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Deterioration Diagnosis Algorithm for Photovoltaic Modules by Considering Electrical Characteristics and Environmental Factors

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Abstract

National policies have been emerging that call for minimizing the built environment's contribution to climate change by means of a comprehensive shift to low-energy buildings powered by renewable energy sources. These policies address other urgent global problems such as depleting energy resources and high energy costs. Under these circumstances, the installations of PV systems which has occupied most one of renewable energy sources have been increasing due to the worldwide interests in eco-friendly and renewable solar energy sources. However, the electrical performance and life span of PV modules installed at outside of buildings has been gradually degraded because the various external environmental conditions such as temperature, humidity, ultra-violet and so on, may cause the deterioration of PV modules. In order to overcome these problems, this paper proposes a diagnosis algorithm for deterioration state of PV modules by considering the electrical characteristics and environmental factors, which is strongly related with annual degradation of PV modules. And also, this paper implements a diagnosis system of PV modules based on the proposed algorithm. From the test results based on the proposed algorithm and diagnosis system of PV modules, it is confirmed that they are practical and useful tool to the performance improvement of PV modules.

Keywords: *Deterioration, State, Diagnosis, Electrical characteristics, Environmental factors, PV modules small hydropower generator*

1. Introduction

Public policies are emerging that call for minimizing the built environment's contribution to climate change by means of a comprehensive shift to low-energy buildings powered by renewable energy sources [1]. Under these circumstances, the installation of PV system in power distribution system is being increased as one of solutions for environmental pollution and energy crisis. Besides, it is reported that Korean government is performing spreading policies, such as RPS(renewable portfolio standard), mandatory installation of renewable energy in public buildings and financial support and so on, to increase renewable energy sources among the total power sources up to 20% until 2030 [2]. However, the electrical performance and life span of PV modules installed at outside of buildings has been gradually degraded because the various external environmental conditions such as temperature, humidity, ultra-violet and so on, may cause the deterioration of PV modules [3]. Moreover, the existing

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PV maintenance systems are simply monitoring the inverter output and camera view of sites, and then are difficult to identify the location and state of abnormal PV modules which are related with output decrease, deterioration and physical damage of PV modules. Therefore, technical solutions to deterioration diagnosis of PV modules are strongly required in order to improve performance of maintenance and operation of PV modules [4][5]. To overcome these problems, this paper proposes diagnosis algorithm for deterioration state of PV modules by considering the electrical characteristics and environmental factors. And also, this paper implements a diagnosis system of PV modules based on the proposed algorithm. From the test results based on the proposed algorithm and diagnosis system of PV modules, it is confirmed that they are practical and useful tool to the performance improvement of PV modules.

2. Deterioration diagnosis algorithm for PV modules

This paper proposes diagnosis algorithm for deterioration state of PV modules in order to overcome deterioration problems of PV modules. Detailed process for diagnosis algorithm by considering electrical characteristics and environmental factors are as follows.

[Step 1] In order to compare initial manufactured output power of PV module with one of currently used PV module, one of PV modules is measured at time interval of maximum solar radiation during a day. The measured one is modified with value of standard test condition(STC), because initial performance value of PV module provided by manufacturer is produced by STC base. Where, temperature and solar radiation of STC are assumed as 25[℃] and 1,000[W/㎡], respectively.

[Step 2] To transform the measured output power of PV module into one of STC temperature(25[℃]), the compensated output power is expressed by compensation coefficient of temperature(γ) which is provided by manufacturer and measured temperature($T_{(t)}$) at each time interval, as shown in Eq. (1).

$$P^*_{(t)} = P_{(t)} + \gamma\left(T_{(t)} - 25\right) \tag{1}$$

where, P^* is compensated output power, P is measured output power, γ is compensation coefficient of temperature and t is time interval.

[Step 3] To transform the measured output power of PV module into one of solar radiation of STC(1,000[W/㎡]), quadratic linear regression equation is formulated as shown in Eq. (2), by using compensated output power calculated in Eq. (1).

$$P^*_{(t)} = \alpha X^2_{(t)} + \beta X_{(t)} + e_{(t)} \tag{2}$$

where, X is solar radiation at each time interval, α and β are compensation coefficient and e is error.

