

## Comparative Analysis To Study The Effects Of Partial Shading On PV Array Withlt-Spice And Matlab/Simulink Environment

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### Abstract

*The simulation based study of PV cells/arrays using LT-Spice and Matlab/Simulink environment is presented in this paper. LT-Spice is an analog/digital circuit simulator that is used to verify circuit designs and to predict the circuit behaviour while Matlab/Simulink is a block diagram environment for multidomain simulation and model-based design. These features of both the softwares are used for the comparative analysis of modelling and simulation of the circuits of PV cells/arrays. Effect of two environmental parameters of irradiance and temperature is observed from the simulated characteristics. Under Partial Shading Conditions (PSCs) the power from the PV array can be drastically reduced and Maximum Power Point Tracking (MPPT) points are affected. Hence, to improve the performance of PV arrays the bypass and blocking diodes are used and their effect on open-circuit voltage ( $V_{oc}$ ), maximum power output ( $P_m$ ), voltage at maximum power output ( $V_m$ ) and the corresponding current at maximum power output ( $I_m$ ) is observed.*

### 1. Introduction

The energy system at the beginning of the 21<sup>st</sup> century is utilized by 6 billion people that live on the Earth and the total energy consumption of approximately  $1.3 \times 10^{10}$  KW has been estimated. It is expected that the world population will grow and reach 10 billion in 2050. In order to provide the growing population with high living standards, further economic development is essential. The concept of sustainable development has been taken into account i.e. fulfilling the needs of the present without compromising the future requirements. The environmental-friendly i.e. renewable or sustainable energy sources has emerged to be a promising alternative for the conventional sources of energy. The solar energy is inexhaustible, environmental-friendly, distributed throughout the earth and includes easy maintenance. Due to this, photovoltaic solar energy has been increasingly used to generate electric power from sunshine. The direct conversion of solar radiation into electricity is known as photovoltaic (PV) energy conversion because it is based on the photovoltaic effect. The photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. Photovoltaic literally means

“light-electricity” as “photo” means light and “volt” is an abbreviation of Alessandro Volta’s name who was a pioneer in the study of electricity. Since a layman does not know the meaning of the word photovoltaic, a popular and common term referring to PV solar energy is solar electricity.

Solar cells or photovoltaic (PV) cells are devices that convert sunlight directly into electric energy using silicon (or other material) PN junction. A PV cell is a basic unit that generates voltage in the range of 0.5 to 0.8 volts depending on cell technology being used. This small generation is not of much commercial use if these cells are not integrated and connected together in a module to give the handsome voltage atleast to charge a standard battery of 12 volts [3].

To experiment with PV cells in the laboratory is a time-consuming and costly task. So, to overcome this problem, simulation techniques are used to simulate the behaviour of PV cells under different conditions. Several simulation softwares are available now days. PSpice has been used for the study of silicon solar cells and modules constructed from such series connected cells-strings [2-3] while Matlab has been used to study the shading effect on PV cells/arrays [1,4,11]. The simple study carried out leads to valuable information that would be useful in the design of PV modules and power supply systems utilizing such modules as their basic energy source to design PV arrays [5-9]. The performance has been evaluated under the standard test condition (STC) i.e. 25°C.

The most important component that affects the accuracy of simulation is the PV cell modelling. For improved accuracy, the two-diode model [1] was proposed as in real solar cell, the recombination (represents a substantial loss) is present especially at low voltages or low insolation. The performance of PV array is affected by temperature, solar insolation, shading and array configuration. Shading can occur when the PV modules or arrays get covered by the shadows of the passing clouds, buildings etc. As a result, the ideal operation of the PV systems gets affected. Under PSCs, the PV characteristics get more complex with multiple peaks. Hence, it is important to understand and predict them in order to extract the maximum possible power [4].

