New & Renewable Energy 2017. 3 Vol. 13, No. 1
ISSN 1738-3935
https://doi.org/10.7849/ksnre.2017.3.13.1.054

[2017-3-PV-006]

Current Induced Stabilization (CIS) of Large Area Commercial Amorphous Silicon Photovoltaic Module and Its Performance Variation

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Received 7 November 2016 **Revised** 15 February 2017 **Accepted** 2 March 2017

ABSTRACT To reduce the demand for fossil fuel energy, one of the solutions is using an renewable energy sources, such as wind and solar. Solar energy is increasingly becoming the hottest issue in recent years because of its merits in installation and operation. In 2015, about 50.7 GW photovoltaic (PV) systems were installed around world. Many renewable energy organizations expect that the total PV system installation will be 60 GW in the coming year.[1] To sustain the long-term stability of the PV system, several institutes have performed tests based on IEC standards, such as IEC 61215 for silicon crystalline PV modules and IEC 61646 for thin film PV modules and IEC 61730-1&2 for safety tests. In the case of amorphous silicon thin film modules,[2,3] its performance can be lowered because its natural characteristics under sun light called, the Staebler-Wronski effect.[4,5] Therefore, some companies conduct light soaking tests to guarantee stable electric performance before shipment. On the other hand, in the case of having high degradation characteristics at the maximum power, this test could take much time for production and lead to an increase in product cost. To solve this technical difficulty and obtain actual stable performance power of silicon-based amorphous solar modules, the current-induced stabilization (CIS) technique was proposed and assessed.

Key words Renewable Energy(신재생에너지), Solar Energy(태양에너지), Photovoltaic Module(태양전지모듈), IEC 61215, IEC 61646, Environmental test(환경시험), Amorphous silicon solar cell(비정질 실리콘 태양전지), Amorphous silicon solar module(비정질 실리콘 태양전지모듈)

Nomenclature

V_{oc} : open circuit voltage
V_{mp} : maximum circuit voltage
I_{sc} : short circuit current
I_{mp} : maximum circuit current
P_{max} : maximum power
P_{min} : minimum power
$P_{average}$: average power
IEC : international electrotechnical commission
UL : underwriters laboratory

1. Introduction and Theoretical Background

IEC 61646 is the sole testing standard for thin film solar modules like CdTe, CIGS, amorphous silicon (a-Si) solar cells. One distinguishable test item is the light soaking test for determining the induced degradation (LID) of maximum generating power,

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which is one of natural thin film modules. Especially the amorphous silicon thin film solar cell has unique characteristics under various conservation conditions like temperature and irradiation conditions. Until now there were significant LID with various types of solar cells that had been observed and reported throughout several decades.

Commonly, there are three sets of defects. The first one is soft with low annealing energy and high recombination capability. In this case, the defect can disappear when proper environmental conditions meet. The second one is hard with a large annealing energy and small recombination capability value so it is needs too much energy to recover the initial state. The third one is a stable type with infinity high annealing energy and very small recombination capability value. So this type of defect has a permanent status and does not change at all.

Experimentally, Takeshi Yanagisawa et al. showed the change of temperature coefficient of a-Si solar cell subjected to light by changing irradiation conditions to annealing conditions. Electric parameters like I_{sc} (short circuit current), V_{oc} (open circuit voltage) and F.F (fill factor) can be reversible.[6]

D. Caputo et al. had a set of amorphous silicon solar cell of 1 cm^2 device area degraded and then annealed at different current intensities. Device performances during the whole experiment have been monitored by current-voltage characteristics and quantum efficiency curves. It has been found that annealing rate increases with current intensity.[7]

Arup Dasgupta et al. proposed a new degradation technique for amorphous silicon solar cells comprising of a combination of current injection and insolation for a-Si:H based solar cells of 1 cm^2 device area.[8]

Kim et al. showed a five year monitoring result of a-Si module of 2.85 kWp grid connected PV system shown in Fig. 1. At the point where 31% of maximum power reductions happened there were no thermal, mechanical and electrical problems.[9]

From the mathematical modeling point of view, various models have been suggested by the works of Pankove, Stutzmannetal, Branz, Biswas, Schumm, Nádaždy and Klaver.[10-16]

International bridges are needed between experimental results and the standard test methods point of view. To commercialize the a-Si module so that the consumer can install the products generating electricity, it is mandatory to pass certificate tests under IEC or UL standards.

