7 DISCUSSIONS

7.1 OVERVIEW

Factors affecting the magnitude of power output loss due to shading can be categorised as directly proportional variables such as type of PV material (viz. Group-IV, III/VI, II/V), band gap voltage of the cell material, irradiance, cell area shade percentage, opacity of the shade material, series resistance and inversely proportional variables such as irradiance, ambient temperature, wind direction cum velocity, ventilation of the module rear surface, superstrate and substrate material, air mass and shunt resistance. The overheating on the surface temperature of the PV cells due to partial shade is plotted with respect to load and shown in Figure. 7.3, 7.4, 7.7 and 7.10.

Hot-spot creation and its temperature rise is strongly influenced by various variables such as cell material, short circuit current of cell, diode breakdown voltage, number of cells connected in series, shade percentage over the cell area, opacity of the shade, type of shade A or B, irradiance, series resistance and ambient temperature and air mass. The reverse bias characteristic of the PV module during shade operation is verified and the dark current analysis is performed for the same. It is verified that magnitude of temperature rise over the hot-spot point is inversely proportional to the hot-spot area (higher shade percentage) and directly proportional to the leakage current.

7.2 ANALYSIS OF POLY CRYSTALLINE PV MODULE (100W$_P$)

The I-V (Current- Voltage) and P-V (Power output vs Voltage) curves for polysilicon with 100Wp are shown in Figure. 7.1 & 7.2., shows the variability of the module output voltage, current and power output at normal and shaded mode. Single cell is shaded in each test either on string 1 or 2. From Figure

7.1, it is observed that produced current of PV system is significantly reduced with shading. Similarly, the power output is also lower for PV cell with shaded mode compared to that of normal mode. The lowest performance is observed for the cell of (9, 3) (i.e. cell matrix location) which is shaded about 70 % with black masking tape material with bypass diode turned ON as seen in the I-V curve. Similarly, other cell locations (5, 2 & 5, 3) which are shaded with black masking tape material at different percentage level showed the reduced performance when compared with normal mode. Actually, bypass diode were not turned ON during lower cell area shade test. However, increasing the shade percentage leads to the bypass diode switch ON (forward bias) function. The shaded string output voltage reached to negative, when the bypass diode switch ON, giving a consistent loss of power output. Also, it is inferred that power output is reduced with all percentage of shaded condition compared to that of normal condition (no cell shaded). The shaded PV cell is reverse biased and its operating current exceeds the short circuit current (I_{sc}), then shaded cell will not generate any energy instead of creating hot-spot over the cell surfaces. It causes to increase energy and thermal conversion loss due to the shading. These solar cells are connected in a series array and forced to carry the same current even though a few cells under shade produce less photon current as seen in Figure7.1 & 7.2. These shaded cells are not only reducing the power but also creating a hot-spot or overheating of shaded cell on PV module.

Figure 7.3 & 7.4 shows the influence of partial shading and behavior of bypass diode on solar cell surface temperature with load current. It is inferred that there is no significant raise of cell surface temperature from clean surface of solar cell (i.e. no shading on solar cell). The partial shading is simulated on the PV module by using black masking tape and charcoal as the shading media. The partial shading of 9, 2 & 9, 3 (module matrix position) on PV cell generates the surface temperature of 347 ^{o}C & 324 ^{o}C on the hotspot point at the rear side of panel, respectively, when the bypass diode is not turned ON. In the front side of the panel, the surface temperature is around 102 ^{o}C.

