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Modeling, Simulation and Analysis of Solar Photovoltaic System with Maximum Power Point Tracker

Monika*, Priyanka Anand, Mittarpal
Department of ECE, BPSMV, Khanpur Kalan,
Haryana, India

Abstract—In this work, mathematical modeling with Simulink model of Photovoltaic (PV) module has been presented in MATLAB/SIMULINK. In addition, the developed model is integrated with DC/DC boost converter along with Perturbation and Observation (P&O) Maximum Power Point Tracker (MPPT) technique has also been presented with their simulation results.

Keywords— Maximum Power Point Tracker (MPPT), Perturbation and Observation (P&O), Photovoltaic (PV), Solar energy.

I. INTRODUCTION

The fast development of modern social economy, industrialization, population increasing electricity demands and degradation of fossil fuels etc. move towards energy environment crisis. Various renewable energy sources viz. solar energy, small hydro, wind energy, biomass and geothermal energy etc. could be a better option to solve these problems. Out of various renewable energy sources, solar energy is more promising due to abundantly, freely available and pollution free etc. Moreover, Government of India also promoting solar energy by launching various schemes like Jawaharlal Nehru National Solar Mission (JNNSM) of achieving a target of 20 GW of solar energy by 2022 [1]. Recently, India's cabinet committee on economic affairs (CCEA) approved INR 50 billion funding for 30% capital subsidy for rooftop solar installation. A solar or photovoltaic (PV) cell can be used to convert solar energy into electrical energy. However, the cost of generated power through solar energy is high so it is necessary to achieve maximum power. Maximum power point tracker (MPPT) is an electronic system is one that can be used for harvesting maximum power from the module/array and delivers it to the load.

II. MODELING OF PV MODULE

Equivalent model of PV cell - A Photovoltaic (PV) cell is mainly a P-N junction diode, when sunlight strikes on PV cell, electrons gets free from their atoms. The free electrons are directed towards the front surface of the solar cell. This procedure creates a current flow that occurs between the negative and positive sides. Further, the equivalent model of photovoltaic cell is shown in Fig.1.

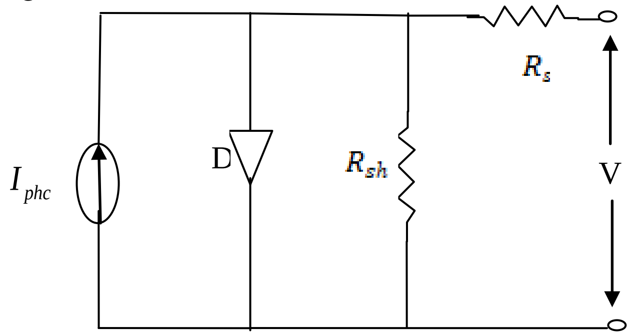

Fig. 1 PV cell equivalent model [4]

Where, (I_{phc}) represent photocurrent, R_s and R_{sh} represent the series and shunt resistance.

Equations of PV module- A Photovoltaic (PV) Module consisting of series combination of PV cells and PV arrays are formed by connecting PV cells in series and parallel [5]. The equations which have been used to describe the I-V and P-V characteristics of PV module are as follows.

Photocurrent- The photocurrent (I_{phc}) of a photovoltaic module, linearly depends on the solar irradiance and temperature, which is given by equation (1) [6]

$$I_{phc} = [I_{scc} + K_c(T_a - T_r)] * \frac{\lambda_s}{1000} \qquad (1)$$

Where

I_{phc}= Photocurrent in ampere (A)
T_r= Reference temperature in kelvin (K)
T_a= Actual temperatures in kelvin (K)
K_c= Temperature coefficient (0.0017A/K)
I_{scc}= Short–circuit current in ampere (A)
λ_s= Solar irradiance

In this work, Solkar 36w PV module has been considered as reference PV module and their key specification is tabulated in TABLE I.