As described in IEC standards, to check the exact stabilized maximum power of thin film modules or solar cells, the CCC Class solar simulator is used for light source under 600 W/m^2 to 1000 W/m^2 light intensity condition and should keep the module's temperature between 40℃ and 60℃.[17,18] Until the stabilizing maximum power meets $(P_{max}-P_{min})/P_{average} < 2\%$, at lease 43 kWh/$m^2$ light energy between two consecutive periods should illuminate on the surface of solar module. In the case of amorphous silicon thin film modules, it needs 3 to 4 periods to get within a 2% maximum power drop ratio. Then it takes an average of seven or eight days under stable solar energy source. Table 1 shows two test results of light soaking tests under light soaking test equipment for a-Si modules. At least, 4 consecutive periods of

Fig. 1. Installed amorphous silicon solar module in test site

Table 1. Light Soaking Test Results for Two Amorphous Silicon Solar Cell Module

Test Cycle (number)	Applied Irradiance (kWh/m^2)	Change in P_{max} after Cycle (Sample 1)	Change in P_{max} after Cycle (Sample 2)
1	43	Not measured	Not measured
2	43	−11.8%	−6.69%
3	43	−2.46%	−9.80%
4	43	1.615	−1.985

172 kWh/m^2 are needed for stabilizing solar module.

To be a stable energy source for thin film solar module as a renewable source, a−Si modules should be shipped to customers with stabilized maximum power. If not, system designers can have much difficulty because of the high initial system voltage of modules that are more than 30% for inverter operations. Several weeks later, the system voltage drops to nominal status so it gives an unstable system management. So, stabilizing technology of the maximum power of a−Si modules within a short time period with low cost and easy method is very important to module manufacturers.

So in this paper, it was introduced the current induced stabilization (CIS) test methods for easy and compatible a−Si stabilizing techniques, which are low cost and fast for manufacturers using commercial a−Si modules.

2. Current Induced Stabilization (CIS) Test Method Principle

There are normally two ways to have stabilized maximum power of a−Si module described in IEC standards. One way is to use light soaking equipment of artificial light bulbs. The other is exposing the module to outdoor conditions until it reaches saturation in the power called sun−light induced degradation test method. The former method is quantitative in nature, but it is an expensive method because of the high electrical consumption and light bulb changes. It typically takes several days to perform this method. The latter method is an easy one, but it takes much more time; around thirty days or more. In a company, the daily volume of manufacturing can be hundreds or thousands of modules. It is almost impossible to use the mentioned two test methods.

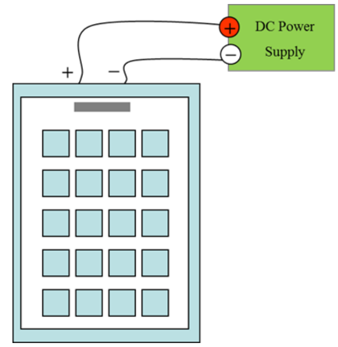

Fig. 2. CIS (Current Induced Stabilization) test method

It was introduced the current injection to the a−Si module up to or higher than the short circuit current (I_{sc}) level of module. If amorphous silicon thin film module is prepared, then (+) side of the module will be connected with the DC power supply (+) and (−) side of the module will be connected with (−) side of the power supply. The current and voltage should be adjusted for allowing current injection to the module. The schematic test method is shown in Fig. 2. And the illumination of light at the test room should be less than 5 W/m^2 of the dark room condition and the room test maintain about 25℃.

To compare and analyze the effect and result of the suggested test method, it has been conducted another two tests. One is using light soaking test equipment and the other is exposing the module to out−door sun light condition explained above.

