MATLAB/SIMULINK based study of series- parallel connected photovoltaic system under partial shaded condition

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Abstract - *The output powers of photovoltaic (PV) system are depending of the generally two variable factors, which are the cell temperatures and solar irradiances. In this study the MATLAB/simulation results of uniform & partial shaded of PV modules are presented. Since, Partial shadow has been identified as a main cause for reducing energy yield of photo voltaic systems. Different partial shading pattern have been considered on series and parallel connected photovoltaic system to find a configuration that is analogously less affected to voltage-current (V-I) mismatching due shaded problems. This paper presents simulation scheme suitable for studying the I–V and P–V characteristics of a series and parallel Photovoltaic modules.*

***Keywords* :** Matlab/Simulink, MPPT, Photovoltaic (PV) arrays, Bypass diodes, V–I and V–P characteristics, Boost converter, Shading effect.

1. Introduction

Solar module is consider as essential power transformation of Photovoltaic (PV) generation system. The performance of a PV system strongly depends on the operating environ-mental conditions i.e solar insolation, temperature, shaded array configuration. Photovoltaic PV modules its nonlinear output characteristics, which vary with the solar insolation and temperature. The characteristics get more complicated if the entire system does not receive uniform insolation, as in partially shaded (cloudy) conditions,[4] resulting multiple peaks. The presence of multiple peaks reduces performance of the existing maximum power point tracking (MPPT) design due to their inability to disfavor between the local and global peaks. We proposed a MATLAB based model of a photovoltaic (PV) module to simulate its characteristics for studying the effect of insolation, temperature and load variation on the available power. However, the module does not consider the effect of shading on the output of PV modules and associated change in their *I–V* characteristics. However, the *V–I* and *V–P* characteristics of the single module, considered in their study, do not predict the presence of multiple peaks, which are common in the *V–I* and *V–P* characteristics of large PV system that receive nonuniform insolation[1]. It requires each element of the cell module, bypass diode, blocking diode to be represented by a mathematical expression. It is not only the total number of modules of the PV array but also its configuration of the number of modules in series and parallel that significantly affects its power output and therefore, the performance of the modules under partial shaded conditions.[3]

1.1. Operating principle of solar cell

A solar cell is mainly a p-n junction which is made two different layers of silicon (Si) doped with a small quantity of the impurity atoms in the case of n-layer atoms with one extra valence electron called donors and in the case of p-layer [5] with one lesser valence electron known as the acceptors. When the two layers are joined together, near the interface the free electrons to the n-layer are diffused p-side, leaving behind an area positively charged by the donors. Similarly, free holes in the p-layer, are diffused n-side, leaving behind a region negatively charged by the acceptors. The build an electrical field between the two sides that is a potential barrier to further flow.The equilibrium is reach in the junction, when the holes and electrons cannot surpass that potential barrier and in consequence they cannot move. This electric field pulls the holes and electrons in opposite directions, so the current can flow in only one way : holes can move from the n-side to the p-side and the electrons in the opposite direction.[7]

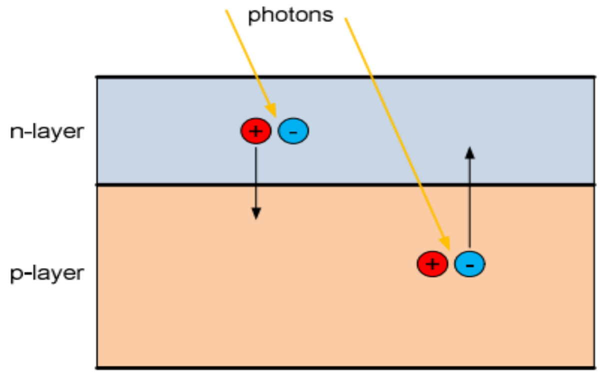


Fig-1: solar cell

1.2. Types of Solar cell

There are different types of solar panels which differ in their material, price, and efficiency.[9]
Mono crystalline Solar cell: It has efficiency approximately 15-18%. They are made a large crystal of silicon (Si). This types of solar panel are the most efficient systems however they are the most expensive. They do somewhat better in lesser light conditions than the other types of solar panels.

Poly crystalline Solar cell: It has efficiency approximately 13-16%. Instead of one large crystal this type of solar panel consists of multiple amounts of smaller silicon crystals; they are the most common type of solar panel on the market today. They are slightly less efficient than the mono crystalline solar panels & less expensive to produce.[9]
Thin film Solar cell: It has efficiency approximately 5-7%. Amorphous silicon, copper indium diselenide (CIS) and cadmium telluride (CdTe) are used as semiconductor (SC) materials. These types solar panels have lower efficiency than the other two types of solar panels, and the cheapest to produce.

