6. EXPERIMENTATION & RESULTS

6.1 OVERVIEW

Actual photographs of the experimental setup with PV modules and shade test and result of hot-spot observation is depicted in Figure 6.1.

Variability can be defined as how spread out or clustered the data and the results depict the surface temperature versus current load for various shade materials and the status of bypass diode. The experimental results illustrate variability of data. Variability of the module output voltage and hot-spot surface temperature from the normal operation to the partial shade operation in different loads is of great interest in this work. The IV & PV performance curves in normal mode and shade operation depicts the variability of the power output loss. Similarly, temperature versus the load plot gives the variability of the hot-spot temperature as well.

Uncertainty can be defined as the chances of each possible event, the reliability of the bypass diode and its uncertainty of functioning, causing the hotspot which is experimentally verified.

The factors influencing the partial shade test are the module current, voltage based on connected load, shade media and shading percentage on the PV cell. The effect of the partial shade is the creation of hotspot over the substrate and superstrate of the PV cell hence surface temperature of the PV module front and rear surface. Additionally, the substring voltage of the module is also recorded for verification of its behavior during bypass diode switch on functions.

At normal condition (i.e., cell is not shaded), module is at ambient surface of temperature, which is around 50 ^{o}C.

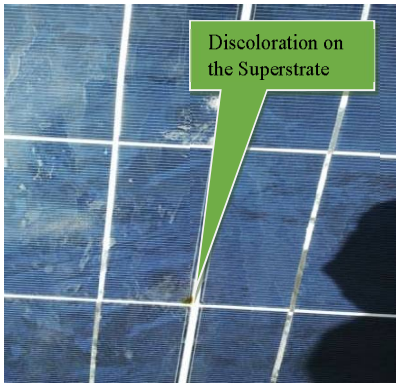
(a)

(b)

(c)

(d)

(e)



(f)

Figure 6. 1 Experimental Setup

(a) All three Modules in the Experimental Setup (b) Poly crystalline 100Wp module with 12V 50W lamp load, (c) Hotspot test with black masking tape shade (d) Hotspot test with dust shade) (e) & (f) Observed Hotspot and Cell damage on front / rear side due to hotspot test

PV module cells are numbered based on its location on the matrix viz. cell (1, 1) at the left side top of the module and to cell (4, 9) at the right side bottom of the module in poly crystalline PV module (100 Wp). Similarly, for poly crystalline PV module (230 Wp) it is numbered as cell (1, 1) & (6, 12) and also for mono crystalline PV module (250Wp) it is numbered as cell (1, 1) & (6, 10) based on its location on the matrix. The experiments were carried out for varying irradiance intensity from 800-1000 W/m2. Other independent variables such as wind direction (SW ~ NW), wind velocity (9~18 km/hr), module tilt (40o~60o) and ambient temperature 31 ~ 41 ºC were reordered. Site irradiance was measured through pyranometer and the maximum value of 1030 W/m2 at zenith was recorded during the test.

At first, each module was tested with no cell shaded condition to verify its healthiness and characterized through I-V & P-V curves as illustrated in Figure 6.2. Then, the PV cell shade simulated by opaque black masking tape, charcoal and hydrocarbon dust as shading media was tested with different percentage of cell shaded. Additionally the substring voltage of the module was also recorded for verification of its behavior during bypass diode switch on functions.

One cell on each module on a specific substring was shaded in this experiment, so that the module voltage drop was observed. Also, the test includes two cell shade on a module but on different substrings, therefore module voltage drop up to 1/2 ~ 1/3 once the bypass diode was forward biased. The cells are shaded with masking tape and sand dust from 20 % ~ 99 % of the area of the cell. The effects on voltage and current and, temperature rise on substrate and superstrate of the PV was noted.

The sequence of test performed on PV cell completely covered for identifying high and low shunt resistance cell. The test were conducted with By-pass Diode and without By-pass Diode (removed). Skin thermocouple (K-Type) with a multipoint temperature scanner was used to measure the front & rear surface temperature of the PV cells. One skin thermocouple was fixed over the PV module superstrate to measure the module surface temperature. One skin thermocouple (XY-1) on the front (superstrate) and another thermocouple (XY-2) on rear (substrate) were fixed on the shaded cell. Laser guided IR thermo gun

with variable emissivity was used for non-contact temperature measurement (X1) around the shaded cell. A support used to install the PV module has variable module tilt adjustment design.