3. Experiment Result

For outdoor exposing test of PV module, a−Si modules of 100 Wp and single p–n junction was used. The testing was done in Daejeon City, South Korea from June of 2010 to March of 2011. The module was connected electric loads for power consumption which is shown in Fig. 3.

Electrical power variation of PV module after each 60 kWh/m^2 light accumulation was measured using a modern solar simulator from Pasan Ⅲb (Belval, Switzerland) which has 0.58% light uniformity, 0.3% light stability and 0.5% instrument precision at 25℃ condition.

Fig. 4 shows the result of maximum power variation under sunlight for nine months. After 60 kWh/m^2 exposure, the maximum power was dropped to 86.5% compared with the initial value. After exposing up to 180 kWh/m^2, the power stabilization $(P_{max}-P_{min})/P_{average}$ has reached to 1.2%. Based on IEC 61646 standards for accepting the stabilization of the test module, it has reached the stable condition of maximum power. But when module continuously subjected to 420 kWh/m^2 light accumulation condition, the maximum power dropped to 66.7% from initial power. Even exposed to outdoor condition for nine months, it is difficult to determine exact stabilized maximum power value even though $(P_{max}-P_{min})/P_{average}$ criteria has been met as shown in this experiment's results.

In the case of indoor light soaking testing methods, metal–halide lamps were used for artificial sunlight source as a class CCC solar simulator shown in Fig. 5. The module temperature was kept from 40℃ to 60℃ under 1 kW/m^2 intensity. The module was connected with the I–V tracer (EKO, MP–170) under maximum power condition and electrical values were monitored every thirty minutes. Fig. 6 shows the short–term maximum power variation from start until the 108 kWh/m^2 irradiation condition. In here, in first 43 kWh/m^2 period, –26.8% maximum power degradation happened. After 86 kWh/m^2 irradiation condition, the maximum power of PV module was stabilized.

As described two test methods above, it normally takes a minimum of seven days to several months for stabilized maximum power of a–Si module depending

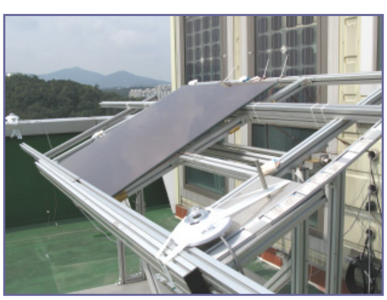

Fig. 3. Outdoor exposure test site

Fig. 5. Light soaking test equipment in test laboratory

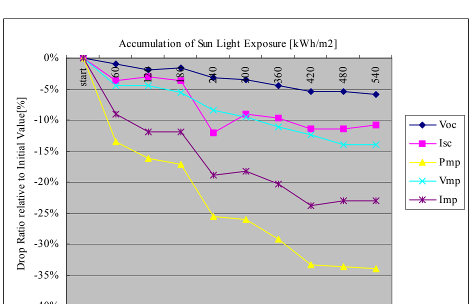

Fig. 4. Maximum power variation under sunlight for 9 months

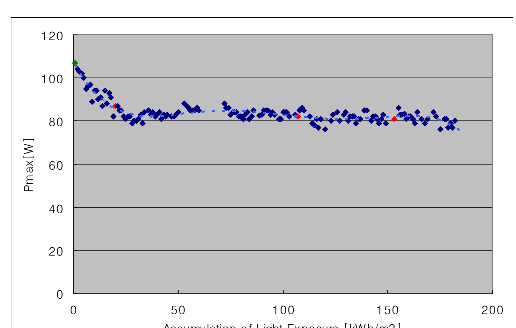

Fig. 6. Maximum power variation under light soaking test

on each test condition.

Alternatively, once injecting a current through solar module up to short circuit current (I_{sc}) level of module, stabilized power of a-Si module could be obtained by test shown in Fig. 2.