Table I Key specification for Solkar 36W PV module

Parameter	**Value**
Maximum Power	37.08Wp
Maximum voltage	16.57V
Maximum current	2.25A
Short circuit current(I_{scc})	2.55A
Open circuit voltage (V_{oc})	21.24V
Total number of cell in parallel (N_P)	1
Total number of cell in series (N_S)	36

Further, Simulink model for photocurrent (I_{phc}) has been developed in MATLAB/SIMULINK using equation (1) which is depicted in Fig. 2. and the result for photocurrent (I_{phc}) at various temperature and irradiance has been demonstrated in TABLE II.

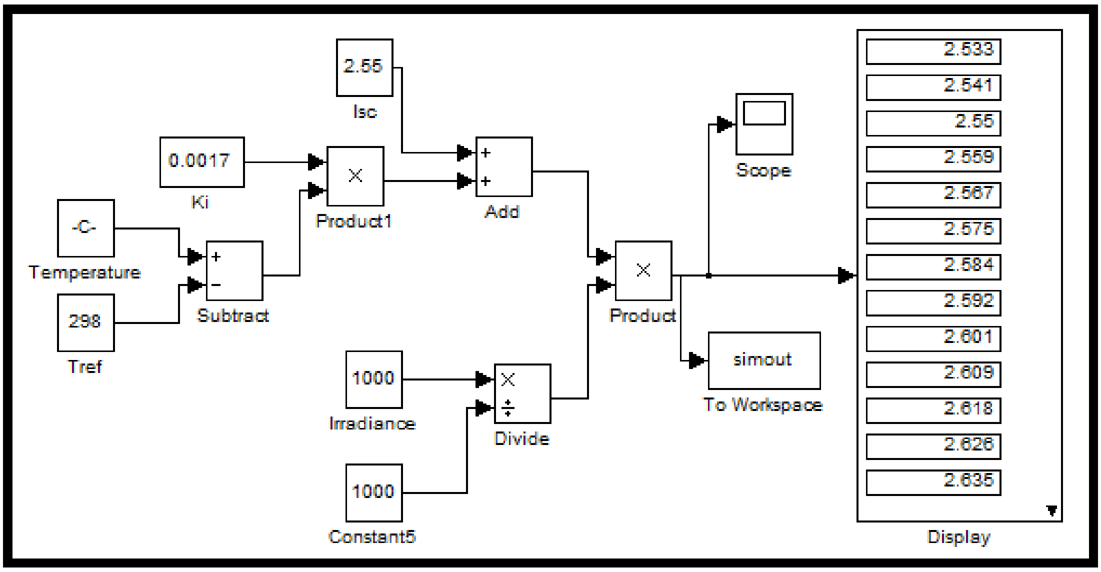

Fig. 2 MATLAB/SIMULINK based model for photocurrent (I_{phc})

Table II Photocurrent (I_{phc}) for various Irradiance (λ_s) and Temperature (T)

Sr. No.	**Irradiance(λ_s) W/m²**	**Photocurrent (I_{phc}) (A)**						
		25°	**30°**	**35°**	**40°**	**45°**	**50°**	**60°**
1.	1000	2.55	2.559	2.567	2.575	2.584	2.593	2.61
2.	800	2.04	2.047	2.054	2.061	2.067	2.074	2.088
3.	700	1.785	1.791	1.797	1.803	1.809	1.815	1.827
4.	600	1.53	1.535	1.540	1.545	1.551	1.556	1.566
5.	500	1.275	1.279	1.282	1.288	1.292	1.296	1.33
6.	250	0.638	0.640	0.644	0.649	0.653	0.658	0.665
7.	100	0.255	0.2559	0.2571	0.2576	0.2584	0.2592	0.2661

Reverse saturation current - The reverse saturation current (I_{rvsc}) of PV module as follows in equation (2) [6].

$$I_{rvsc} = \frac{I_{scc}}{[\exp(\frac{qV_{oc}}{N_s K_{btc} A T_a}) - 1]} \qquad (2)$$

Where
I_{rvsc} = Reverse saturation current in ampere (A)
V_{oc} = Open-circuit voltage (21.24 V)
q = Charge of electron ($1.6*10^{-19} C$)
N_s = Number of cells in series combination (36)
A = Ideality factor (1.6)
K_{btc} = Boltzmann constant ($1.38*10^{-23} J/K$)
I_{scc}= Short circuit current (2.55 A)

Further, MATLAB/SIMULINK based model for reverse saturation current (I_{rvsc}) on the basis of equation (2) is depicted in Fig.3and the result of reverse saturation current (I_{rvsc}) at different temperature is tabulated in TABLE III.