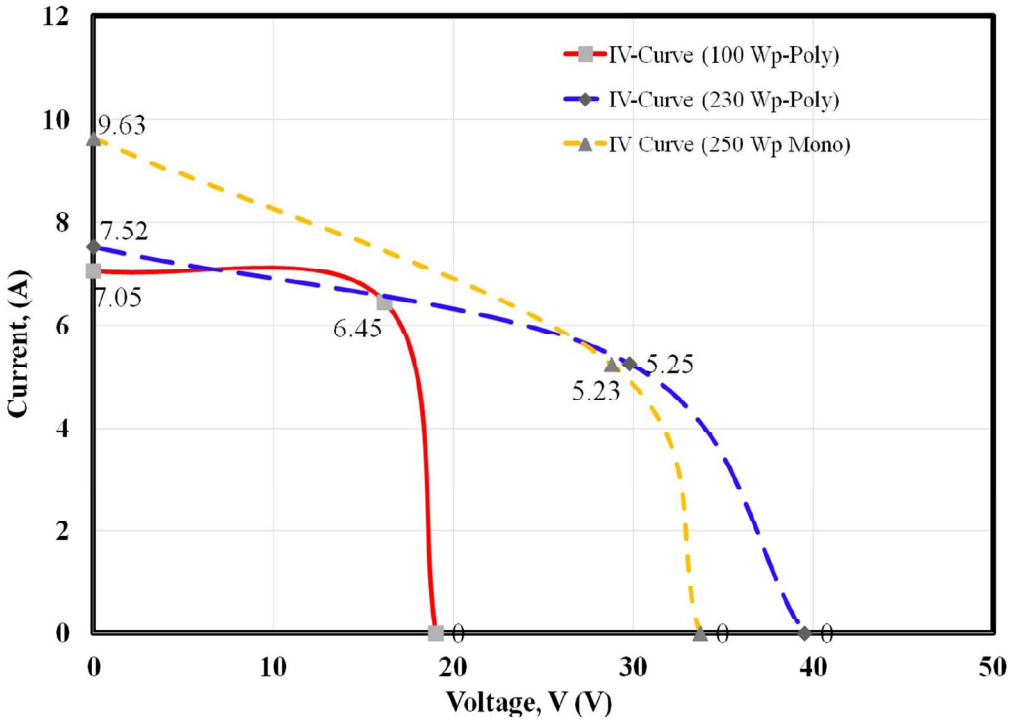


Figure 6.2 IV (Current-Voltage) curve for PV performance modules

6.2 RESULTS POLY CRYSTALLINE PV MODULE (100W_P)

The test results of poly crystalline PV module (100Wp) are given in Table-6.1.

6.3 RESULTS POLY CRYSTALLINE PV MODULE (230W_P)

The test results of poly crystalline PV module (230 Wp) are given in Table-6.2.

6.4 RESULTS OF MONO CRYSTALLINE PV MODULE (250Wp)

The test results of mono crystalline PV module (250Wp) are given in Table-6.3.

6.5 SUMMARY

Empirical study, testing and data collection has progressed smoothly due to the preparatory and planning phases of the design. Captured data are recorded in a pre-defined table for each test. Every module is tested in unshaded and shaded conditions with masking tape, charcoal dust and hydrocarbon dust with a combination of diode configurations. Theory of hot-spot phenomena was successfully verified and temperature data are recorded. Damages due to hot-spot formation were observed in the rear of the PV modules.

Table 6.1 Poly Crystalline 100Wp Hotspot Test Summary

Primary Data		Site Insolation	*1030 **	*W/m²*	Wind Direction	*SW*	Ambient Temperature	*31 ~ 41*	°C	Bypass Diode Status
		Voc	*19.3*	*Volts*	Wind Velocity	*9 ~18 Km/Hr*	Module Tilt (β)	*47 ~ 68*	*Deg*	
		Isc	*7.05*	*Amps*	Partial Shade	*One Cell*	Shade Level	*70 ~ 90%*		
Sl.No	Test Cell No.	Voltage	Current	Load	Shaded Cell Temperature - °C	Sub-String Voltage - Volts		Shaded Cell Surface Temperature -°C		
		Volts	Amps	Watts	X1 (Rear)- IR	VD1	VD2	XY-1 (Front)	XY-2 (Rear)	
TEST WITH BYPASS DIODE - Black Masking Tape										
1	No cell shaded	16.2	6.45	104.49	45	7.94	7.98	46	45	
2	9, 1	7.75	4.12	31.93	47	-0.79	8.86	46	45	Bypass Diode Turned ON
3	9, 2	12.9	5.5	70.95	148	5.23	8.28	98	347	Bypass Diode NOT Turned ON
4	9, 3	10.24	5.05	51.71	160	4.96	8.16	102	324	Bypass Diode NOT Turned ON
TEST WITHOUT BYPASS DIODE - Black Masking Tape										
1	1, 4	8.2	4.6	37.72	109	4.2	3.4	43	107	
2	2, 4	12.7	5.3	67.31	125	8.2	4.65	48	117	
3	2,3	14.8	6.08	89.98	144	7.4	7.4	48	308	

TEST WITH BYPASS DIODE - Charcoal Dust										
1	9,1	7.8	2.8	21.84	41	8.6	-0.5	39	45	Bypass Diode Turned ON
2	9,3	10.1	3.13	31.61	45	5.6	3.9	55	307	Bypass Diode NOT Turned ON
Notes:	1. Lamp Load 12 V / 50 W									
	2. Diode 10 A 10 HY									
	3. VD1, VD2: Substring Measured Voltage between Diodes D1, D2.									
	* Site Insolation Measured Through Pyranometer and Maximum Value at Zenith Recorded.									