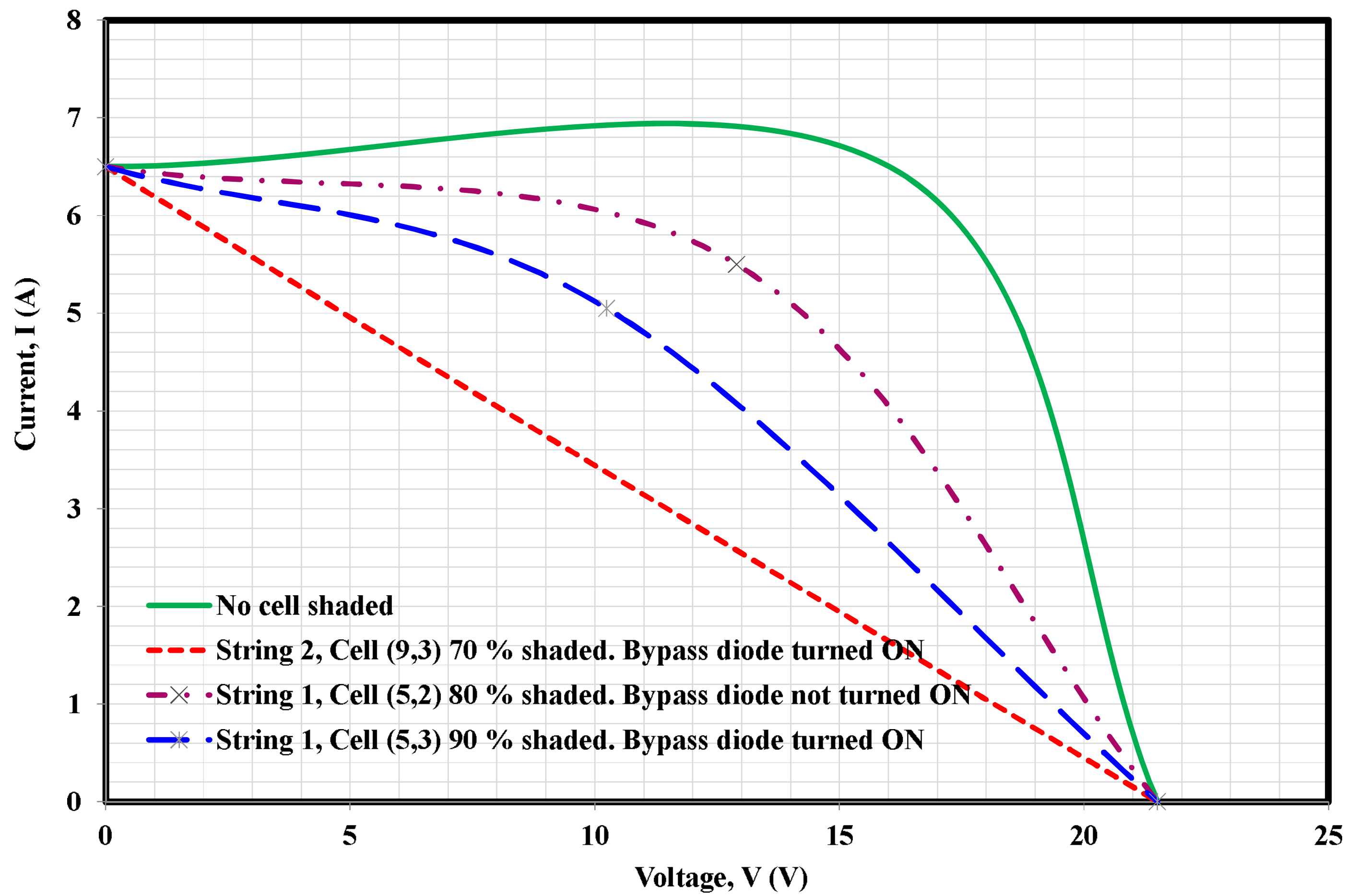

Figure 7.1 Current–Voltage Performance of the 100 Wp - Poly Crystalline PV module

