The thermal reliability study of bypass diodes in photovoltaic modules

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Introduction

Bypass diodes are a standard addition to PV (photovoltaic) modules. The bypass diodes' function is to eliminate the reverse bias hot-spot phenomena which can damage PV cells and even cause fire if the light hitting the surface of the PV cells in a module is not uniform. The design and qualification of a reliable bypass diode device is of primary importance for the solar module. To study the detail of the thermal design and relative long-term reliability of the bypass diodes used to limit the detrimental effects of module hot-spot susceptibility; this paper presents the result of high temperature durability and thermal cycling testing and analysis for the selected diodes. During both the high temperature durability and the thermal cycle testing, there were some diodes with obvious performance degradation or failure in J-box 1 with bad thermal design. Restricted heat dissipation causes the diode to operate at elevated temperatures which could lower its current handling capability and cause premature failure. Thermal cycle with forward biased current to the diode, is representative of hot spot conditions, can impose a strong thermal stress to diode, and may cause failure for bypass diodes in some PV module that may be able to pass the present criteria of IEC 61215.

Experiments

Test samples(shown in fig.1 and fig.2) :

- 3 types of junction boxes for testing
- J-boxes were attached on mini laminate modules
- 3 diodes per j-box
- Diode rated current > 10A
- Thermocouples were bonded to diode cases

Data monitoring

- Measure forward and reverse characteristics of diodes before each thermal durability test
- Monitor current and voltage data of diodes and/or power supply
- Monitor case temperature of each diode

Test Procedure

- Test 1
  - Put the samples in chamber with controlled temperature of 50, 60, 75°C
  - Add forward current of 10A to bypass diodes
  - Monitor the bypass diode case temperature and forward voltage drop and current
  - 1000 hours
- Test 2
  - Chamber temperature cycled from -40° C to 85° C
  - 3 hours per cycle
  - Dwell time at both 85° C & -40° C are 10~30 minutes
  - Add forward bias current of 10A to diodes when the chamber temperature is higher than 25° C
  - One power supply is used for one J-box (3 power supplies).
  - 100 cycles
- Test3
  - Chamber temperature cycled from -40° C to 85° C
  - 3 hours per cycle
  - Dwell time at both 85° C & -40° C are 10~30 minutes
  - Add reverse bias voltage of 12V to diodes when the chamber temperature is higher than 25° C.
  - One power supply is used for one diode(9 power supplies).
  - 100 cycles
- Next step
  - Chamber temperature at 75°C
  - One hour of reversed bias (12 V) plus one hour of forward bias(10A) per cycle
  - 20 cycles

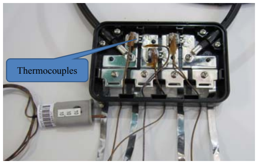

Fig. 1. Junction box sample for testing

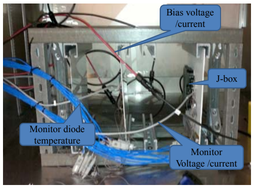

Fig. 2. Assembled testing samples in the chamber

Results

Test 1

High temperature endurance testing with forward biased current was applied to bypass diodes to assess diodes operating performance under long-term hot spot condition.

- Diodes temperature rise of 3 J-box during the testing(shown in fig.3 and fig.4) :
  - Box 1: Temperature rises of diodes 1-1 and 1-2 increased by 20°C . The highest diode case temperature reached 220°C when the chamber temperature was 60°C
  - Box 2: Temperature rises of diodes were very stable.
  - Box 3: Temperature rises of diodes 3-1, 3-2 and 3-3 increased slightly
  - Temperature rises of diodes decreased when ambient temperature increased.
  - Diode temperature rises of J-box 1 and 3 went up after restart testing.
- Diodes forward voltage of 3 J-box during the testing:
  - J-box 1: Voltages varied with testing time. Forward voltage of diodes 1-2 increased dramatically after restarted testing(Oct. 6), while voltage of diodes1-1, 1-3 decreased.
  - J-box 2: Voltages were stable
  - J-box 3: Voltages were stable
- No diode failed after the high temperature testing.

Note:
1. Temperature rise is the temperature difference between diode case and chamber
2. Diode 1-2, 2-2, 3-2 is the middle diodes of box 1, box 2 and box 3.
3. The temperature of middle one is highest in the box.

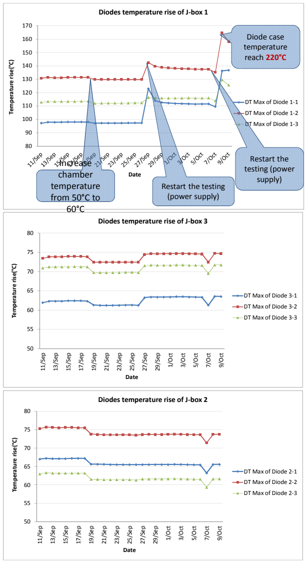

Fig. 3. Diode case temperature rise for 3 J-box during high temperature testing

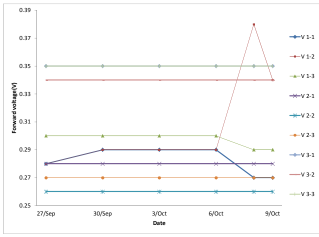

Fig. 4 Diodes forward voltage of 3 J-box during the high temperature testing

Test 2

Thermal cycle plus forward bias endurance testing was applied to bypass diodes to assess diodes reliability under thermal cycling caused by ambient temperature change combined with hot spot current flow.