In this paper, LT-Spice and Matlab/Simulink environment has been used and simulation circuits and models of PV modules and arrays have been developed in both the softwares to study the effect of two environmental parameters of irradiance and

temperature. LT-Spice is a high performance SPICE (Simulation Program with Integrated Circuit Emphasis) simulator, schematic capture and waveform viewer. It is simple and easy to simulate the I-V and P-V characteristics of the PV system. The DC-Sweep analysis has been used for the variation in the parameter values. P-V characteristics can be plotted using add trace feature. Matlab is a high performance language for technical computing. It uses solar cell block for the simulations and other blocks such as solver, ps-constant, spice environment parameters, current sensor, ps-simulink converter, PWL voltage source, voltage sensor and scope have been used in addition to it. The effect of introduction of bypass and blocking diodes in the PV arrays has been observed. The paper deals with the simulation studies of PV cells and arrays under the effect of partial shading. The results of both the softwares have been analysed and compared.

## 2. PV module modelling

The most important component that affects the accuracy of the simulation is the PV cell model. Modelling of PV cell involves the estimation of the I-V and P-V characteristic curves to emulate the real cell under various environmental conditions. The equivalent circuit diagram of the PV cell is shown below:-

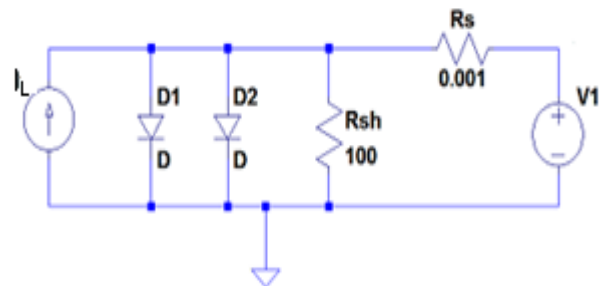


Fig.1: Equivalent circuit of PV cell

The output current of the cell can be given as:-

$$I = I_L - I_{01} \left[ e^{\frac{V+IR_s}{a_1 V_t 1}} - 1 \right] - I_{02} \left[ e^{\frac{V+IR_s}{a_2 V_t 2}} - 1 \right] - \frac{(V+IR_s)}{R_p} \quad (1)$$

Where,  $I_L$  is the illumination current i.e. the current induced by the cell.

$$I_L = I_{L0} \times \frac{I_r 0}{I_r} \quad (2)$$

$$V_{t1,2} = \frac{N_s k T}{q} \quad (3)$$

$I_r$  is the irradiance (light intensity) in  $W/m^2$  falling on the cell.

$I_{L0}$  is the measured illuminated or photo-generated current for the standard irradiance  $I_{r0}$ .

$I_{01}$  and  $I_{02}$  are the reverse saturation currents of diode1 and diode2 respectively.

$V$  is the voltage across the solar cell electrical ports.

$I$  is the output current of the cell.

$V_{t1,2}$  is the thermal voltage of the PV module having  $N_s$  cells connected in series.

$q$  is the electron charge ( $1.6 \times 10^{-19}C$ )

$K$  is the Boltzmann constant ( $1.38 \times 10^{-23} J/K$ )

$T$  is the measurement temperature parameter value.

$a_1$  and  $a_2$  are the ideality factors of diode1 and diode2 respectively.

### 3. The PV module and array study

Shading of PV cells is a critical issue in their performance because the shaded cells start consuming instead of generating power as they get reverse-biased resulting in the loss of total output power. Also, there is current imbalance in the array due to shading of some part of the array which may affect the PV system and damage it.

In each of the simulations carried out, a set of curves for I-V characteristics and P-V characteristics have been obtained. The values of  $V_{oc}$ ,  $P_m$ ,  $V_m$  and  $I_m$  have been tabulated for each case.

#### 3.1PV module

In a PV module, 36 cells have been connected in series because 17-18V output voltage is produced which makes it compatible with 12V applications. A simple symbol has been generated to depict the single solar cell circuit so that it can be connected in series to form PV modules with less consumption of time. The PV modules were then arranged in series-parallel configuration to form PV array.