To solve the compensation coefficients of α, β in Eq. (2), the least square method to minimize error is introduced as shown in Eq. (3).

$$S = \sum(P^*_{(t)} - \alpha X^2_{(t)} + \beta X_{(t)})^2 = \sum e^2_{(t)} \tag{3}$$

With derivatives for α, β in Eq.(3), the compensation coefficients(α, β) can be obtained as shown in Eq.(4) and Eq.(5), respectively.

$$\alpha = \frac{\sum P^*_{(t)} * X^2_{(t)} * \sum X^2_{(t)} + \sum P^*_{(t)} * X_{(t)} * \sum X^3_{(t)}}{(\sum X^3_{(t)})^2 - \sum X^4_{(t)} * \sum X^2_{(t)}} \tag{4}$$

$$\beta = \frac{\sum X_{(t)}^4 * (\sum P_{(t)}^* * X_{(t)}^2 * \sum X_{(t)}^2 + \sum P_{(t)}^* * X_{(t)} * \sum X_{(t)}^3)}{\sum X_{(t)}^3 * (\sum X_{(t)}^3)^2 - \sum X_{(t)}^4 * \sum X_{(t)}^2} - \frac{\sum P_{(t)}^* * X_{(t)}^2}{\sum X_{(t)}^3} \tag{5}$$

Finally, modified output powers of PV module can be obtained with α, β, e and solar radiation (1,000[W/㎡]) of STC, as shown in Eq. (6).

$$P_{(N)}^{**} = \alpha * X_{STC}^2 + \beta * X_{STC} + e \tag{6}$$

where, $P_{(N)}^{**}$ is modified output power at STC and X_{STC} is solar radiation of STC.

[Step 5] Compare the modified output power($\mathrm{P}_{(\mathrm{N})}^{**}$) of PV module with the initial performance value ($\mathrm{P}_{\mathrm{initial}}$) in order to diagnosis deterioration state of PV modules. If $\mathrm{P}_{(\mathrm{N})}^{**}$ is bigger than $\mathrm{P}_{\mathrm{initial}}$, PV module is evaluated as normal one, otherwise, PV module is as abnormal one. In order to categorize deterioration state of PV modules, calculate fill factor(FF) and short-circuit current(I_{SC}) as shown in Eq. (7) and Eq. (8).

$$FF = \frac{V_m \times I_m}{V_{oc} \times I_{sc}} \tag{7}$$

$$I_{sc} = \frac{X}{X_{STC}} * I_{sc}^* \tag{8}$$

where, V_m is maximum voltage of PV module, I_m is maximum current, V_{oc} is open circuit voltage, I_{sc} is open circuit current, I_{sc}^* is open circuit current of STC.

[Step 6] Compare electrical characteristics of fill factor(FF) and short circuit current(I_{sc}) of PV module with initial performance values provided by manufacturer. If FF of PV module is smaller than FF of initial performance value, deterioration state of PV module is classified as ribbon wire corrosion or cell crack. Meanwhile, if I_{sc} of PV module is smaller than I_{sc} of initial performance value, deterioration state of PV module is classified as encapsulant discoloration or back sheet delamination.

[Step 7] In order to improve the accuracy of deterioration diagnosis using electrical characteristics in [step 6], the environmental factors such as solar radiation, temperature and humidity need to be considered with the detailed classification as referred in [4].

Therefore, the flowchart of deterioration diagnosis procedure of PV module is illustrated as shown in [Figure 1].

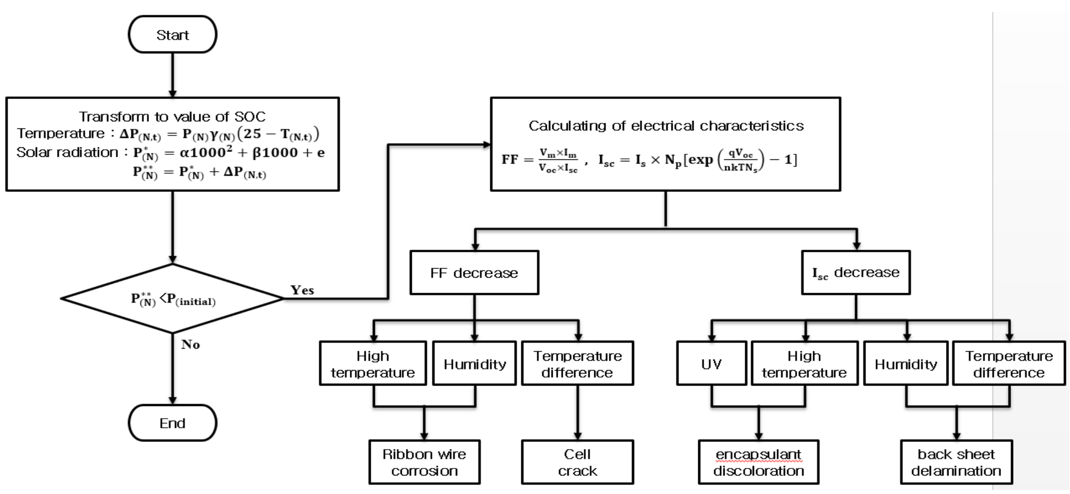

Figure 1. Deterioration diagnosis algorithm of PV modules

3. Case studies

3.1. Implementation of deterioration diagnosis system for PV modules

Based on the proposed algorithm mentioned earlier, this paper implements deterioration diagnosis system of PV modules which is composed of 4 sections including PV modules, data measurement devices, communication devices and deterioration diagnosis devices as shown in [Figure 2]. Specifically, the section of PV modules is implemented by 16 modules of 250W with 8 series and 2 parallel connections. And the section of data measurement devices is consisted of various sensors to measure performance data(voltage and current) of each PV module and environmental data(solar radiation, temperature and humidity).