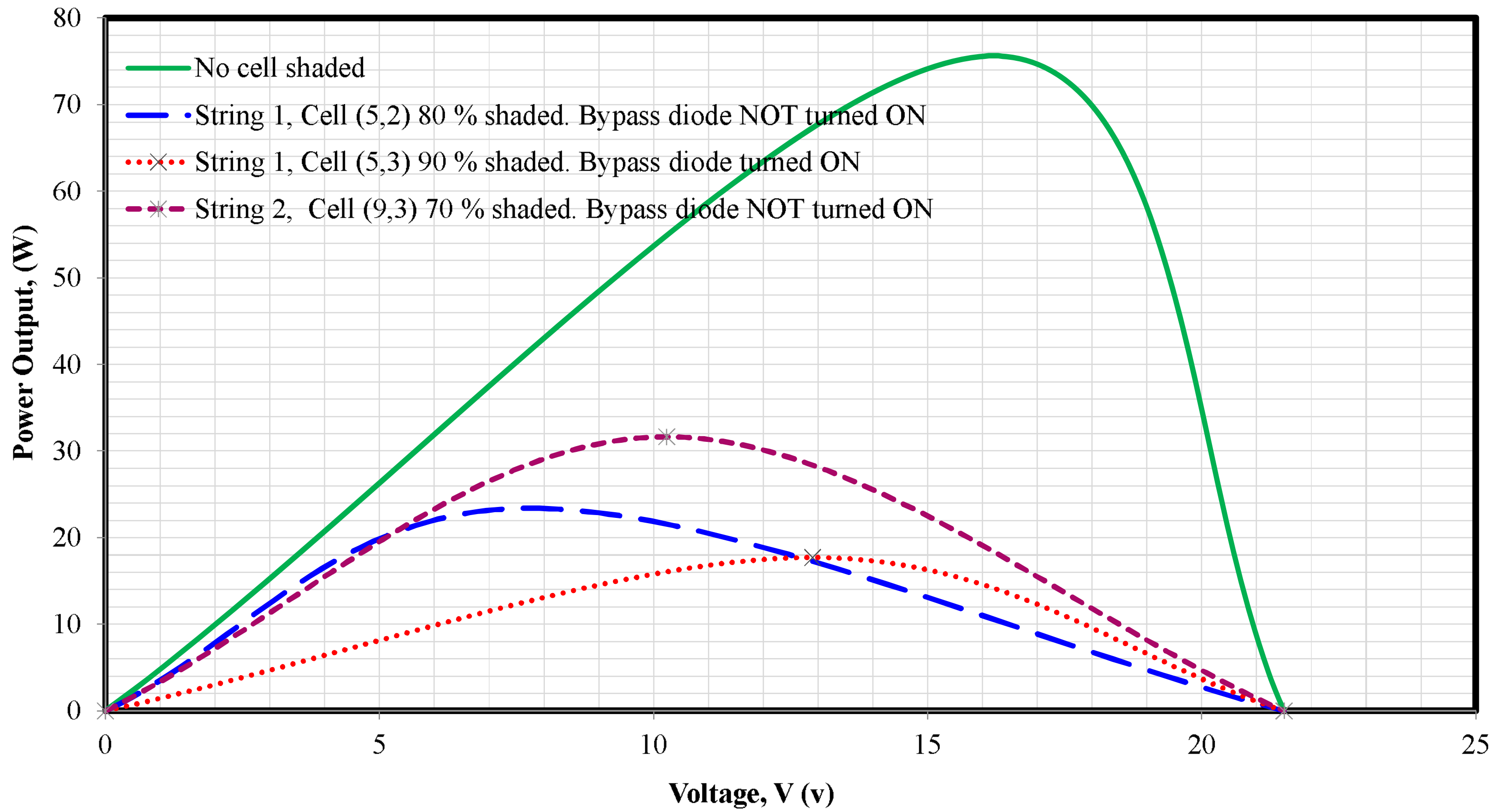

Figure 7. 2 Power–Voltage Performance of the 100 Wp – Poly Crystalline PV module

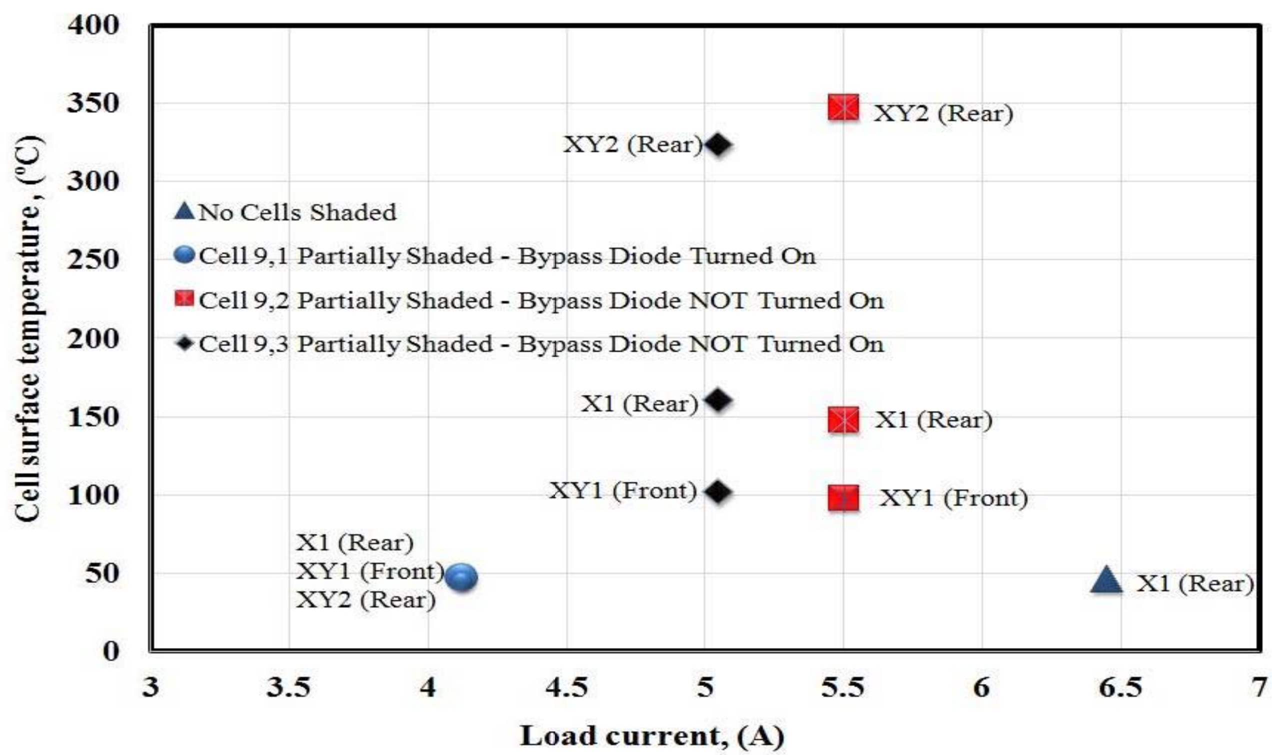

Figure 7.3 Cell Partial Shade Temperature Rise Poly crystalline 100 Wp Module with bypass diode