Diodes case temperature during the testing :
- Box - 1: - 40 ~ 214°C
- Box - 2: - 40 ~ 158°C
- Box - 3: - 40 ~ 157°C

Diodes performance after the testing:
- Diodes forwards bias voltage of Box-1 increase dramatically after 40 cycles. Diodes of Box-1 totally failed after this testing.
- Reverse current(at reverse voltage of 10 - 16V) of diodes 3-2 (middle diode of box-3) and 2-2 increased by 10~20%.
- Diodes forward bias voltage of Box-2 remained steady
- Diodes forward bias voltage of Box-3 increased by 0.5V

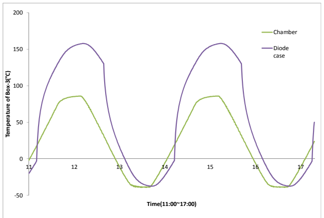

Fig. 5. Chamber temperature and diode case temperature of box 3 during diodes thermal cycle plus forward bias testing

Test 3

Thermal cycle plus reverse bias endurance testing was applied to bypass diodes to assess diodes reliability under thermal cycling caused by ambient temperature change without hot spot.

Diodes case temperature are very close to chamber temperature during the testing

Diodes performance after the testing:
- 12V reverse biased voltage was applied to diodes when the chamber temperature is higher than 25°C.
- Diode case temperature was close to chamber temperature.
- No failure or obvious degradation of diodes were observed during or after the test.

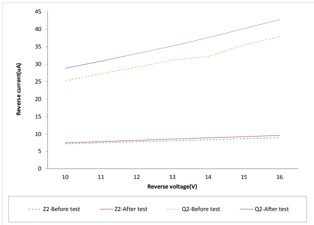

Fig. 6. Reverse characteristics of diodes 2-2(Q2) and diode 3-2(Z2) before and after diodes thermal cycle plus reverse bias testing

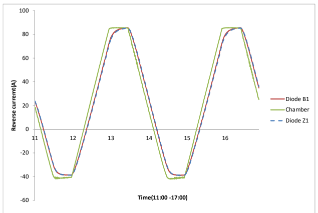

Fig. 7. Chamber temperature and diode case temperature of box 3 during diodes thermal cycle plus reverse bias testing

Discussion

To assess diodes thermal reliability of PV modules, three indoor tests were designed to simulate 3 types of diodes operating condition. The related test results were shown in above section.

High temperature endurance testing with forward biased current was applied to bypass diodes to assess diodes operating performance under hot spot condition. Mini modules with three types of junction boxes were put in chamber with controlled temperature. Forward biased current of 10A was added to bypass diodes; and the bypass diode case temperature and forward voltage drop and current were monitored during the testing. After 1000 hours' testing, though there is no abnormal appearance of diode were found and no appreciable changes in terms of reverse diode characteristics were detected, the temperature rise of worst diodes in one J-box increased by 25° C. The temperature rises of diodes in J-box 1 and 3 went up by 2-15° C and their forward voltage increased dramatically after cool down the diodes and restart testing, while that of J-box 2 was stable. Based on the test result above, we can find if the heat dissipation is not good, there is still some possibility of diodes degradation in PV modules in hot spot condition. When the diodes is forward biased with hot spot current flow, the forward current may make the diode hot enough for the dopants that create the N- and P-type areas in the diode to diffuse across the junction, wrecking the semi-conducting behavior that we rely on, and cause performance degradation.

Two types of thermal cycle testing were processed to assess the diodes' durability of thermal cycling stress caused by ambient temperature change with or without hot spot in PV modules. Three types of J-boxes were tested in chamber with cycling temperature range from -40° C to 85° C. For the first 100 cycles, forward biased current of 10A was applied to diodes when the chamber temperature is higher than 25° C. One of diodes totally failed with open circuit after the first 100 thermal cycles testing. The high temperature combined with thermal cycling will cause the diodes resistance increase and damage the PN junctions. For the second 100 cycles, -12V reverse biased voltage was added to diodes during the chamber temperature is higher than 25° C. The diodes case and junction temperatures were close to ambient temperature during the second 100 cycles test. And there was no failure or obvious degradation of diodes were observed during or after the test. The diodes performance of PV module is stable if there is no hot spot issue.

The diode performance is stable if the diode is reverse-biased with low diode temperature. However, the leakage currents doubles every 10° C as the temperature increase, and eventually the current may reach a level where the heat dissipation within the junction is high enough for the junction temperature to run away. For the field operating condition, the PV modules may encounter momentary shading caused by cloud or bird, etc. The diodes in the modules will work under the condition of high temperature with hot spot current flow firstly when the shading is on the modules. Then the diodes will be reverse-biased in high temperature condition after the shading is gone. For next step, the experiments need be designed to access the diode thermal reliability under simulated the field condition of momentary shading .

Conclusions

Based on the test result above, we can find if the heat dissipation is not good, there is still some possibility of diodes degradation or failure in PV modules under hot spot condition. Thermal cycle condition with forward biased current to diode, really representative of hot spot conditions, can impose a strong thermal stress to diode, and may cause failure for bypass diodes of some PV module that may be able to pass present criteria of IEC 61215.

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