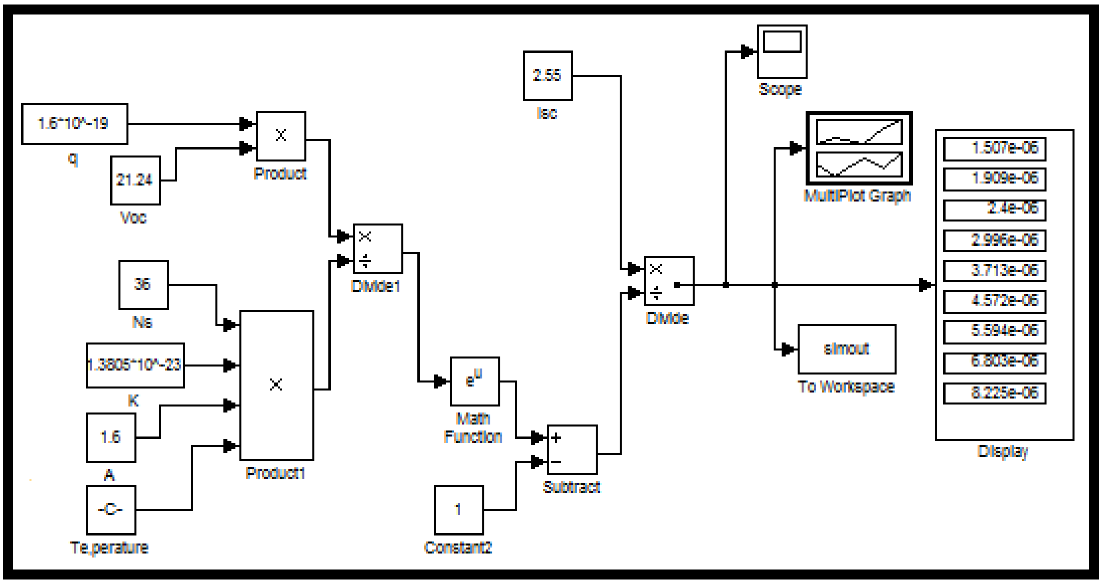

Fig. 3 MATLAB/SIMULINK model for reverse saturation current (I_{rvsc})

Table III Reverse saturation current (I_{rvsc}) at various temperature

Sr. No.	Temperature (˚c)	Reverse Saturation Current (A)
1.	25	1.507e-06
2.	30	1.909e-06
3.	40	2.996e-06
4.	50	4.572e-06
5.	60	6.803e-06
6.	90	8.965e-06

Module Saturation Current- The module saturation current at different temperature is given by equation (3) [5]

$$I_{sc} = I_{rvsc}[\frac{T_a}{T_r}]^3 \exp[\frac{q*E_{gp}}{AK_{btc}}\{\frac{1}{T_r} - \frac{1}{T_a}\}] \qquad (3)$$

Where
E_{gp} = Energy band gap of the semiconductor (E_{gp} ~ 1.1eV)
I_{rvsc} = Reverse saturation current (I_{rvsc}) in ampere (A)
I_{sc}= Saturation current in ampere (A)

On the basis of equation (3), the Simulink based model for module saturation current (I_{sc}) has been developed in MATLAB/SIMULINK and presented in Fig.4.and the output of saturation current (I_{sc}) at different temperature is shown in TABLE IV.