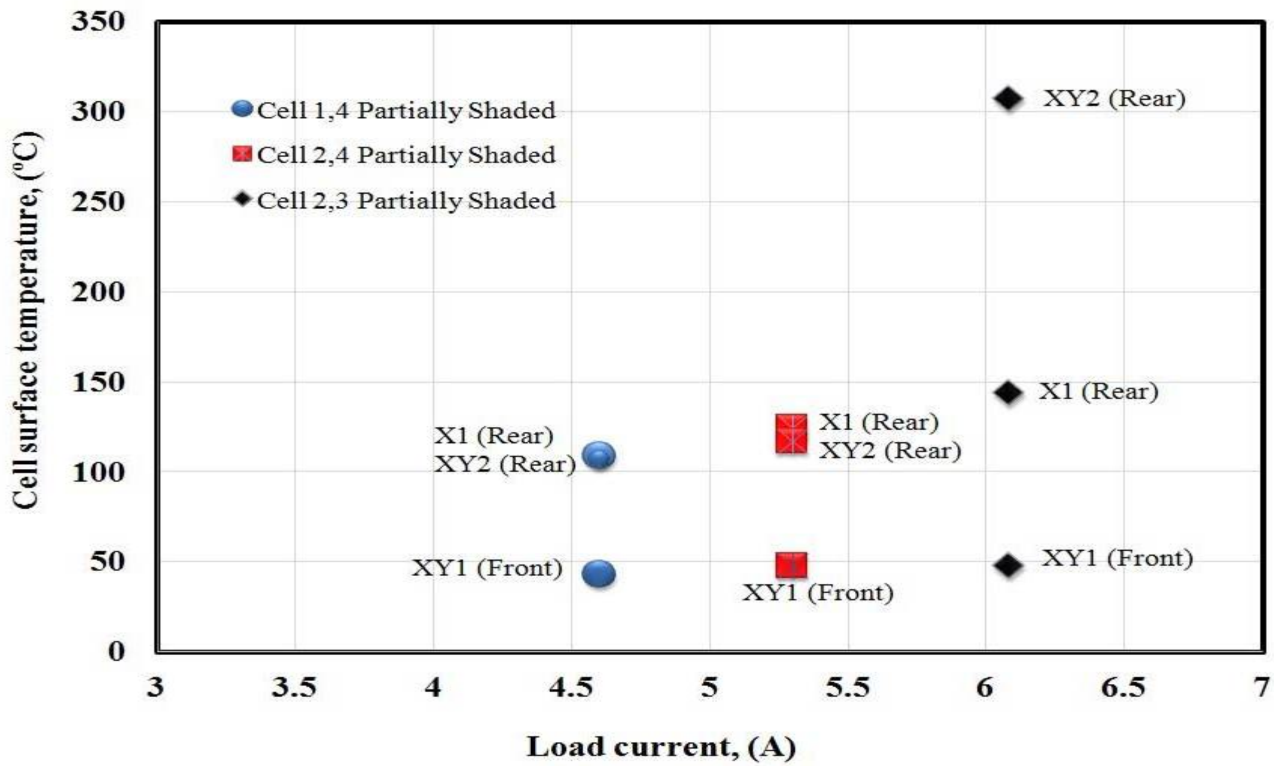

Figure 7. 4 Cell Partial Shade Temperature Rise Poly crystalline 100 Wp Module without bypass diode

The rear surface temperature is higher than the front surface due to presence of glass superstrate. Subsequent partial shade test on cell 9, 3 with charcoal as shade media has recorded a point temperature rise up to 307 °C with bypass diode has not been switched ON.

Test conducted without bypass diode and with black masking tapes as partial shade media has recorded a temperature 308 °C rise on rear surface.

The cell damages are observed at the cell junction with discoloration of cell surface. In addition, uncertainty of the bypass diode switching on during the partial shade is verified during this test.

7.3 ANALYSIS OF POLY CRYSTALLINE PV MODULE (230W$_P$)

The I-V and P-V curves for poly silicon with 230 Wp are shown in Figure7.5&7.6, it shows the variability of the module output voltage, current and power at normal and shaded mode. Single or dual cell is shaded in each test either on string 1 or 2 or 3. From Figure 7.6, it is illustrated that the performance of PV system is better for normal mode as the current is significantly reduced for the same given voltage with shading. The performance of poly silicon of 230 Wp module was studied with and without shading condition as shown in Figure7.6. The cell matrix locations (2, 6) & (3, 2) were shaded by sand dust material at 75 percentage level showed the reduced performance of I-V when bypass diode was turned ON.

Similarly, other cell locations (1, 4 & 1, 6) were shaded by sand dust material at 90 percentage level. It is inferred that the overall power is reduced with all percentage of shaded condition compared to that of normal condition (no cell shaded).

The output power loss is occurred from shaded cell and also mismatch of current within a PV string and mismatch of voltage between parallel strings of 1 & 3. It is also inferred that one third of the output power is lost, even if a single cell in a string is shaded with bypass diode turned ON as shown in

Figure7.6.

The cell surface temperature versus load current at shading material of hydrocarbon dust is shown in Figure. 7.7. It is observed that the cell surface temperature is less than 50 ^{o}C in the most of the times when bypass diode is switched ON, which is minimising the surface temperature rise. The cell surface temperature of 63 ^{o}C is observed when multiple cells are shaded or with bypass diode not switched ON scenarios.

In addition, there is no temperature rise by using charcoal and hydrocarbon dust with bypass diode ON as shown in Figure 7.7 and Table 6.2. Also it indicates that measured module surface front glass temperatures (XY1) under $T < 45^{o}C$ and module surface rear (XY2) temperature under $T < 46^{o}C$ for charcoal dust material are not critical for modules. For hydrocarbon dust, the measured module surface front glass temperatures (XY1) under $T < 63^{o}C$ and module surface rear (XY2) temperature under $T < 56^{o}C$ are not critical for modules.