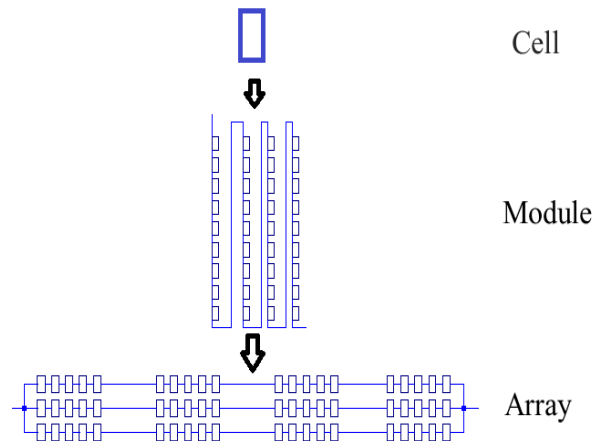


Fig.2: Hierarchy of PV system

#### 3.2 PV array with different shading patterns

The PV arrays have been formed to have larger output power. Practically, they were installed for generating power or electricity. The simulations were carried at different temperatures in order to study the effect of temperature and shading on the I-V and P-V characteristics of the array. The PV array of  $20 \times 3$  configuration has been used for studying the effect of shading, where 20 and 3 represent the number of series and parallel modules connected in the array. This array has further been divided into four groups, each having  $5 \times 3$  configuration. Different shading patterns have been given to the four groups at  $25^\circ C$  and  $50^\circ C$ . Here, 1 corresponds to illumination current of 4A. Likewise, 0.75, 0.5 and 0.25 corresponds to 3A, 2A and 1A illumination current respectively. The different shading patterns that have been used are listed below:-

Type A: With no shading (Group A, B, C, D=1)

Type B: With partial shading (Group A=1, Group B=1, Group C=1, Group D=0.75)

Type C: With partial shading (Group A=1, Group B=1, Group C=0.75, Group D=0.5)

Type D: With partial shading (Group A=1, Group B=0.75, Group C=0.5, Group D=0.25)

The shading pattern of type D has been clearly shown in Fig.3. Here, the group with blue series-parallel connection of modules depicts that 4A illumination current or 544.959 irradiance has been provided while grey, pink and yellow depicts 3A (408.719), 2A (272.479) and 1A (136.239) illumination

current/irradiance respectively. Similarly the circuits with other shading pattern configurations can be developed easily.

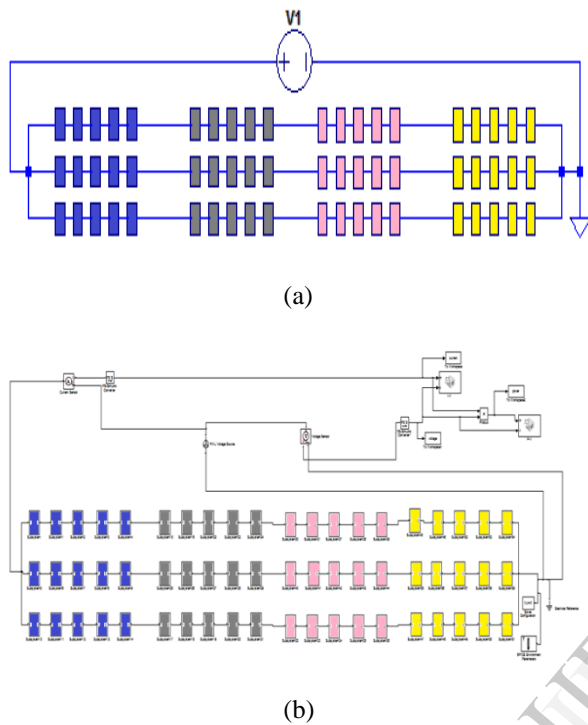


Fig.3: PV array with Type D shading pattern (a) LT-Spice (b) Matlab

The simulation study of PV array with different levels of irradiance at 25°C and 50 °C have been carried out effectively.

### 3.3 Effect of Bypass diode

The bypass diode was connected to each PV module to prevent hot spot formation in the PV array. The type D shading pattern has been used to clearly explain the effect of shading. However, the simulations have also been carried out for the other shading patterns. During Uniform Shading Condition (USC), the entire PV modules generate same amount of current. However, the shaded cell will generate less current during PSC. The shaded module limits the overall current generation of the PV array. As a result, the solar cells get reverse-biased due to the mismatched effect and dissipate power in the form of heat.