1.3. Battery charging mode

The charging of the battery is done in three modes. These are described as follows:[6]

Bulk Charge mode: When the battery is fully or partially discharged the charging is done in this mode. A heavy constant current is given to the battery to refill the charge into the battery and as the battery charges the battery voltage increases. If the battery is almost 80% charged the charging is switched to another mode called absorption mode.
Absorption mode: In this mode battery is almost 80% charged charger holds its output voltage constant and battery continues to draw charging current which decreases exponentially. When charging current becomes almost the 10% of the current value in the bulk charging mode it switches over to next stage of charging which is called Float charge mode.
Float charge mode: In this mode charger tries to maintain the battery voltage just above the fully charged no load voltage which helps the battery to maintain 100% charged condition. Charger turned off when no load battery is monitored. When the voltage decreases below a threshold value, charger comes on in constant voltage mode. when the battery is charged nearly about 100% i.e. in Float charge mode to ensure very less current in the charging we incorporate a system which off the charge controller when no load voltage is monitored and When the voltage decreases below a threshold value, charger comes on in constant voltage mode.

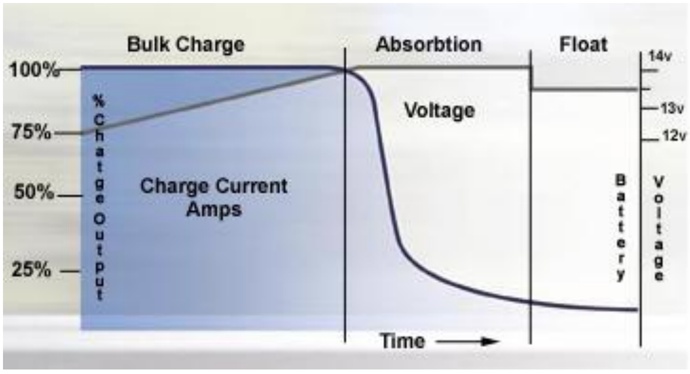


Fig-2: Three different charging modes of Battery

2. Model of a Solar cell

The user specifies the nature & dimensions of each component and the application provides a detailed analysis of the characteristics of the system. The accuracy of PV array calculations and the simulation time needed varies depending on the level of detail require and the type of data provided. They are used to verify the sizing of the system & investigate the impact of future change in the systems being simulated.[1]

In the first place describe to the solar system which constitutes the prime source of power for the whole photovoltaic installation. The equivalent model of the electrical circuit to use a s the main element of the panel is formed by a current source that depends on the solar radiation in W/m^2, of temperature in Celsius (T), the shunt diode whose intensity of inverse saturation in series depends the temperature and a resistance, which represents the effect of the internal resistance of each solar cell and of the contacts of the generator as it.
A photovoltaic cell can be represented by an equivalent circuit, as shown in Fig.1.This PV cell characteristics can be obtained using standard equations [4]. For simulation an entire PV array system the model of a photovoltaic (PV) module is developed first. The each PV module system considered in this paper comprises 36 PV cells connected in series providing an open circuit voltage (Voc) and a short-circuit current.

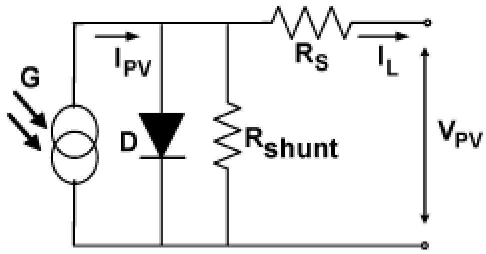


Fig-3: equivalent circuit of a PV cell

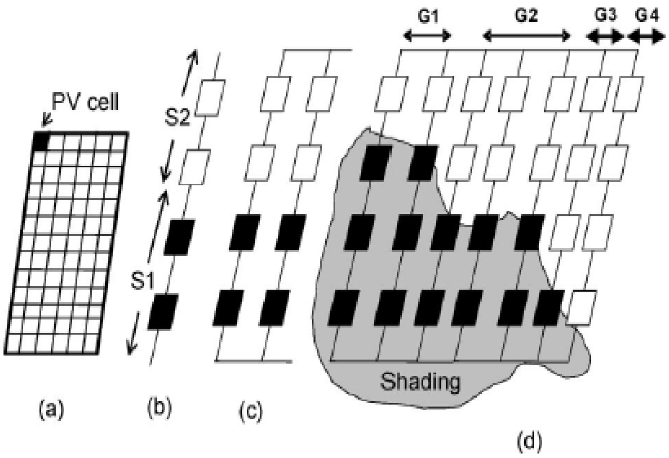


Fig-4: PV array,(a) PV module (b) Series-assembly with two series-connected subassemblies S1 and S2 (c) Group. (d) PV array with groups G1 to G4.