Table 6. 2 Poly Crystalline 230Wp Hotspot Test Summary

Primary Data		Site Insolation	*1030 **	*W/m²*	Wind Direction	SW	Ambient Temperature		*31 ~ 41*	°C	Bypass Diode Status
		Voc	*39.5*	*Volts*	Wind Velocity	9 ~18 Km/Hr	Module Tilt (β)		*47° ~ 77°*	*Deg*	
		Isc	*7.52*	*Amps*	Partial Shade	One Cell	Shade Level		*70 ~ 90%*		
Sl.No	Test Cell No.	Voltage	Current	Load	Shaded Cell Temperature - °C	Sub-String Voltage - Volts			Shaded Cell Surface Temperature - °C		
		Volts	Amps	Watts	X1 (Rear)-IR	VD1	VD2	VD3	XY-1 (Front)	XY-2 (Rear)	
TEST WITH BYPASS DIODE - Charcoal Dust											
1	No Cell Shaded	29.8	5.25	156.45	44	9.4	9.5	9.2	44	46	
2	2,2	20.7	4.17	86.319	43	-0.7	10.7	10.6	45	46	Bypass Diode Turned ON
3	3,4	20.7	4.23	87.561	45	10.4	-0.4	10.5	43	44	Bypass Diode Turned ON
TEST WITH BYPASS DIODE - Hydrocarbon Dust											
1	8,3	20.5	4.28	87.74	48	10.6	-0.5	10.6	48	56	Bypass Diode Turned ON

2	1,6	29	5.27	152.83	53	9.6	9.6	9.6	63	55	Bypass Diode NOT Turned ON (20% Cell Shade)
3	1,4+1,6	14.8	4.13	61.12	53	1.1	2.8	10.2	63	55	Bypass Diode Turned ON (90% Cell Shade) Load 200W Bulb
4	2,6+3,2	12.2	3.75	45.75	47	3.9	9.8	-0.5	57	46	Bypass Diode Turned ON (25% Cell Shade) Load 200W Bulb
Notes:	1. Lamp Load 24 V / 150 & 200 Watts										
	2. VD1, VD2, VD3: Substring Measured Voltage between Diodes D1, D2, D3.										
	* Site Insolation Measured Through Pyranometer and Maximum Value at Zenith Recorded.										

Table 6. 3 Mono Crystalline 250Wp Hotspot Test Summary

Primary Data		Site Insolation	*1030 **	*W/m^2*	Wind Direction	*SW*	Ambient Temperature		*31 ~ 41*	*°C*	Bypass Diode Status
		Voc	*33.7*	*Volts*	Wind Velocity	*9 ~18 Km/Hr*	Module Tilt (β)		*47*	*Deg*	
		Isc	*9.63*	*Amps*	Partial Shade	*One Cell*	Shade Level		*70 ~ 90%*		
Sl.No	Test Cell No.	Voltage	Current	Load	Shaded Cell Temperature - °C	Sub-String Voltage - Volts			Shaded Cell Surface Temperature - °C		
		Volts	Amps	Watts	X1 (Rear)-IR	VD1	VD2	VD3	XY-1 (Front)	XY-2 (Rear)	
TEST WITH BYPASS DIODE - Charcoal Dust											
1	No Cell Shaded	28.8	5.23	150.62	44	9.6	9.6	9.6	44	46	
2	3,5	20.3	5.35	108.60	44	9.9	9.8	-0.2	43	41	Bypass Diode Turned ON
3	4,6	20.4	4.26	86.90	45	9.9	9.8	-0.2	43	44	Bypass Diode Turned ON
TEST WITH BYPASS DIODE - Hydrocarbon Dust											
1	6,5	19.9	4	79.6	52	-0.279	10	10	53	52	Bypass Diode Turned ON
2	5,6	22.7	4.3	97.61	47	2.8	9.8	9.8	51	50	Bypass Diode NOT Turned ON (80% Cell Shade)

3	5,6	20.1	4.31	86.63	46	-0.1	9.8	9.8	42	68	Bypass Diode Turned ON (90% Cell Shade)
4	4,2	20.1	4.2	84.42	46	10.1	10.1	-0.1	42	52	Bypass Diode Turned ON (50% Cell Shade)
TEST WITHOUT BYPASS DIODE - Hydrocarbon Dust											
1	7,3	0	0.29	0	46	10.8	-19.2	9.8	58	46	Centre String Bypass Diode Only Removed (90% Cell Shade)
2	7,3 & 8,3 & 9,3	25	4.25	106.25	46	10.1	4.9	9.8	58	46	Centre String Bypass Diode Only Removed (20% Three Cells Shade)
3	9,3	25.8	4.8	46	46	10.2	5.7	10	58	46	Centre String Bypass Diode Only Removed (90% Cell Shade)
4	9,2	27.3	4.93	134.58	46	10.1	9.9	7	58	135	All String Bypass Diode Removed (90% Cell Shade)
Notes:	1. Lamp is used as Load 12 V / 150 W										
	2. Diode MBR 1545S DEC3119										
	3. VD1, VD2,VD3: Substring Measured Voltage between Diodes D1,D2,D3										
	* Site Insolation Measured Through Pyranometer and Maximum Value at Zenith Recorded.										