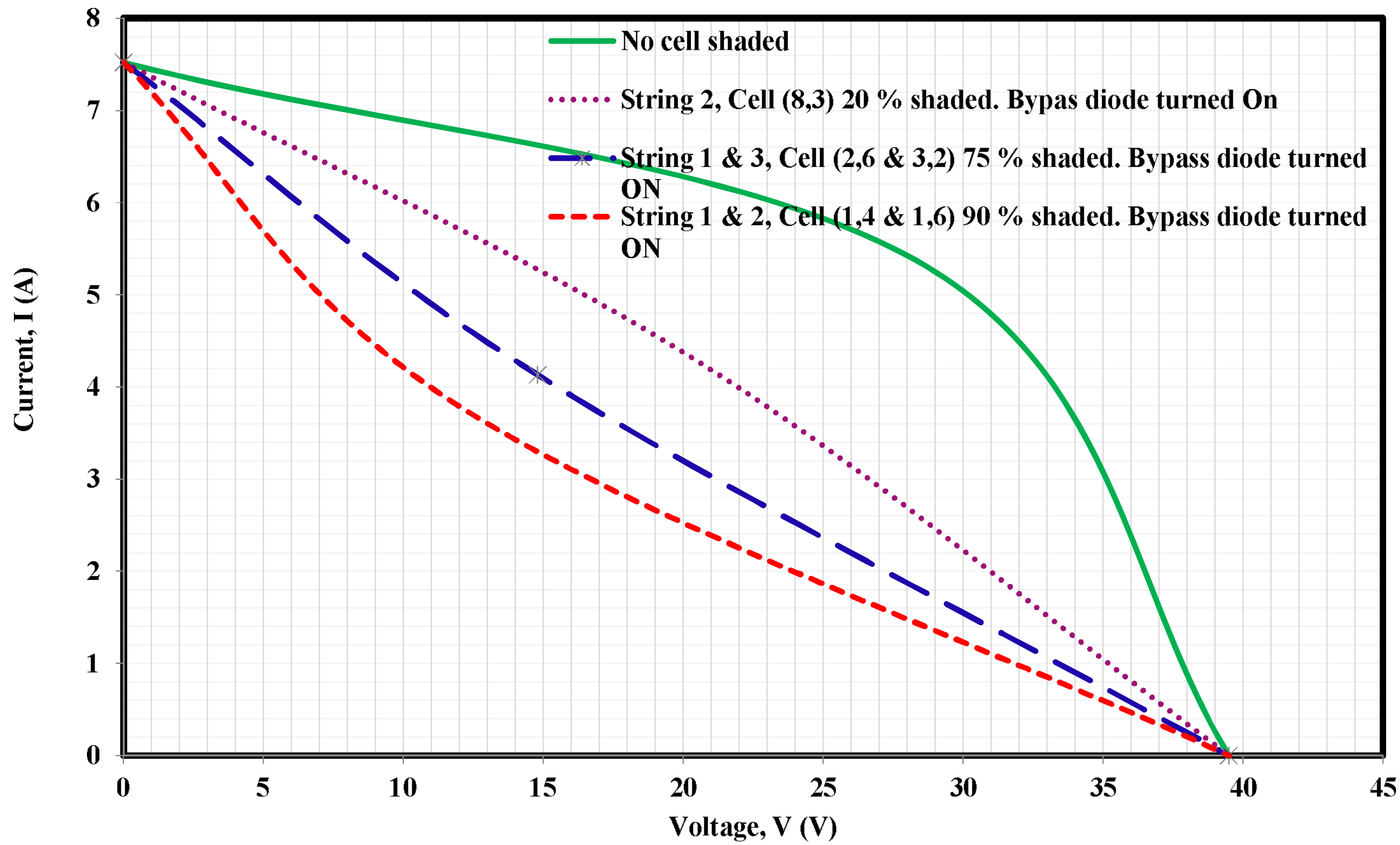

Figure 7.5 Current–Voltage Performance of the 230 Wp – Poly Crystalline PV module