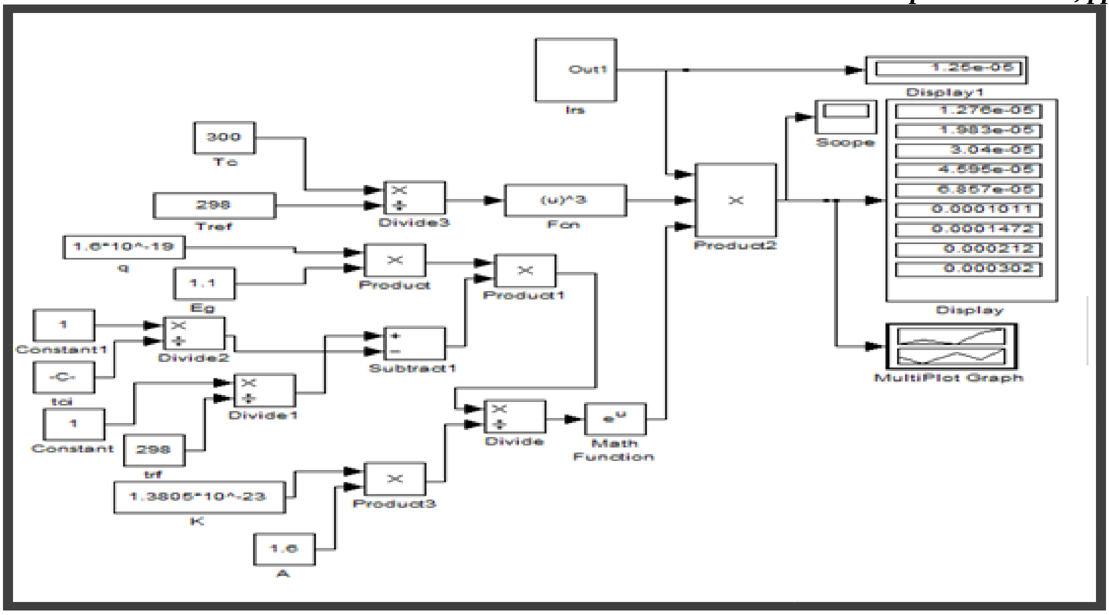

Fig. 4 MATLAB/Simulink based model for saturation current (I_{sc})

Table IV Saturation current (I_{sc}) at various Temperature (T)

Sr. No.	Temperature (˚C)	Saturation current (A)
1.	25	1.507e-06
2.	30	2.968e-06
3.	40	1.079e-05
4.	50	3.622e-05
5.	60	0.000113
6.	90	0.02359

Module output current (I_{PV}) - The output current is expressed in terms of voltage, current and temperature is given by (4) [6]

$$I_{PV} = N_P * I_{phc} - N_P * I_{sc}[\exp\{\frac{q*(V_{PV} + I_{PV} R_s)}{N_S A K_{btc} T_a}\} - 1] \qquad (4)$$

Where

I_{PV} = Module output current in ampere (A)

