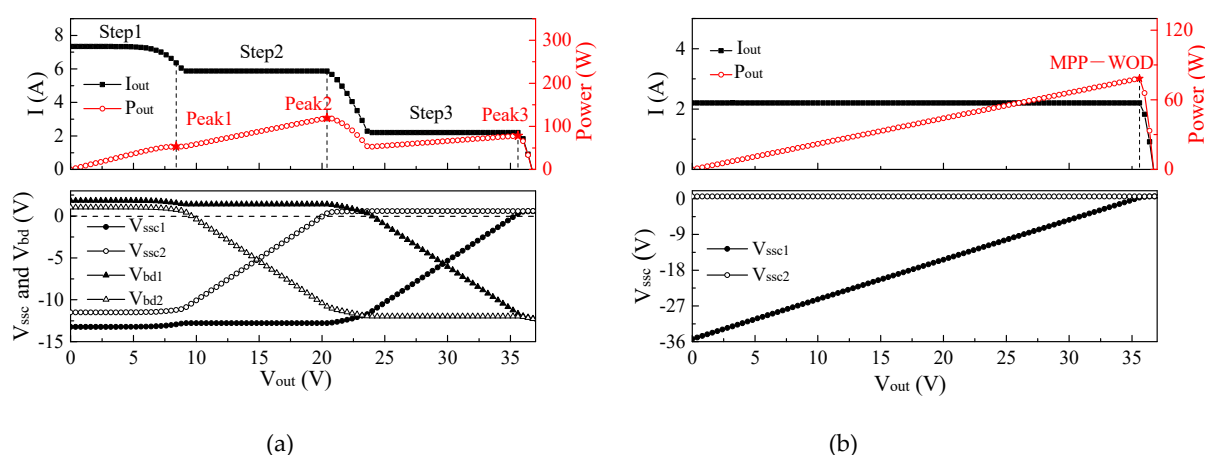# Supplementary Materials: Necessity Analysis of Bypass Diode for AC Module under Partial Shading Condition

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For the condition of three EPPs in the P-V curves of a PV module, we set two bypass diode branches to receive shading ratios differently, i.e., Cell 1 of String 1 is shaded by 70% of its surface area, and Cell 2 of String 2 is darkened by 20% of its surface area. The relevant bypass diodes for String 1 and String 2 are D1 and D2, respectively. Output characteristics and the terminal voltage of the shadowed solar cells and the relevant bypass diodes are shown in Figure S1(a) and Table S1. As we can see from Figure S1(a), under these shading conditions, there are three power peak points in the P-V curve of the PV module, among which Peak 2 is the MPP. At the working point of Peak 1, both diodes D1 and D2 are ON, and the terminal voltages of Cell 1 (Vssc1) and Cell 2 (Vssc2) are -12.93 V and -11.21 V, respectively. Under the role of the bypass diodes, the short-circuit current of the entire PV module is equal to that of the PV module with normal illumination. However, the values of Isc for Cell 1 and Cell 2 are smaller than the output current of the PV module in Peak 1 because of shadows. Therefore, Cell 1 and Cell 2 are both in a state of energy consumption, and the consumed power is 28.45 W and 65.80 W, respectively. At the working point of Peak 2, D1 is ON, and D2 is OFF. Vssc1 is -12.78 V, and the power consumption of Cell 1 is 28.12 W. While Vssc2 is 0.32 V, which means Cell 2 is in a state of generating electricity. Figure S1(b) shows the output characteristics of the PV module without bypass diode receiving the same shading conditions as in Figure S1(a). Comparing Figure S1(a) and (b), Peak 3 for the PV module with bypass diodes has the same peak position and value with the only Peak of the PV module without bypass diode, which signifies that the PV module with bypass diode working at Peak 3 has the same operation states with the PV module without bypass diode working at MPP. At Peak 3 for the PV module with bypass diode, both bypass diodes are OFF, and both Cell 1 and Cell 2 are forward biased, which is the same as without bypass diode. Although electricity generated by these two shadowed solar cells is small, neither of them consumes any energy to heat themselves.

Consequently, for the multi-peak condition of the AC module, if the last power peak point (from left to right in the direction of the output voltage) is the MPP, all bypass diodes are OFF, and all shadowed solar cells consume no energy to form local heat. Moreover, the output power of the PV modules with bypass diodes is the same as that of the PV module without bypass diode under the same shading condition at the working point of the last EPP. If the MPP is one of the other EPPs in the P-V curve, at least one of the bypass diodes turns on depending on the occlusion, and the shadowed solar cell protected by the "ON" bypass diode will withstand a large reverse bias to consume energy, which provides an opportunity for a local hot spot.

(a)   (b)

Figure S1. Output characteristics of the simulated PV module, and the terminal voltages of the shadowed solar cell and relevant bypass diode (only in the figure of module with bypass diode) when two solar cell strings receive different shading conditions: (**a**) module with bypass diode, (**b**) module without bypass diode.

Table S1. Parameters for the shadowed solar cell and the simulated PV module when two solar cell strings receive different shading conditions.

Operating Point	Module			Cell 1 (70%)			Cell 2 (20%)		
	I_{out} /A	V_{out} /V	P_{out} /W	I_{ssc1} /A	V_{ssc1}/V	P_{ssc1}/W	I_{ssc2} /A	V_{ssc2}/V	P_{ssc2}/W
Peak 1	6.36	8.40	53.46	2.20	-12.93	-28.45	5.87	-11.21	-65.80
Peak 2	5.87	20.4	119.71	2.20	-12.78	-28.12	5.87	0.32	1.88
Peak 3	2.20	35.6	78.36	2.20	0.26	0.57	2.20	0.59	1.30
MPP-WOD	2.20	35.6	78.36	2.20	0.26	0.57	2.20	0.59	1.30