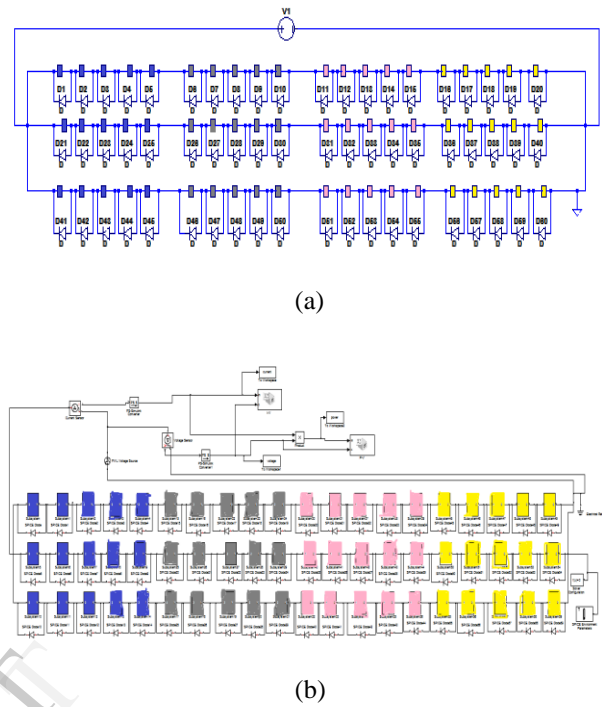
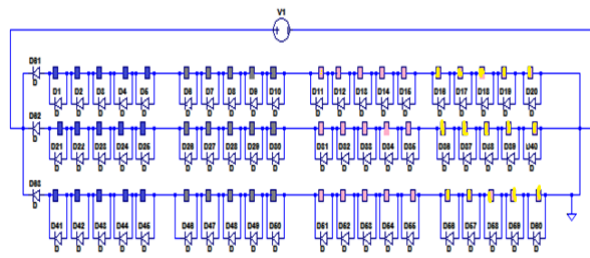


Fig.4: PV array with bypass diodes in Type D shading pattern (a) LT-Spice (b) Matlab

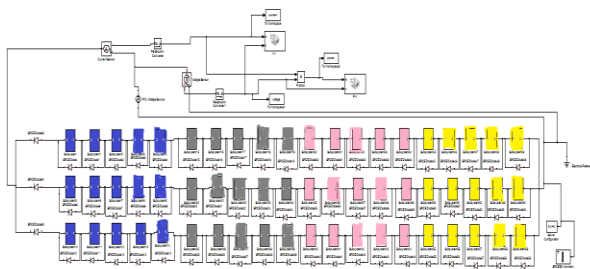
Hence, the shaded cells start consuming instead of generating power as reverse current flows across the shaded cells, thus reducing the generated output power. In order to avoid this, the bypass diodes are connected in parallel across each PV module of the array with the above mentioned shading patterns. The bypass diode provides a path to bypass the reverse current across the PV module and hence all the cells of the module become forward-biased.

### 3.4 Effect of blocking diode

The blocking diodes were connected in series with the string of series connected PV modules in order to avoid current imbalance caused by shading. The function of blocking diode is to prevent the reverse flow of current particularly from the secondary power sources such as batteries or inverters during the absence of light. It has been used for all the above mentioned shading patterns. The simulations have been carried out for all the above mentioned shading patterns while Fig.5 shows the type D configuration clearly.



(a)



(b)

Fig.5: PV array with bypass and blocking diodes in Type D shading pattern (a) LT-Spice (b) Matlab

Besides removing the current imbalance condition, blocking diode prevents the module from loading the battery at night by avoiding current flow from the battery through the PV array.

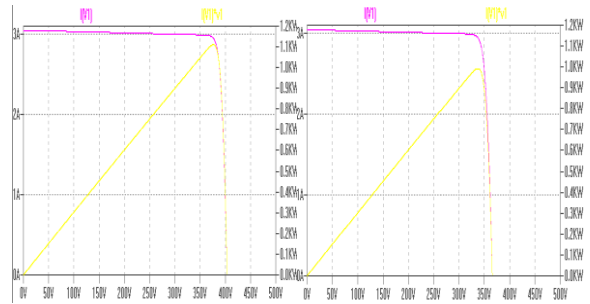
#### 4. Simulation results

This section describes the usefulness of the proposed simulation circuits in simulating and understanding the effect of bypass and blocking diodes in array configuration with different shading patterns.