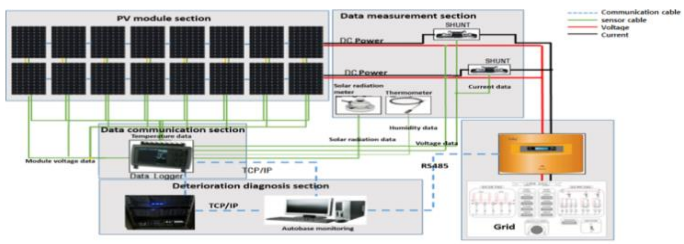

Figure 2. Configuration of deterioration diagnosis system

3.2. Electrical characteristics for deterioration states

In order to confirm how electrical characteristics of initial PV modules may change depending on deterioration conditions, the fill factor(FF), short-circuit current(Isc) and open-circuit voltage(Voc) of PV module where ribbon wire corrosion or yellowing phenomenon are occurred, are compared with initial PV module characteristics. As shown in Table 1, it is confirmed that the change of electrical characteristics of ribbon wire corrosion at PV module has very little difference in short-circuit current, but has big decrease by 7.3[%] in open-circuit voltage and 4.6[%] in fill factor.

Table 1. Electrical characteristics of PV module with ribbon wire corrosion

parameter	initial value	deterioration value	deterioration rate [%]
V_{OC} [V]	23.3	21.6	-7.3
I_{SC} [A]	4.68	4.66	-0.4
FF [%]	74.4	69.76	-4.6
P_{max} [W]	81.22	70.21	-13.5

In addition, it is confirmed that PV module with yellowing phenomenon influenced by UV ray and humidity has a little decrease in electrical performance compared to initial characteristics, which is 1.2[%] of open-circuit voltage and 0.3[%] of fill factor, but has significant decline in short-circuit current of 12.4[%] as shown in [Table 2]. Therefore, it is clear that deterioration diagnosis algorithm proposed in this paper can perform accurate diagnosis of deterioration state, because the electrical characteristics of PV modules may change differently according to deterioration conditions.

Table 2. Electrical characteristics of PV module with encapsulant discoloration

parameter	initial value	deterioration value	deterioration rate [%]
V_{OC} [V]	18.0	17.77	-1.2
I_{SC} [A]	3.32	2.91	-12.4
FF [%]	72.1	71.8	-0.3
P_{max} [W]	43.0	37.19	-13.5

3.3. Deterioration characteristics for environment factors

In order to evaluate the deterioration states of PV module categorized by electrical characteristics, this paper adapts analysis method of environmental factors including radiation, temperature and humidity. Where, the deterioration state analysis using the environmental factors utilize the accelerated deterioration experiment data of the PV module, which is performed based on the IEC 61215 test standard. For example, temperature cycle test causes cracks at PV cell junction with temperature difference and then the electrical characteristics of the PV module are illustrated in [Table 3], which shows decrease of 0.8[%] in open-circuit voltage and 3.0[%] in fill factor, respectively.

Table 3. Characteristics of accelerated temperature cycle test

parameter	initial value	deterioration value	deterioration rate [%]
V_{OC} [V]	34.62	34.33	-0.8
I_{SC} [A]	7.88	7.92	+0.5
FF [%]	74.1	71.9	-3.0
P_{max} [W]	202	195.4	-3.3

In addition, the high temperature and humidity test causes ribbon wire and EVA corrosion and then the electrical characteristics of the PV module are illustrated in [Table 4], which shows decrease of 1.7[%] in short-circuit current and 0.7[%] in FF, respectively. Thus, it is confirmed that deterioration states of PV module can be evaluated more accurately by considering environmental conditions through the analysis method that the change of electrical characteristics and deterioration phenomenon is occurred differently depending on environmental factors.

Table 4. Characteristics of accelerated high temperature and humidity test

parameter	initial value	deterioration value	deterioration rate [%]
V_{OC} [V]	34.71	34.68	-0.1
I_{SC} [A]	7.81	7.68	-1.7
FF [%]	74.4	73.9	-0.7
P_{max} [W]	201.8	197	-2.4

4. Conclusions

This paper has proposed diagnosis algorithm for deterioration state of PV modules by considering the electrical characteristics and environmental factors, which is strongly related with annual degradation of PV modules. From the test results based on the proposed algorithm and diagnosis system of PV modules, it is found that the proposed deterioration diagnosis system properly shows decrease rate of output power by using gauge bar function and performs indication of alert lamp depending on deterioration state. From the test results based on the proposed algorithm and diagnosis system of PV modules, it is confirmed that they are practical and useful tool to the performance improvement of PV modules.

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