MODEL FOR PREDICTING THERMAL RUNAWAY IN BYPASS DIODES

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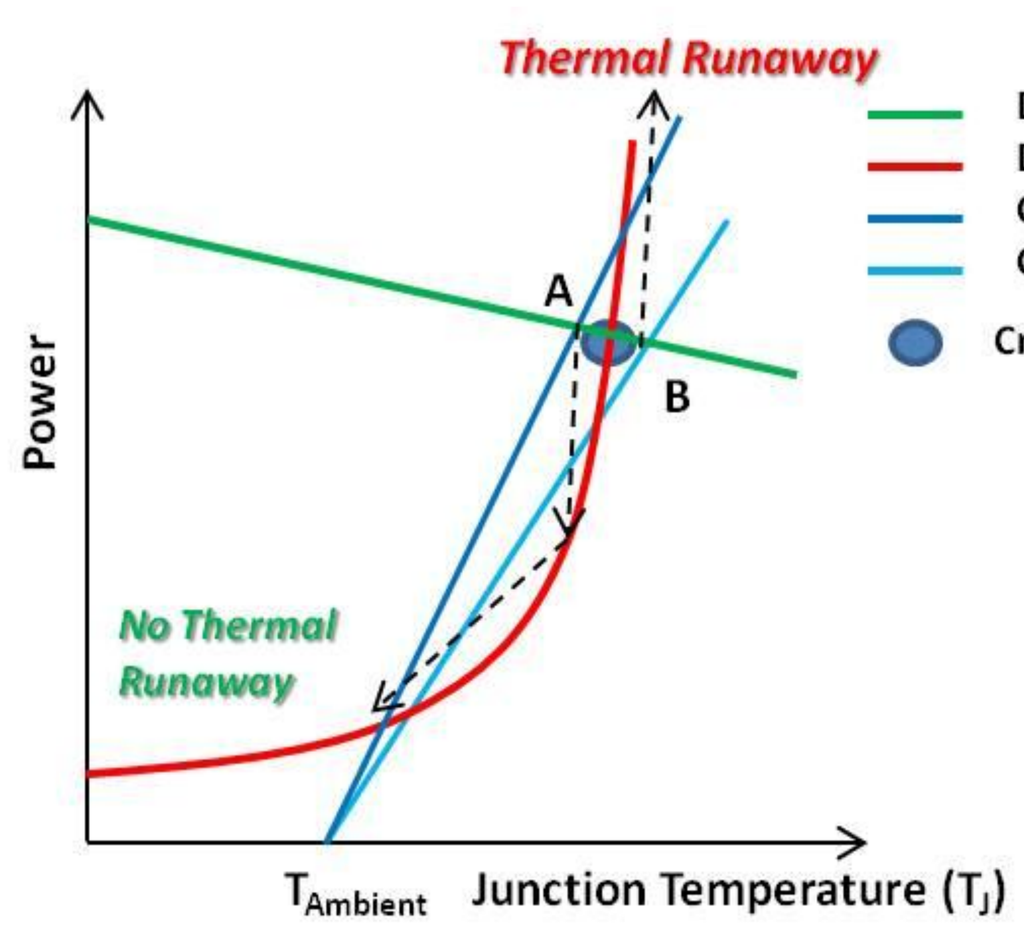
INTRODUCTION

- Bypass diodes are used in Photovoltaic (PV) modules to prevent the application of reverse voltage across the cells in the event of shading or current mismatch. Failure of bypass diodes often causes significant degradation in PV modules due to formation of hot spots.
- When shading on PV modules is suddenly removed, bypass diodes can undergo thermal runaway while transitioning from forward bias condition to reverse bias.
- Current bypass diode test in IEC 61215 test standard does not address this failure mode. Recently, a new “thermal runaway test” has been proposed.
- Theoretical framework to understand the dynamics of thermal runaway in any bypass diode-junction box system, and predict the vulnerability of the bypass diode for thermal runaway is presented.
- Predictions from the model are verified using a specially designed setup for thermal runaway testing of bypass diodes.