N_P = Total number of cells in parallel

N_S = Total number of cells in series

R_s = Series Resistance in ohm

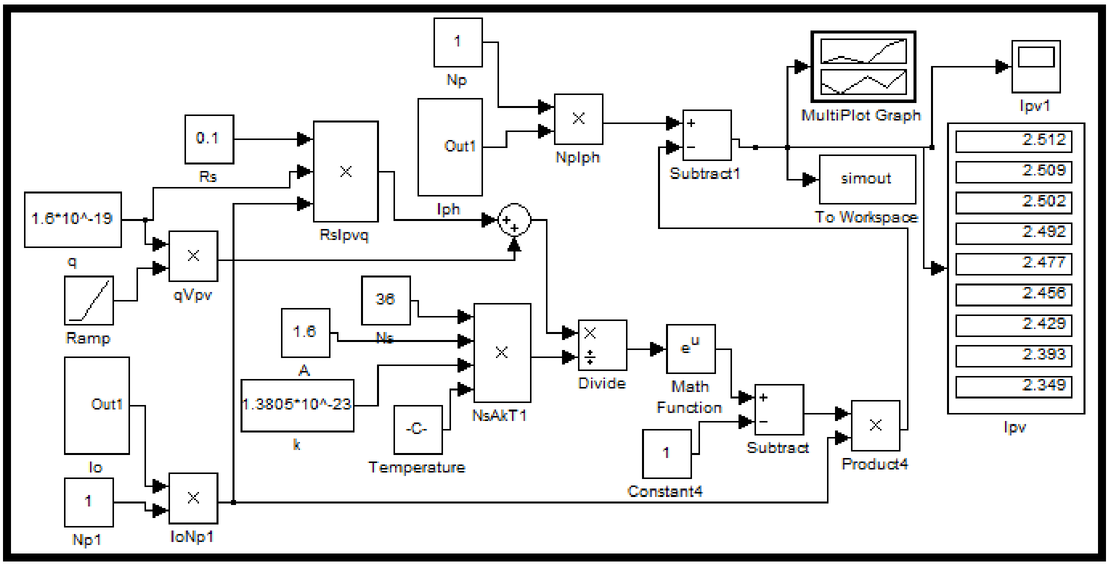

Fig. 5 Simulink model of PV module photovoltaic current (I_{PV})

The Simulink model of module output current of PV module is presented in Fig.5. In this model, temperature (T), irradiance (λ_s) and module voltage (V_{PV}) are taken as input voltage and measure the output current (I_{PV}) and obtained (I-V) and (P-V) characteristics which has been shown in Fig. 6.

