, reliability, could be analyzed

4. Power supply is unavailable. In order to match the power supply to the load-side demand, it was considered to keep the DC link terminal voltage constant while supplying it from the battery.

5. The physics of failure POF-calculation based on the lifetime can be study the system performance, in this process, the lifetime of the semiconductor of power-electronics can be used.

6. The reliability calculation of adjusting the heat sink temperature according the IGBT's gives accurate results Whether obtained from the simulation or the actual system.

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