The shaded pattern for a large solar array is very complex to model. These are explained with the help of Fig-3. The "subassemblies" is formed with several series-connected PV modules receiving the same level of insolation. Several such series connected subassemblies, each with a different level of insolation, form a series assembly [Fig-3(b)]. Series assemblies, having similar shading patterns, form a "group" [Fig-3(c)]. Various group having different shading patterns & connected in parallel, form a PV array, shown in Fig-3(d).

2. Maximum Power Point Tracking (MPPT)

The goal of MPPT algorithms is to move the operating point of Photovoltaic module's to the optimum point (Imp, *Vmp).* This is done by continuously altering the Duty-cycle of the DC-DC (Boost) converter. Some MPPT controller use analog circuitry to update the duty-cycle while the majority use digital ones. The typical and basic control system of MPPT controllers is shown in below.[8]

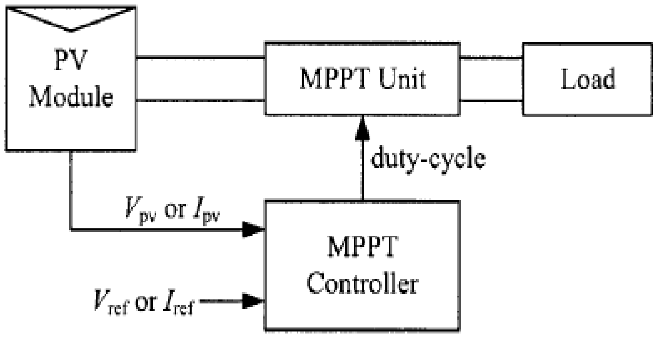


Fig-5: Typical MPPT control system

PV cell characteristics with the variation of atmospheric conditions. When cell temperature increases, the short circuit current (I_{sc}) increases slightly and the open circuit voltage decreases. Than output power of the cell decreases with increasing temperature. When the module irradiance increases the output current increases, while to the open circuit voltage increases slightly and short circuit current (I_{sc}) increases. Also maximum output power increases.[4]

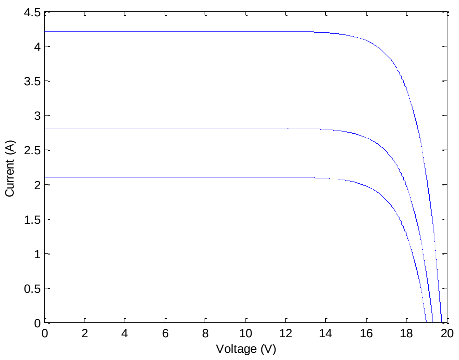


Fig-6: The effect of irradiance on the *V-I* of PV Panels

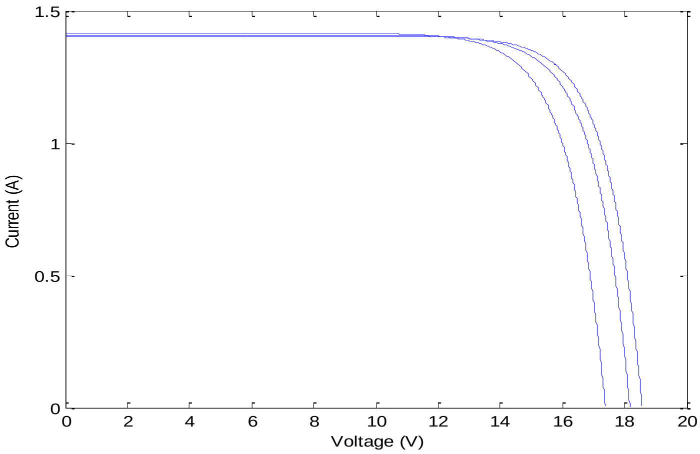


Fig-7: The effect of temperature on the *V-I* of PV Panels

This change in the *I-V* plot leads to the displacement of the maximum current Imp as shown in Fig-8,and maximum voltage V_{mp} as shown in Fig-9. Imp is mainly affected by the irradiance levels and V_{mp} is affected by temperature levels. As a result, the maximum power point (MPPT) tracking concept was introduced to track Imp and V_{mp} under these varying atmospheric conditions.