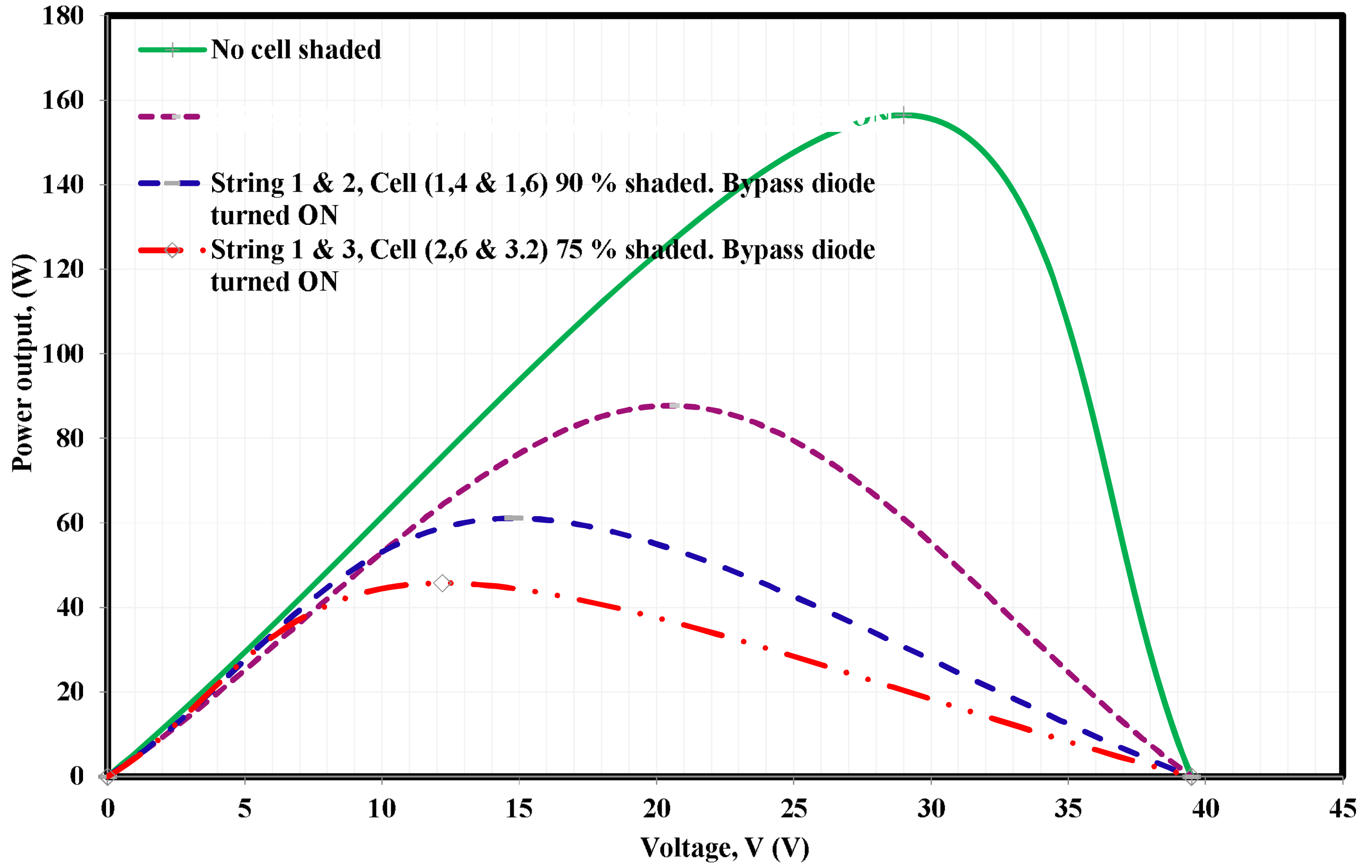

Figure 7. 6 Power–Voltage Performance of the 230 Wp – Poly Crystalline PV module

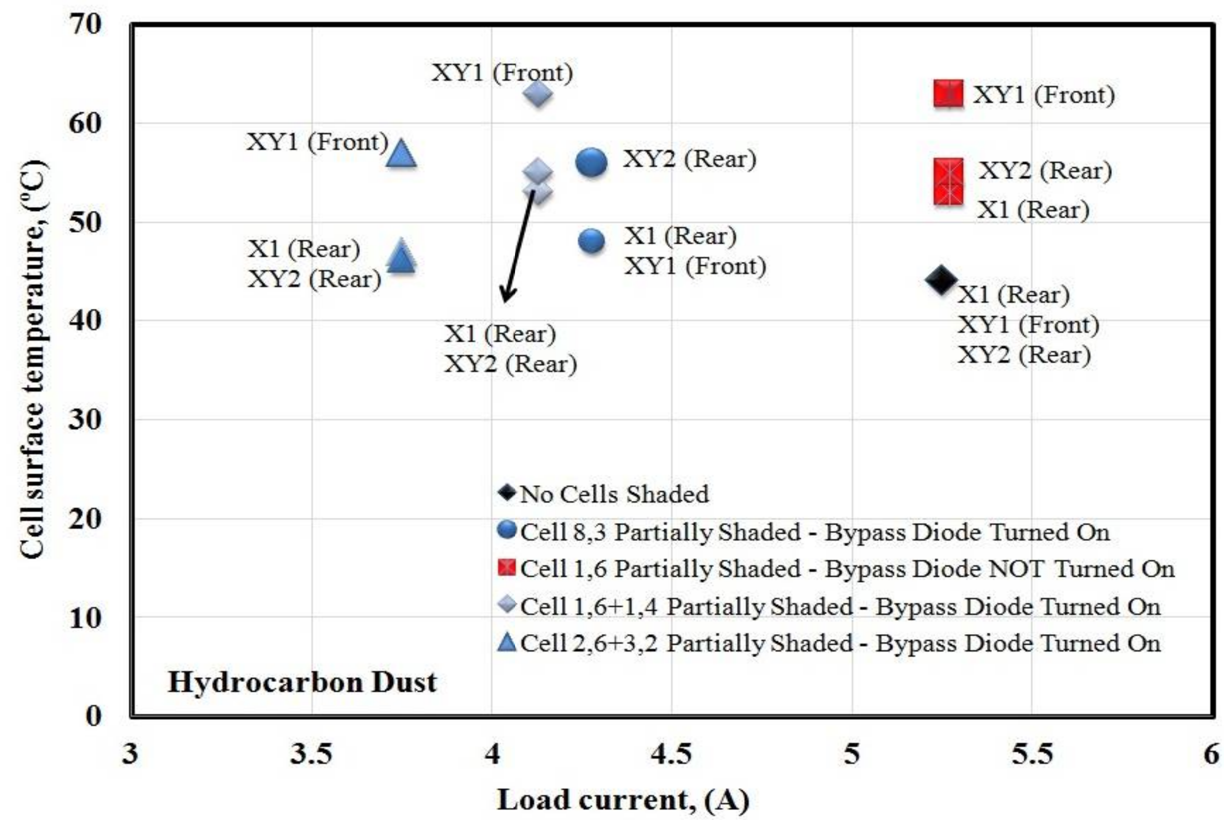

Figure 7.7 Cell Partial Shade Temperature Rise - With Bypass Diode Poly crystalline 230 Wp 24V Module

7.4 ANALYSIS OF MONO CRYSTALLINE PV MODULE (250W$_P$)

The I-V and P-V curves for mono silicon with 250 Wp are shown in Figure7.8 &7.9, it shows the variability of the module output voltage, current and power at normal and shaded mode. Single cell is shaded in each test either on one string. From Figure 7.8, it is illustrated that the performance of PV system is better for normal mode, as the current is significantly reduced for the same given voltage with shading. The performance of mono silicon of 250 Wp system was studied with and without presence of shading condition as shown in Figure 7.8. The cell matrix location (9, 2) which are shaded by sand dust material at 70 percentage level and it showed that the reduced performance of I-V when bypass diode is turned ON. Similarly, other cell location (5, 6) is shaded with black masking material at 80 percentage level. It is inferred that the overall power is reduced with all percentage of shaded condition compared to that of normal condition (no cell shaded). The cell surface temperature was noted for mono silicon 250 Wp with and without presence of bypass diode condition. Figure7.10 shows the hot-spot temperature on the rear and front side of PV cell under partial shade condition.

The test result of mono crystalline PV module is given in Table 6.3. Figure 7.10 shows the cell surface temperature versus load current at shading material of hydrocarbon dust. It is observed that the surface temperature reached up to 68^{o}C with bypass diode for hydrocarbon dust partial shade test. Table 6.3 indicates that measured module surface front glass temperatures (XY1) under $T < 53^oC$ and module surface rear (XY2) temperature under $T < 68^oC$ are not critical for modules. The module surface temperature of XY2 (rear side) is raised $T= 135^oC$ without bypass diode. In this condition, the cell gets slightly damaged on rear surface of shaded cell of 9, 2.