THERMAL RUNAWAY CRITICAL TEMPERATURE



Diode V_f x I_f
Diode V_r x I_r
Cooling Curve - Low Thermal Resistance
Cooling Curve - High Thermal Resistance
Critical Temperature

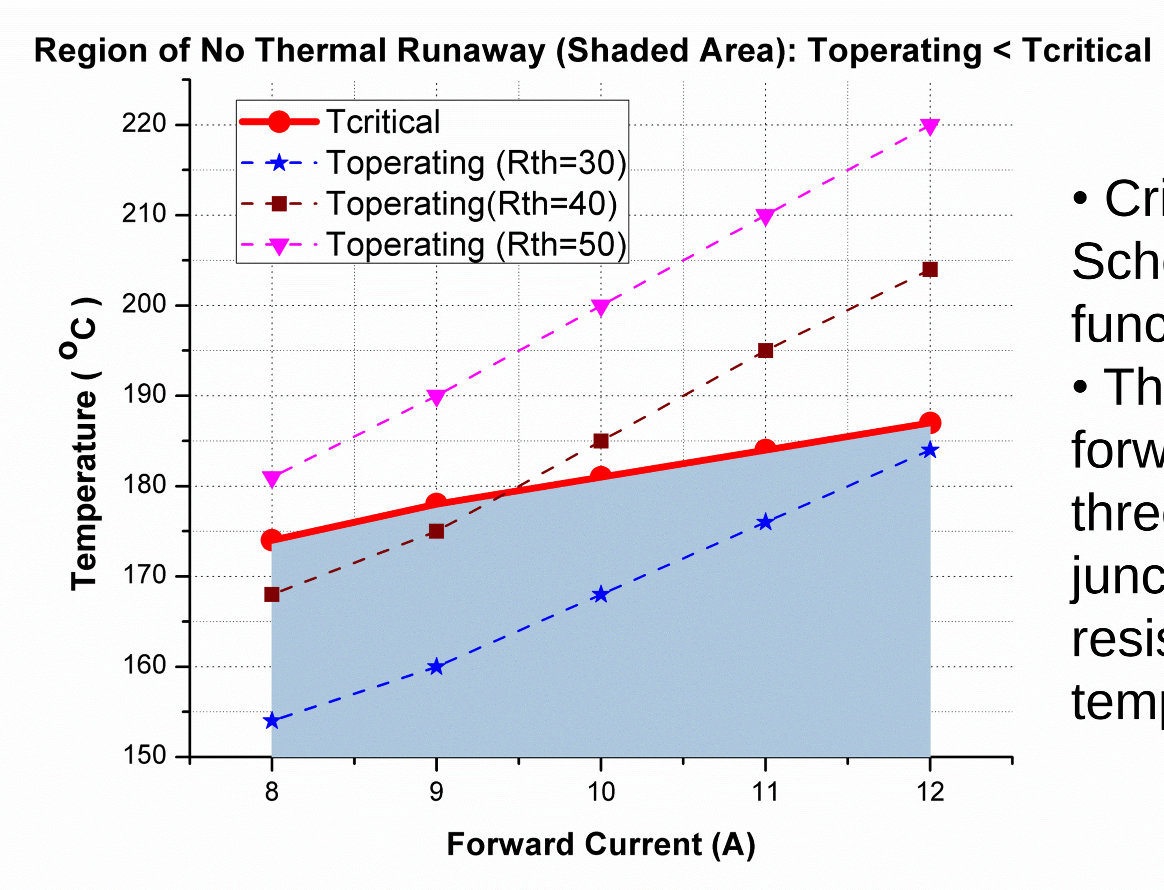
- When a PV module is shaded, the corresponding bypass diode becomes forward biased. The diode junction temperature increases until it reaches thermal equilibrium at point A (for low thermal resistance system) or point B (high thermal resistance system). Once shading is removed, diode reverts to reverse bias.
- If the power dissipation in reverse bias is greater than the power dissipation in forward bias (point B), temperature of diode begins to increase. Increased temperature results in increased conductivity of diode and this leads to increase in current. The increased current further heats up the diode and this cyclic process results in diode failure by thermal runaway.
- The temperature at which power dissipation in diode in forward bias is equal to the power dissipation in reverse bias, for given forward current and reverse voltage, is termed as the **Critical Temperature** for thermal runaway.

- **The diode undergoes thermal runaway during forward to reverse transition only when:**

Operating Junction Temperature > Critical Temperature

- The operating temperature is determined by various factors such as thermal resistance of junction box, ambient temperature and forward current.
- However the critical temperature is only dependent on the diode parameters, for a given forward current and reverse voltage. Therefore, the critical temperature can be used as a tool to predict vulnerability of bypass diodes for thermal runaway.
- Critical temperature data can be obtained using the following two methods
1. Application of Schottky diode model to diode manufacturer’s datasheets
2. Experimental measurement of forward and reverse power dissipation in diode at various temperatures.
- Both methods were found to give similar results.