For one perid of test, injection current was maintained for 1.6 ampere and total input energy was 1.38 kWh. Total experiment time was about eight hours and maximum power of a-Si module was measured periodically. The test sequence is shown in Fig. 7. And Fig. 8 shows the electric parameter's (I_{sc}, V_{oc}, P_{mp}, I_{mp}, V_{mp}) change depending on each test step. Finally, −15.6% maximum power reductions were achieved by injecting only 6.91 kWh to a-Si module. It was quite a short time compared with the light soaking and outdoor exposure testing method. It shows effect that is almost the same with 120 kWh/m^2 outdoor sun irradiation effect and 21 kWh/m^2 metal halide light effect on the surface of a-Si module.

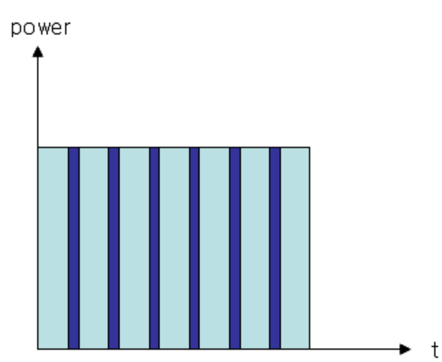

Fig. 7. Current injection sequence (current injection), (I-V measurement)

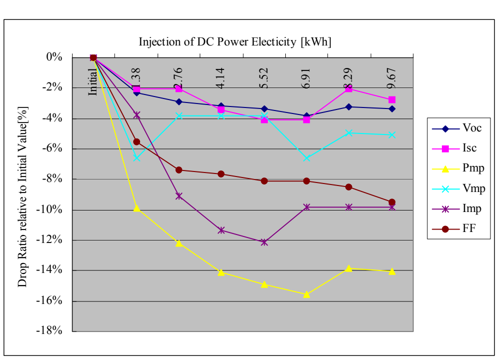

Fig. 8. The electric parameter (I_{sc}, V_{oc}, P_{mp}, I_{mp}, V_{mp}) changes from CID method

To check the structural and material damage of a-Si module, EL (electroluminescence, ITEX PV100, Japan) camera was used. There were no distinguishable visible differences with initially fabricated a-Si module like cracks, electrical dead zones, hot-spots and the like.

If this proposed CIS method could be adapted in thin film module manufacturers, stabilizing PV module's maximum power can be conducted within a short period of time. And it would be beneficial to both system managers and customer sites.

4. Suggestion of CIS for Conventional Test Method for Manufacturer

For obtaining stabilized thin film PV module's maximum power, there is needed only power supply with high voltage up to V_{oc} and current level I_{sc} of module conducting in condition with dark room conditions. For considering low cost operation, manufacturer can build up PV system which works like power source meter. Then the electric cost can greatly reduce. The idea is proposed on Fig. 9.

5. Conclusion

This paper presents a current induced stabilization (CIS) test method for amorphous silicon solar cell

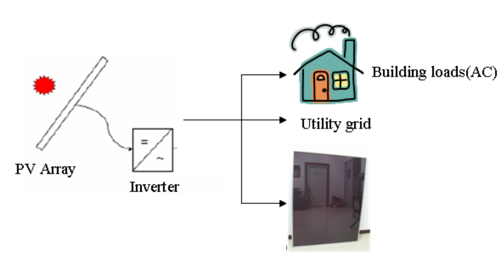

Fig. 9. Suggestion of CID for convention test method for manufacturer

modules, which injects current to amorphous photo-voltaic modules in a dark room condition and compared existing power stabilization techniques according to IEC 61646 standards like outdoor exposure and light soaking test items. Through this simple suggested test method, it was able to shorten the time for determining nominal maximum power of amorphous thin film solar cells. This proposed method will give a more economical, easy and fast testing method for thin film module manufacturers and developers.

The methodology presented can be extended and suggested to current IEC test methods

Acknowledgement

This work was supported by the New & Renewable Energy of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20153030012160, Development 4-Step Process Laminator for Photovoltaic Module making over 2.5times Productivity)

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