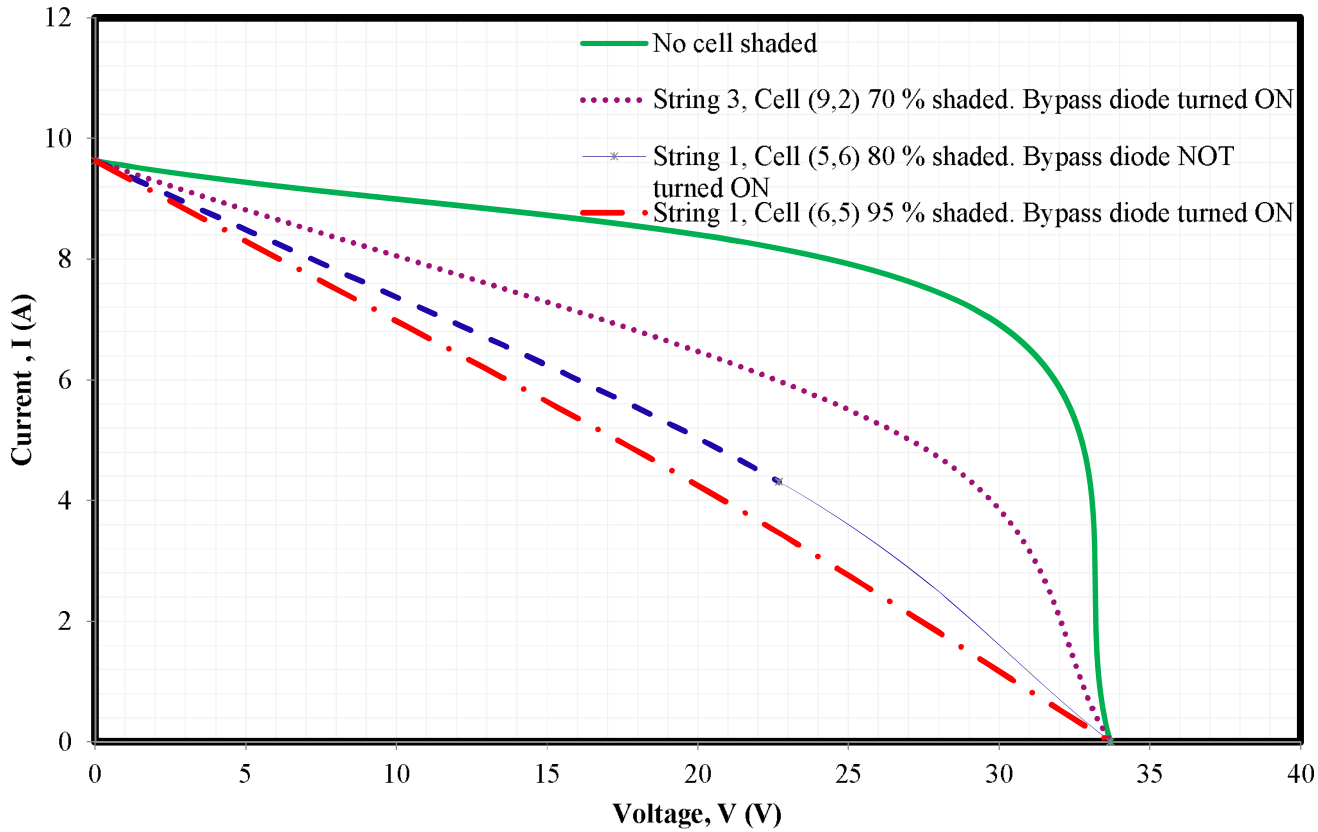

Figure 7.8 Current–Voltage Performance of the 250 Wp – Mono Crystalline PV module