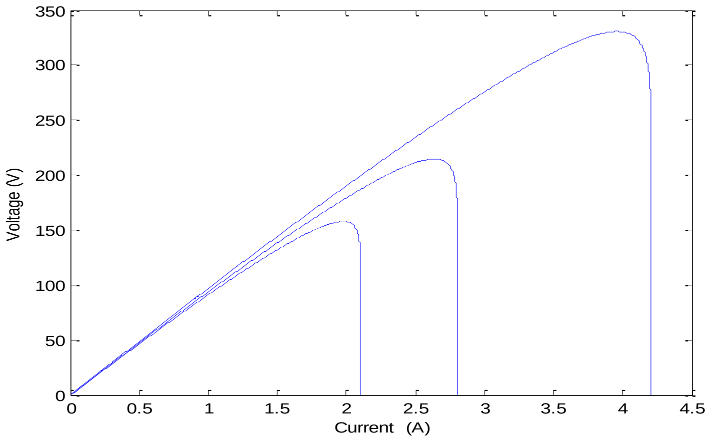


Fig-8: The effect of irradiance on the *P-I* of PV Panels

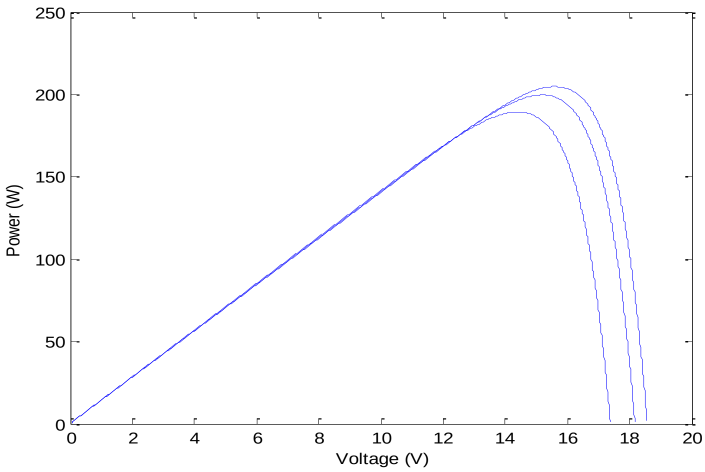


Fig-9: The effect of temperature on the *P-V* of PV Panels

3. Boost Converter

PV generators are not directly connected to the load but through Boost(DC-DC) converter. This is done to meet the desire voltage at the load end. Again the maximum power point tracker(MPP) controls the duty ratio of the converter directly or indirectly to tracking maximum power point (MPPT). Hence the Boost (DC/DC) converter is the most important member of PV generation family.[4]

$$\mu = \frac{Vo}{Vi} = T/T_{off} = \frac{1}{1-D} \quad 3.1$$

Where; T_{off} is the duration that the switch is not active.

The boost converts an input voltage to a higher output voltage. The boost converter is also known as the step-up converter. The name implies its typically application of converting a low input-voltage to a high out-put voltage, essentially functioning like reversed buck converter.

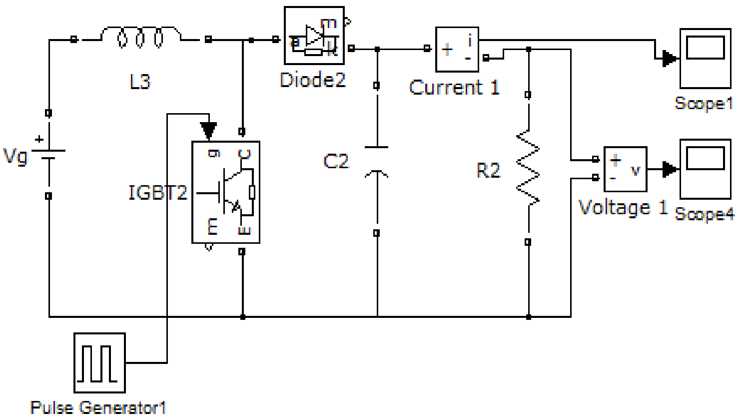


Fig-10: Boost converter

It consists of a switch, diode, inductor, and capacitor. The conversion ratio for the boost converter can be determine by assuming that the inductors and capacitors are large enough that we can treat voltages and currents as DC values. The switch can be replaced by an equivalent voltage source with value (1- D) V_{out}. The complementary duty cycle D'= (1 - D), represents the fraction of time when the diode conducts. Assuming an ideal diode, during this time period, the intermediate voltage is shorted to V_{out}. When the switch is on, the intermediate voltage shorts to ground. Thus, its average value is equal to (1 - D)V_{out}. Since at DC the inductor can be replaced by a short, $\mathbf{V_{in} = (1\text{-}D)\, V_{out}}$