Where, the pink and yellow curves show the I-V and P-V characteristics respectively.

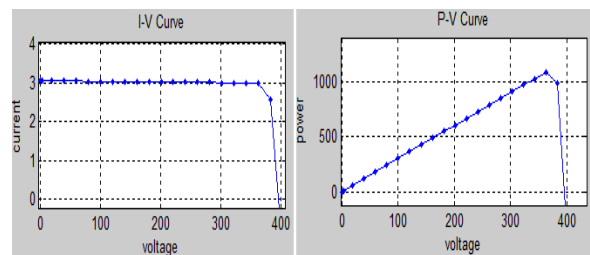
##### 4.1 Illustration 1

The effect of shading on PV curve for the PV array with different shading patterns has been simulated at 25°C as well as 50°C. Here, the PV curves for Type D shading pattern has been shown in Fig.6.

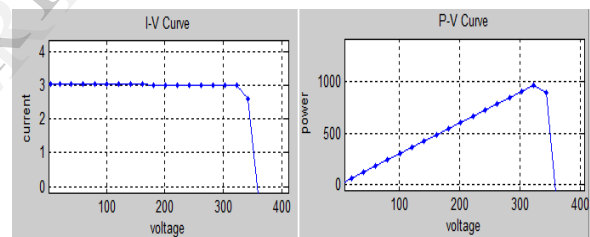


(a)

(b)



(c)



(d)

Fig.6: Effect of shading on PV array with Type D shading pattern at (a) LT-Spice 25°C (b) LT-Spice 50°C (c) Matlab 25°C (d)Matlab 50°C

The effect of shading and temperature variation has been tabulated for both the softwares in Table 1 for the above mentioned shading patterns.

		LT-SPICE						LT-SPICE			
Temp(°C)	Voc (V)	Vm (V)	Im (A)	Pm (W)	Temp(°C)	Voc (V)	Vm (V)	Im (A)	Pm (W)		
25	414.664	356.385	11.397	4059	25	407.46	372.694	9.529	3303		
50	377.578	313.382	10.859	3588	50	370.21	333.495	9.735	2946		
		MATLAB						MATLAB			
25	407.505	342.824	11.595	3975.166	25	407.45	363.024	8.931	3242.209		
50	370.365	302.424	11.546	3418	50	368.779	322.624	8.923	2878.9		

(a)

(b)

LT-SPICE					LT-SPICE				
Temp(°C)	Voc(V)	Vm(V)	Im(A)	Pm(W)	Temp(°C)	Voc(V)	Vm(V)	Im(A)	Pm(W)
25	410.11	377.195	5.763	2229	25	403.689	376.298	2.771	1110
50	372.655	338.185	5.661	1993	50	365.687	336.955	2.962	992
MATLAB					MATLAB				
25	404.475	363.024	5.975	2169.295	25	397.075	363.024	2.981	1082.328
50	366.042	322.624	5.775	1927.7	50	358.063	322.624	2.981	961.999

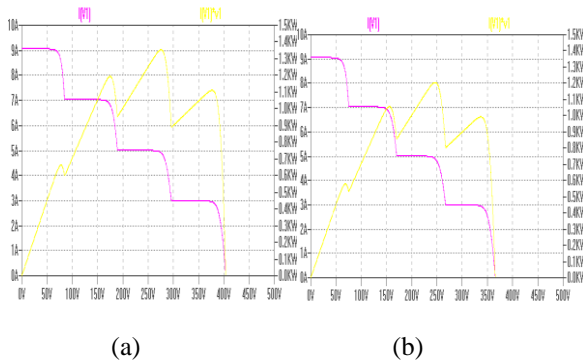
(c) (d)

Table 1: PV array with shading patterns (a) Type A (b) Type B (c) Type C (d) Type D

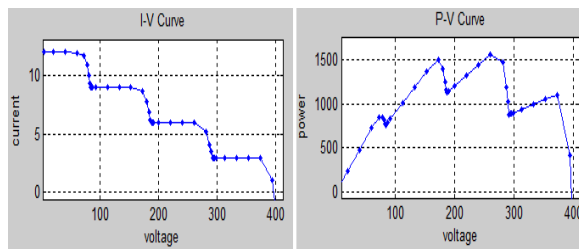
Observations from simulations of PV arrays with different shading patterns at 25°C as well as 50°C are shown in Fig.6 and Table 1. It can be observed that the increase in temperature and shading level adversely affected the power from the PV array. It has also been observed that the power deteriorates by 11-12% with the increase in temperature by 25°C. However, the observations through both the softwares are almost same.