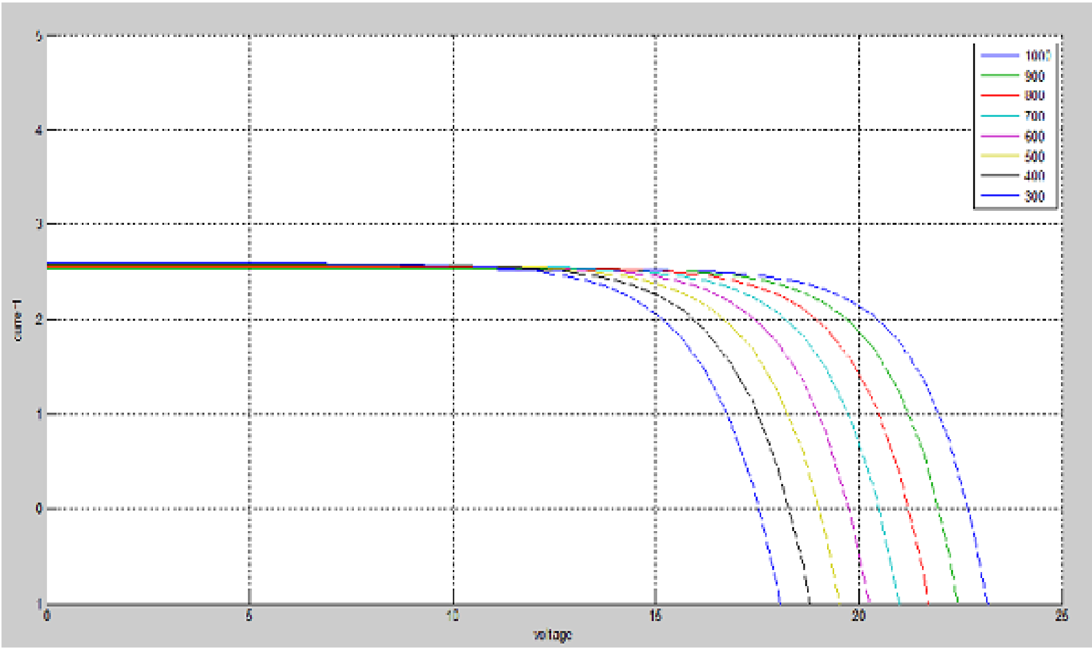

Fig. 6 (a) I-V characteristics of PV module

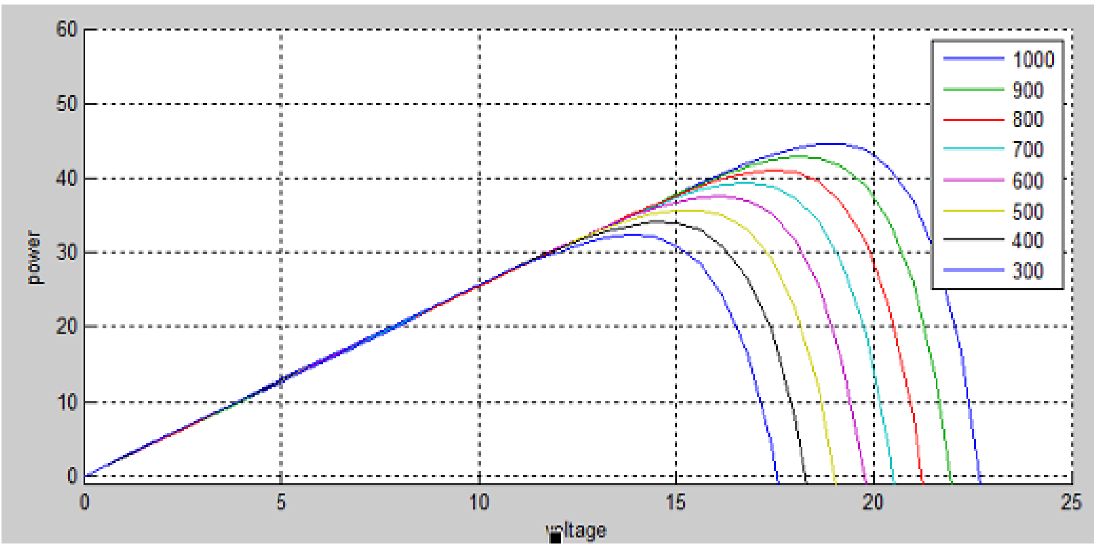

Fig. 6 (b) P-V characteristics of PV module

It has been revealed from Fig. 6(a) and Fig. 6(b) that, the output current of PV module increases with irradiance level at constant temperature and net power of the module increases with increase in output voltage.

III. MODELING OF MAXIMUM POWER TRACKER SYSTEM

PV module output power change continuously by changing the temperature and irradiance. So, it is necessary to find out maximum power at definite temperature and irradiance. Maximum Power Point Tracker (MPPT) is one which is used to extract the maximum power from PV module and supply it to the load. To get maximum power from PV module, the input impedance of PV module must be matched to the load [7], which can be done by adjusting the duty cycle. Further, To obtain maximum power point operation, PV modules are integrated with DC/DC converter. This type of converter can be used as buck, boost and buck-boost [13]. In order to step up the low voltage to higher, DC/DC boost converter are used, which has been described in the following section.

III (A). Modeling of DC/DC Boost Converter

A DC/DC boost converter consisting of diode D, inductor L, capacitor C, IGBT switch S, input voltage source V_{in} and load resistance R and has shown in Fig. 7. It link loads and PV module and is used to transfer the maximum power.

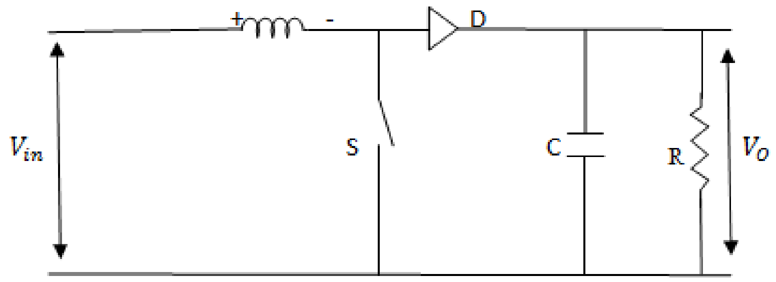

Fig. 7 Configuration of DC/DC boost converter

The DC voltage gains of DC/DC boost converter are presented by equation (6) [9]

$$\frac{V_o}{V_{in}} = \frac{1}{1-D_{dtc}} \qquad (6)$$

Where

V_o= Output voltage

V_{in}= Input voltage

D_{dtc}= Duty cycle of the pulse generator signal used to control the ON-OFF state of the switch.

A MATLAB/SIMULINK based model of DC/DC boost converter which has been presented in Fig.8 and the result of the boost converter is shown in Fig.9. and tabulated in Table V.