When the switch S is in the on state, the current in the boost inductor increases linearly. The diode D is off at the time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the input RC circuit.[4]

at $0 \le t \le Ton$

$$Vg = L\frac{diL}{dt} \quad 3.2$$

$$\Delta iL = Ton\frac{Vg}{L} \quad 3.3$$

at $Ton \le t \le T$

$$Vg - Vo = -L\frac{diL}{dt} \quad 3.4$$

$$\Delta iL = \frac{Vo-Vg}{L}(T - Ton) \quad 3.5$$

From equation

$$Vo = \frac{Vg}{1-D} \quad 3.6$$

Where duty ratio $D = \frac{Ton}{T} \quad 0 \le D < 1$

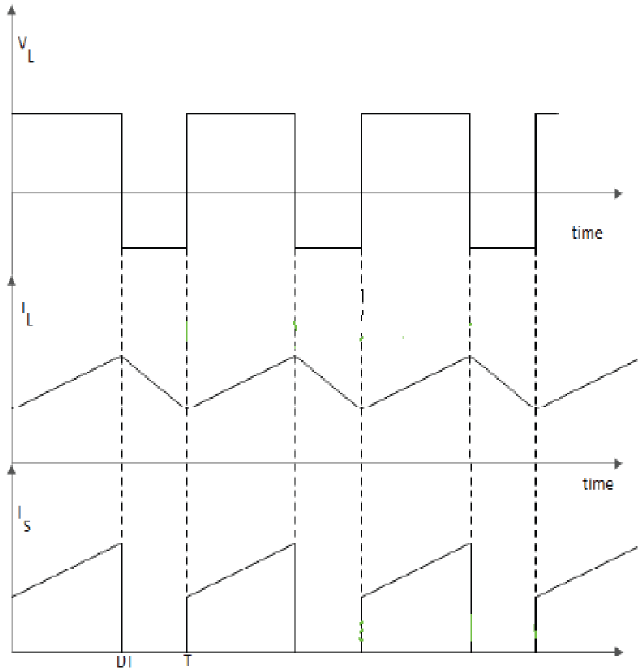


Fig-11: Waveform of Boost converter

4. Series connected PV cells under shading

The two PV cells or modules are connected in series as shown Fig-12. As a PV partial shaded example, the PV_1 module is under full irradiance whereas the second PV_2 module under shadowing. In that situation, current I_1 is always greater than current I_2 and the load current I_L. However, I_2 might be greater or less than I_L according to the load impedance value. Here I_1 & I_2 are the photo-currents (almost the Isc) of the first and the second PV modules respectively. The diode D_2 is in the forward biased mode if I_2 is greater than I_L, and so the module voltage V_2 is still positive even though the system is under a partial shaded condition. With a decrease in the load impedance, the modules' currents increase as well as the load current and therefore at a specific point I_L will be greater than I_2. At the mentioned point the surplus current (about I_L-I_2) is leaked in reverse through the diode D_2 and the shunt resistance. The reverse biasing of D_2 means V_2 is negative, so the power is dissipated in the shaded module causing a hot-spot. The reduction of the PV generated power is due to the fact that the reverse current through D_2 is strictly limited so the string current is significantly reduced [6].

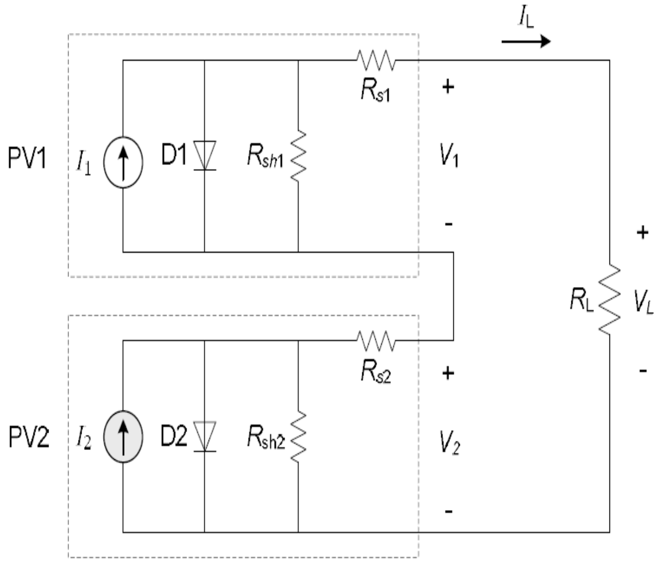


Fig-12: Two PV modules connected in series under shaded

Fig-13.a, where each PV cell/module system are represent by a current source. Assume two connected PV sources are perfectly matched and their short circuit current Isc value under 100% is 5A. Assume the irradiance on PV_2 ($module_2$) is reduced to 40%, the PV2 short circuit current (I_{sc}) drops to about 2 A. As PV_1 is generating 5 A its surplus 3 A has to pass through the bypass diode. Though this enables PV_1 to operate according to the level of its the irradiance which is higher, while preventing PV_2 from being damaged, PV_2 can not produce any power due to V_{PV2} being equal to zero. In order to the overcome these shortcoming, General Control Circuit provides the means to bypass the surplus current while maintaining the operating voltage V_{PV2}, non-zero as illustrated in Fig-13.b.[9]