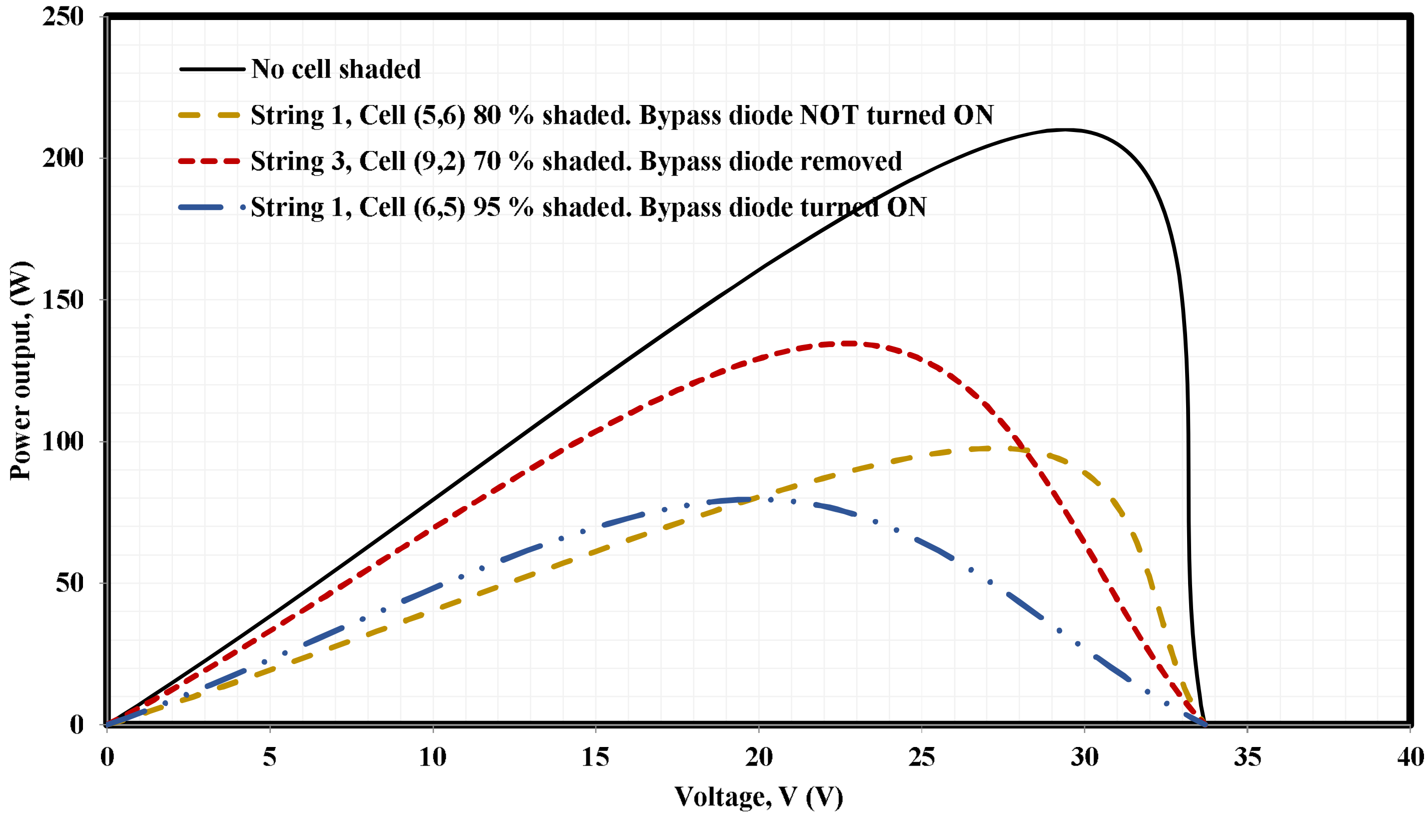

Figure 7. 9 Power–Voltage Performance of the 250 Wp– Mono Crystalline PV module

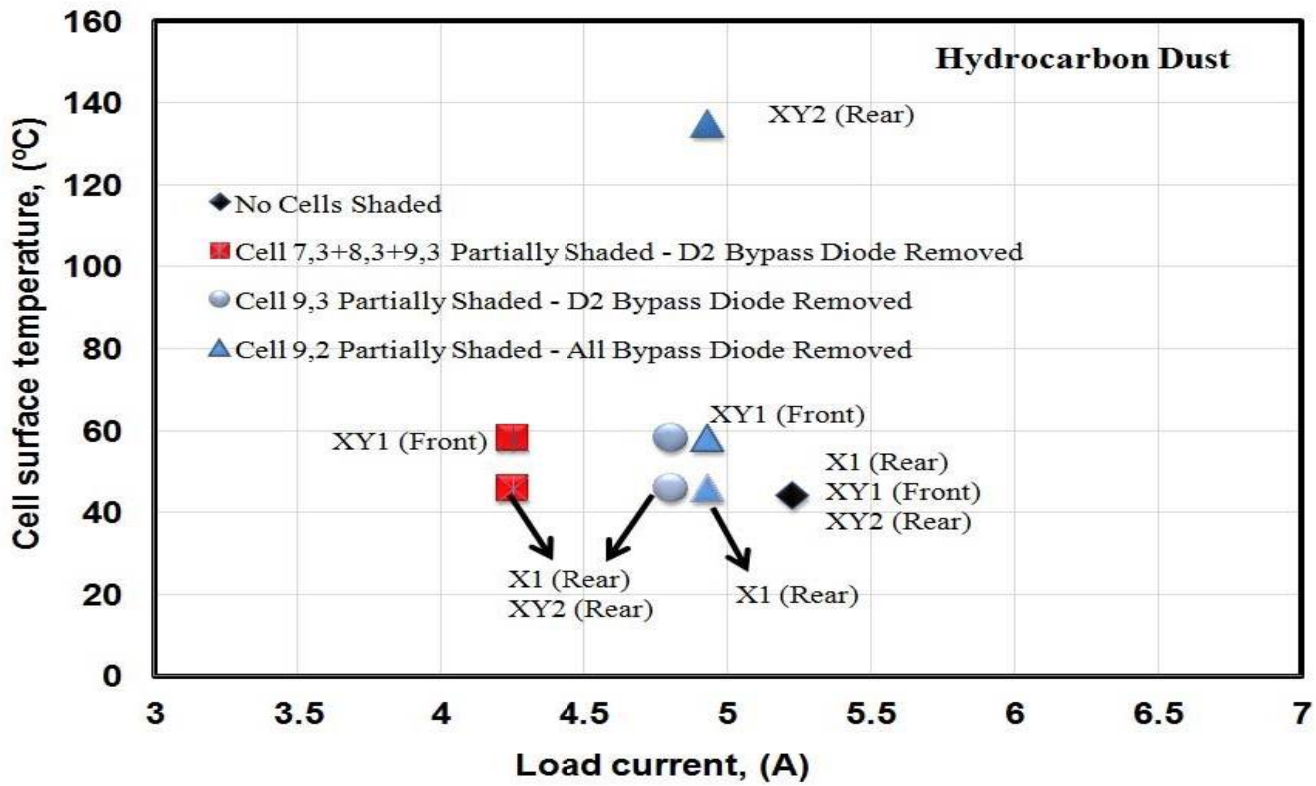

Figure 7.10 Cell Partial Shade Temperature Rise - Bypass Diode Removed Mono crystalline 250 Wp 24V Module