### 4.2 Illustration 2

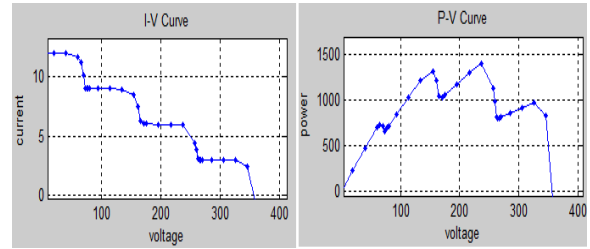
The effect of bypass diodes on PV curve for the PV array with different shading patterns has been simulated at 25°C as well as 50°C.



(a) (b)



(c)



(d)

Fig.7: Effect of bypass diodes on Type D shading pattern at (a) LT-Spice 25°C (b) LT-Spice 50°C (c) Matlab 25°C (d) Matlab 50°C

LT-SPICE					LT-SPICE				
Temp(°C)	Voc(V)	Vm(V)	Im(A)	Pm(W)	Temp(°C)	Voc(V)	Vm(V)	Im(A)	Pm(W)
25	414.66	356.265	11.119	4059	25	413.312	372.694	11.216	3303
50	377.58	318.216	10.801	3588	50	376.136	333.361	10.19	2946
MATLAB					MATLAB				
25	408.122	350.324	11.401	3994.22	25	406.874	372.941	8.631	3218.858
50	371.333	313.349	11.228	3518.6	50	369.636	331.975	8.661	2875.3

(a) (b)

LT-SPICE					LT-SPICE				
Temp(°C)	Voc(V)	Vm(V)	Im(A)	Pm(W)	Temp(°C)	Voc(V)	Vm(V)	Im(A)	Pm(W)
25	410.111	273.065	11.636	2408	25	403.696	275.476	8.778	1352
50	372.654	243.867	11.603	2142	50	365.683	246.385	9.354	1205
MATLAB					MATLAB				
25	403.828	258.555	8.967	2318.663	25	398.261	260.365	5.974	1555.647
50	364.864	228.172	8.963	2045.2	50	358.153	236.374	5.929	1401.6

(c) (d)

Table 2: Effect of bypass diodes with shading patterns (a) Type A (b) Type B (c) Type C (d) Type D

Observations from simulations of PV arrays with bypass diodes having different shading patterns at 25°C as well as 50°C are shown in Fig.7 and Table 2. It can be observed that the increase in temperature and shading level adversely affected the power from the PV array. It can also be observed that as the level of shading under the effect of bypass diode was increased, the performance of the array was improved as compared to the case where no bypass diodes were used i.e. the generated power of the array was increased. However, with the usage of bypass diodes in the PV array, the generated output power has been improved.

### 4.3 Illustration 3

The effect of bypass and blocking diodes on PV curve for the PV array with different shading patterns has been simulated at 25°C as well as 50°C.