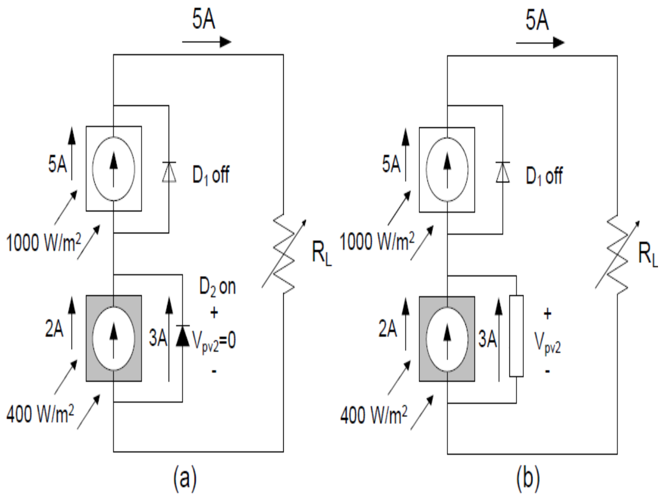


Fig-13: Two PV cell rep. current sources connect in series

5. Result & Analysis

5.1 Simulation

SIMULINK model of PV system is represents Fig-14 model of boost converter with P&O MPPT and Fig-15 model of P&O Algorithm.

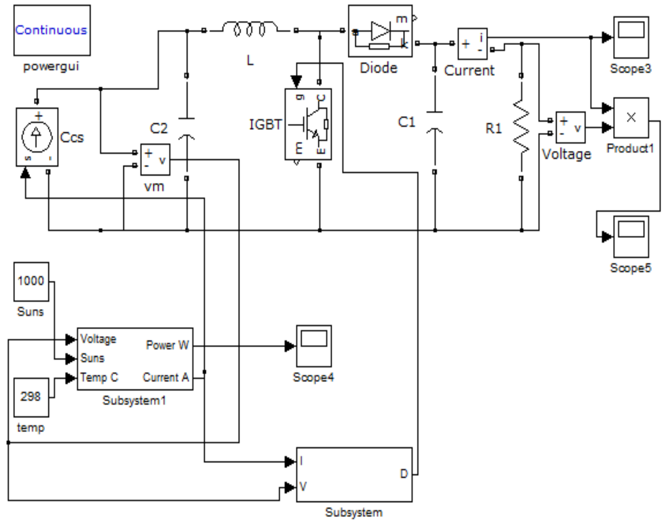


Fig-14: SIMULINK model of boost converter with P&O MPPT

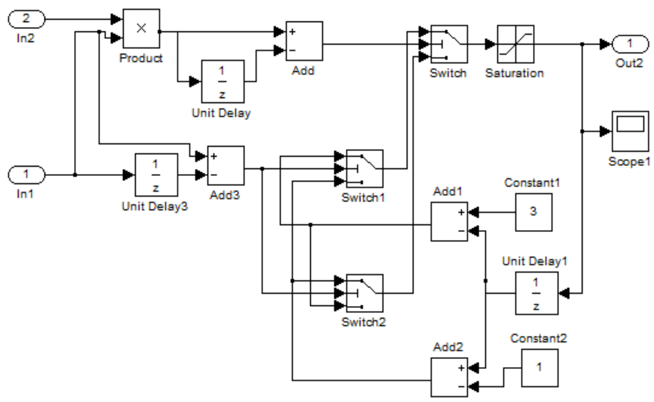
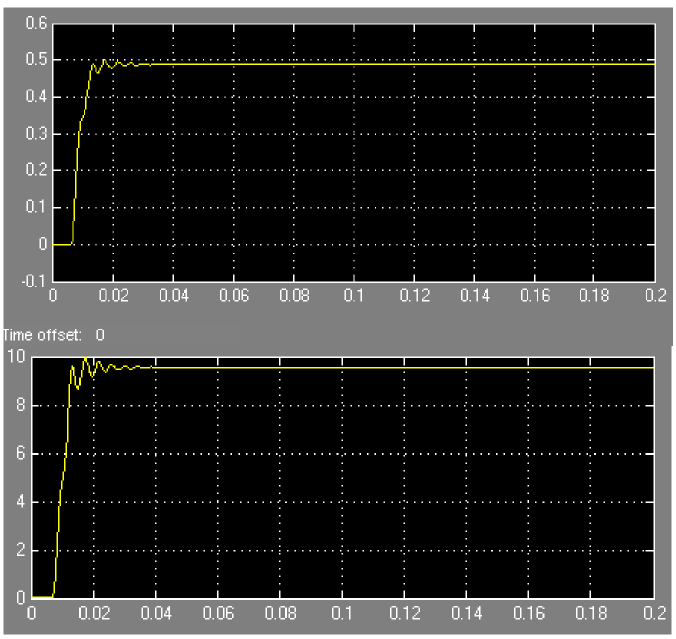