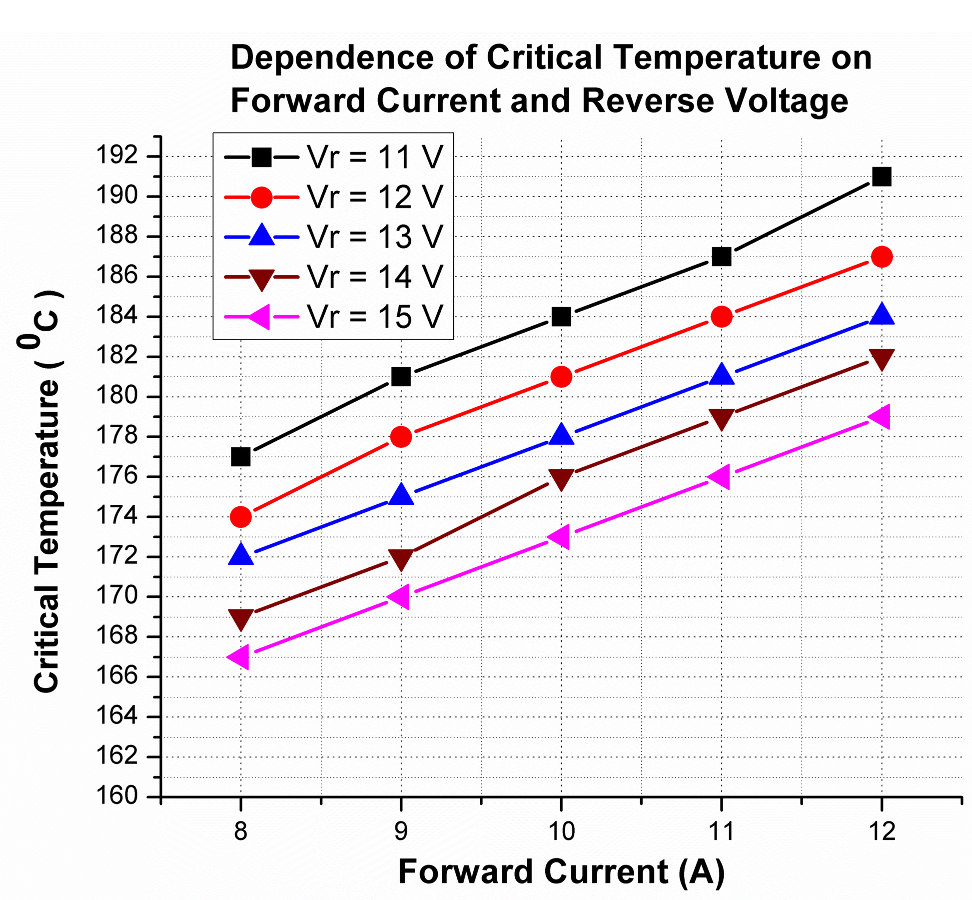
AVOIDING THERMAL RUNAWAY



- Critical temperature of an axial Schottky diode was measured as a function of forward current.
- The operating temperature in forward bias was estimated using three representative values of junction to ambient thermal resistances (Rth) at an ambient temperature of 90 ºC.

- This analysis can be used to choose the appropriate value of forward current (Isc or 1.25 x Isc) during thermal runaway test.
- In order to avoid thermal runaway, the diode-junction box system must be chosen in such a way that the diode operating temperature is always less than the corresponding critical temperature (shaded area).
- Using such an analysis, it is possible to obtain quantitative information about how close the diode is operating to the thermal runaway point.
- Additionally, comparative risk analysis can be carried for various bypass diodes and junction boxes in order to asses the vulnerability for thermal runaway.

DESIGN GUIDELINES



- The critical temperature is experimentally measured at various values of forward current and reverse voltage.
- Critical temperature is seen to increase when the forward current is increased and reverse voltage is reduced.

- The information about variation of critical temperature with forward current and reverse voltage can act as a design guideline for PV module manufacturers to choose appropriate bypass diodes for specific module types, depending on the short circuit current of the module and open circuit voltage of individual strings.

RECOMMENDATIONS

- The operating temperature of the diode at 1.25 x Isc during the bypass diode test in IEC 61215 can be used as an estimate for worst-case operating temperature.
- This information, along with the critical temperature data obtained by either of the described methods can be used to understand the vulnerability of bypass diode towards thermal runaway.
- Whenever necessary, the “thermal runaway test” can be carried out as an additional test.
- In order to avoid potential for thermal runaway, the diode should be operated several degrees below critical temperature as the region near critical temperature is experimentally found to be unstable.