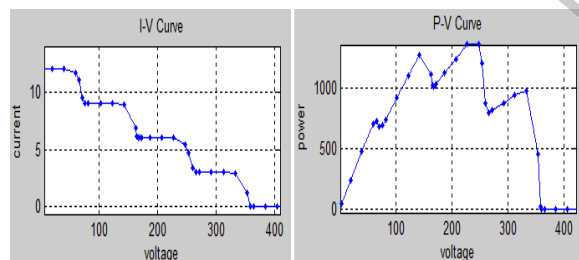
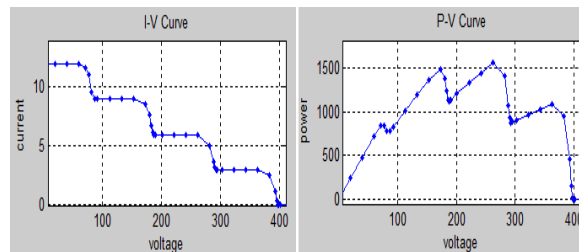
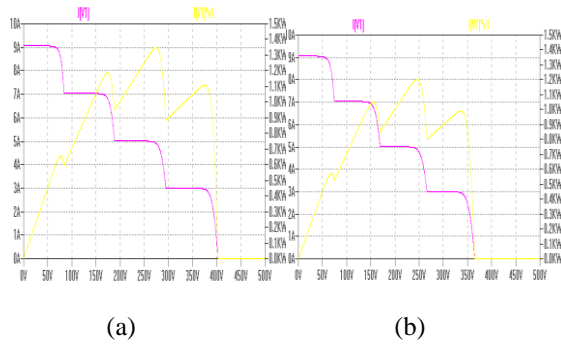


Fig.8: Effect of bypass and blocking diodes on Type D shading pattern at (a) LT-Spice 25°C (b) LT-Spice 50°C (c) Matlab 25°C (d) Matlab 50°C

LT-SPICE					LT-SPICE				
Temp(°C)	Voc (V)	Vm (V)	Im (A)	Pm (W)	Temp(°C)	Voc (V)	Vm (V)	Im (A)	Pm (W)
25	413.95	355.498	11.718	4049	25	412.681	371.778	11.853	3295
50	377.156	317.478	10.947	3578	50	375.588	332.665	10.185	2939
MATLAB					MATLAB				
25	409.045	358.548	11.033	3955.961	25	407.149	372.804	8.585	3200.737
50	371.484	307.903	11.381	3504.4	50	370.04	322.695	8.91	2875.3

(a)

(b)

LT-SPICE					LT-SPICE				
Temp(°C)	Voc (V)	Vm (V)	Im (A)	Pm (W)	Temp(°C)	Voc (V)	Vm (V)	Im (A)	Pm (W)
25	409.44	272.176	11.428	2401	25	403.083	274.594	8.973	1348
50	371.894	243.096	11.458	2135	50	364.964	245.556	8.427	1201
MATLAB					MATLAB				
25	404.5	268.712	8.772	2362.643	25	397.996	268.093	5.904	1582.982
50	366.559	236.66	8.833	2090.6	50	359.592	227.193	5.978	1358.3

(c)

(d)

Table 3: Effect of bypass and blocking diode on PV array with shading patterns (a) Type A (b) Type B (c) Type C (d) Type D

Observations from simulations of PV arrays with bypass and blocking diodes having different shading patterns at 25°C as well as 50°C are shown in Fig.8 and Table 3. The function of blocking diodes is to avoid current imbalance caused by shading, hence preventing damage to the array.

### 5. Conclusions

A general approach on modelling and simulation of PV cells and arrays has been proposed. The simulation study of such circuits and models has been carried out in LT-Spice and Matlab. LT-Spice is a circuit-based simulator that is used to verify circuit designs and predict the circuit behaviour while Simulink is a block diagram environment for multidomain simulation and model-based design. It provides a graphical editor, customizable block libraries and solvers for modelling and simulating dynamic systems. Simulink is integrated with Matlab, enabling us to incorporate Matlab algorithms into models and export simulation results to Matlab for further analysis. Matlab coding was done to find the maximum power output ( $P_m$ ), the corresponding voltage at maximum output power ( $V_m$ ) and the corresponding current at maximum output power ( $I_m$ ).

The PV characteristics for each case have been investigated under the partial shading conditions (PSCs) and its affect has been observed. The power deteriorates as the level of shading has been increased in the cell. The simulation studies of bypass and blocking diodes have been carried out and it has been observed that the introduction of such diodes in the array improves the generated output power during PSCs. However, the use of bypass and blocking diodes introduces multiple peaks in the I-V and P-V characteristics curve. This becomes more prominent for

cases where shading is relatively high. Under PSCs, the PV curves show MPPs and the number of peak points in the curve is equal to the number of shading patterns provided in the array. This paper provides the reader with all necessary information to easily develop the PV array model for analysing and simulating the array.

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