Fig-15: SIMULINK model of P&O Algorithm



Time

Fig-16: output I & V of boost converter with respect to Time

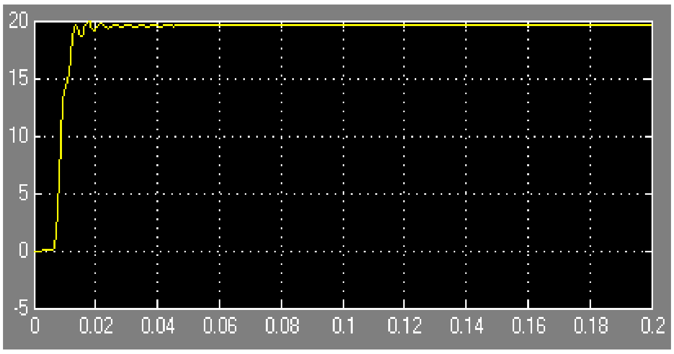


Fig-17: Output power of boost converter with resp. to time

5.2 Series-Parallel modules with bypass diodes

Fig-19, V-P characteristic has multiple peak & V-I chara. has multiple steps. This multiple peak & step is presence of due to bypass diode in antiparallel across the module.

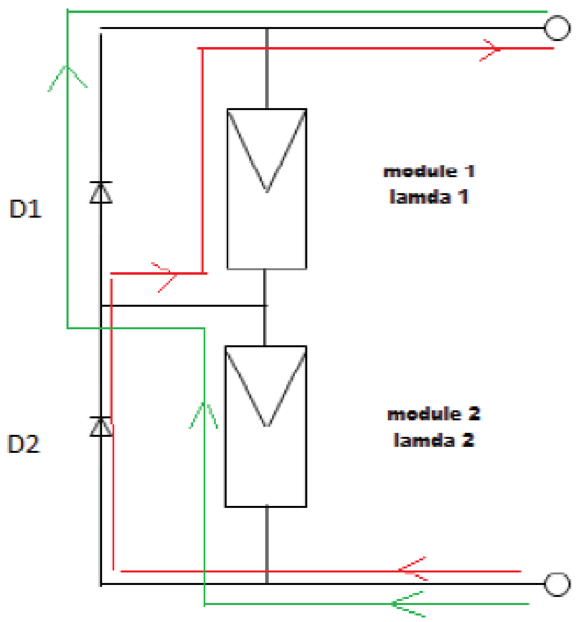
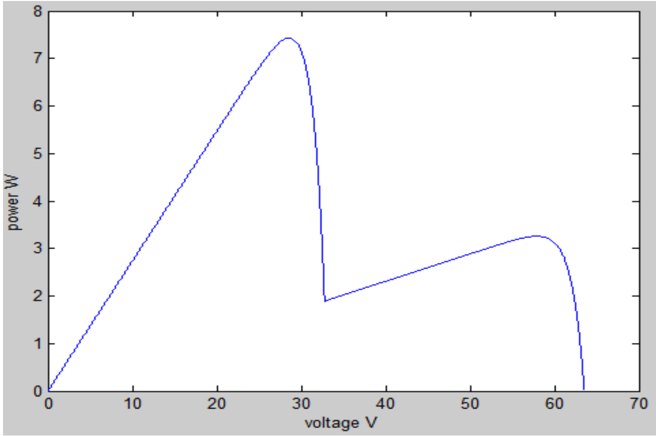


Fig-18: Two series connected modules with bypass diode



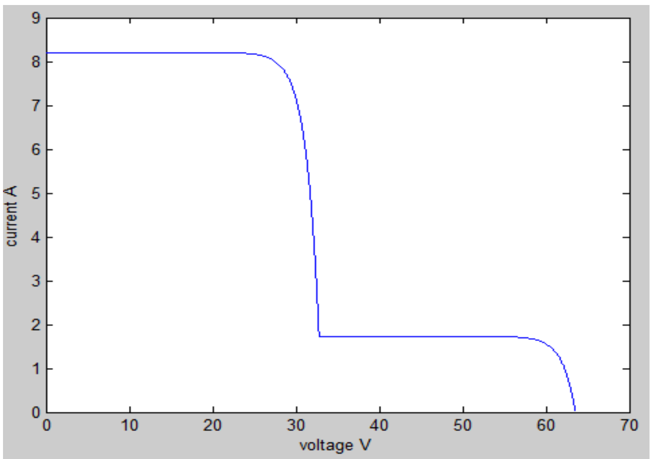


Fig-19:chara. of two series connected panel under shaded

Fig-20 shows two parallel connected panels with bypass diodes. Two panels are of different irradiation due to the partial shaded or mismatching. P-V and I-V characteristics are given in Fig-21. It is clear from the Figure 21 that I-V chara. does not contain multiple step and P-V chara. does not have multiple peak. In parallel system output current is the sum of all individual current and hence the level of output current & peak power increases than series config.

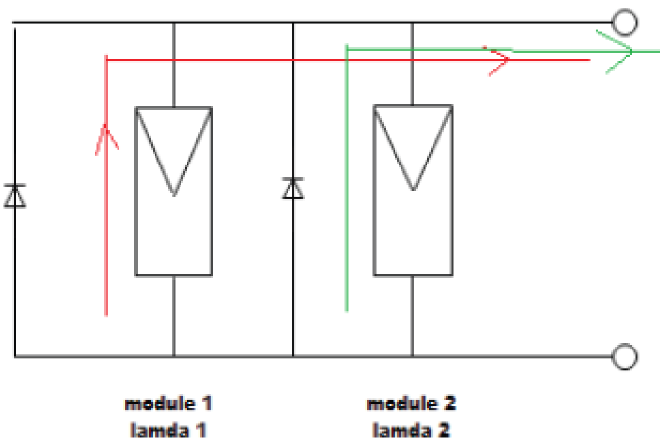
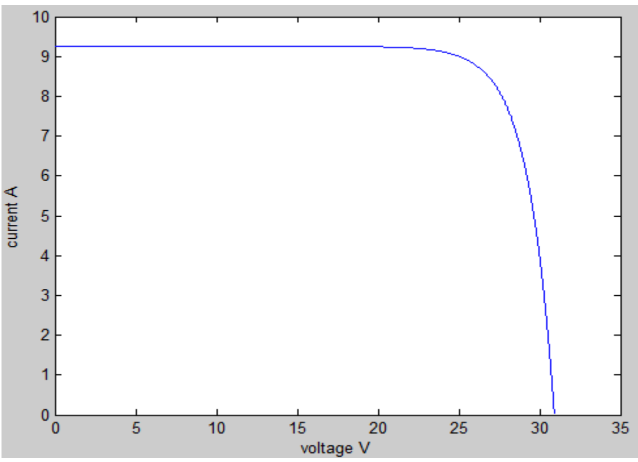


Fig-20: Two parallel connected panels with bypass diodes



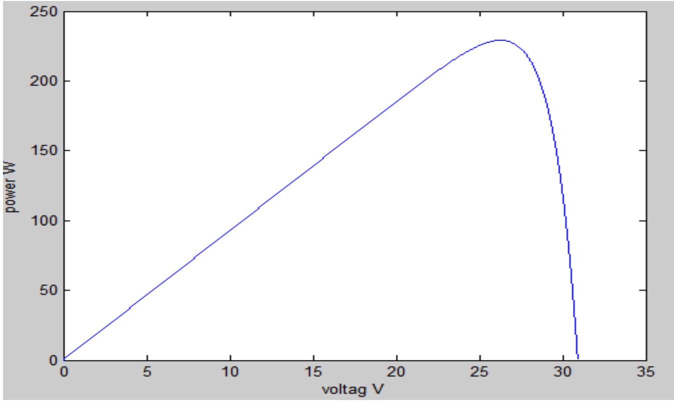


Fig-21:chara. of two parallel connected panel under shaded

6. CONCLUSIONS

Two identical (i.e one series & second parallel) PV panels were used with to the different partial shading pattern, one pattern was two PV cells shaded in one sub-module (series - parallel) , and the other pattern was one PV cells shaded in each sub-module (series-parallel). While the result was shown in the both cases that one sub-module shading to power generated greater than the each sub-module shading system. For partial shaded PV panels are connected in the series with bypass diode because of current generation are less and voltage generating are more compare to parallel connected PV module with shading pattern.

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