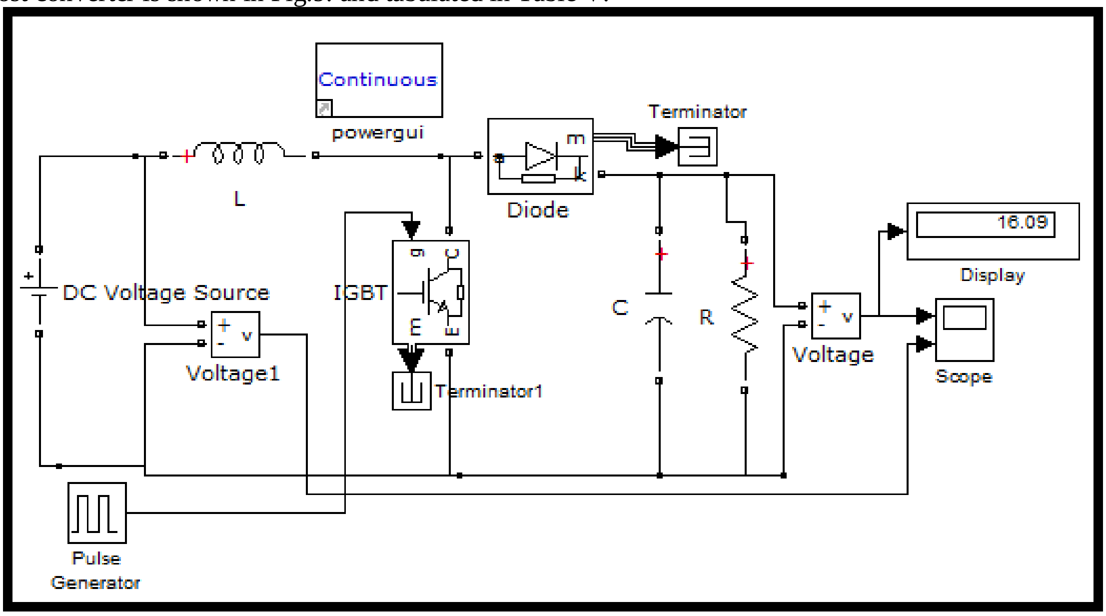

Fig. 8 Simulink model of DC/DC boost converter

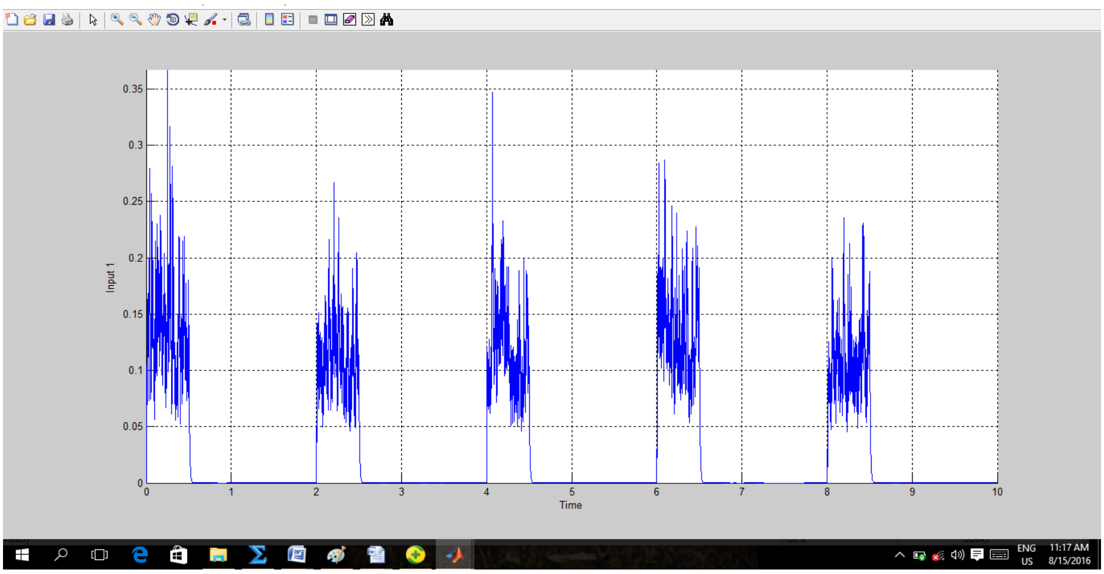

Fig. 9 Multiport graph of boost converter

Table V Simulink output of DC/DC boost Converter

Sr. No.	**Input Voltage (Volt)**	**Output Voltage (Volt)**	**Duty Cycle** $(D_{dtc}=1-\frac{V_{in}}{V_{Out}})$
1.	14	14.96	0.06
2.	15	16.09	0.08
3.	16	17.22	0.07
4.	17	18.36	0.07
5.	18	19.49	0.08
6.	19	20.62	0.08
7.	20	21.76	0.08

III (B). Modeling of MPPT Control Algorithm Method

In this work, Perturbations and observation (P&O) algorithm has been used to accomplish the maximum power point.

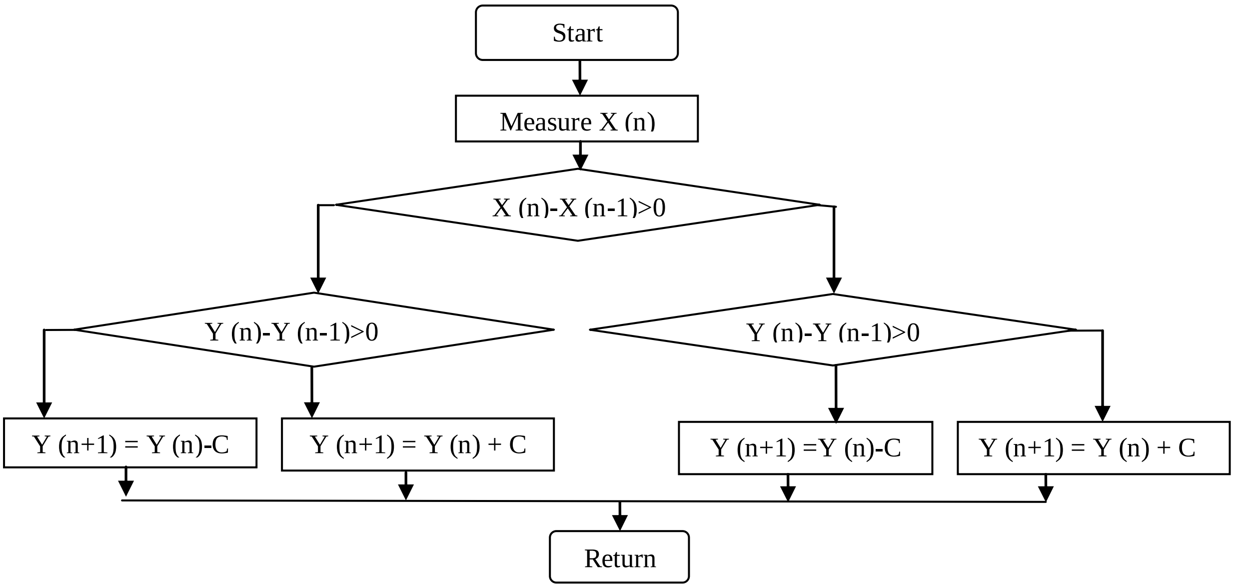

Fig. 10 Flowchart of Perturbation and Observation (P&O) MPPT algorithm

This is one of the simplest online method (P&O) can be implemented by applying perturbations to the reference voltage or the reference current signal of the solar module[6], [14].Due to change in perturbation change in power of the solar module. If the value of the power increase due to perturbation then perturbation is continued ($D+\Delta D$) in the same direction after reaching the maximum power. After reverse perturbation ($D-\Delta D$) the power at the next instant decrease. The flow chart of Maximum Power Point Tracker (MPPT) Perturbation and Observation (P&O) algorithm is shown in Fig.10. The Simulink model of (P&O) is presented in Fig.11.

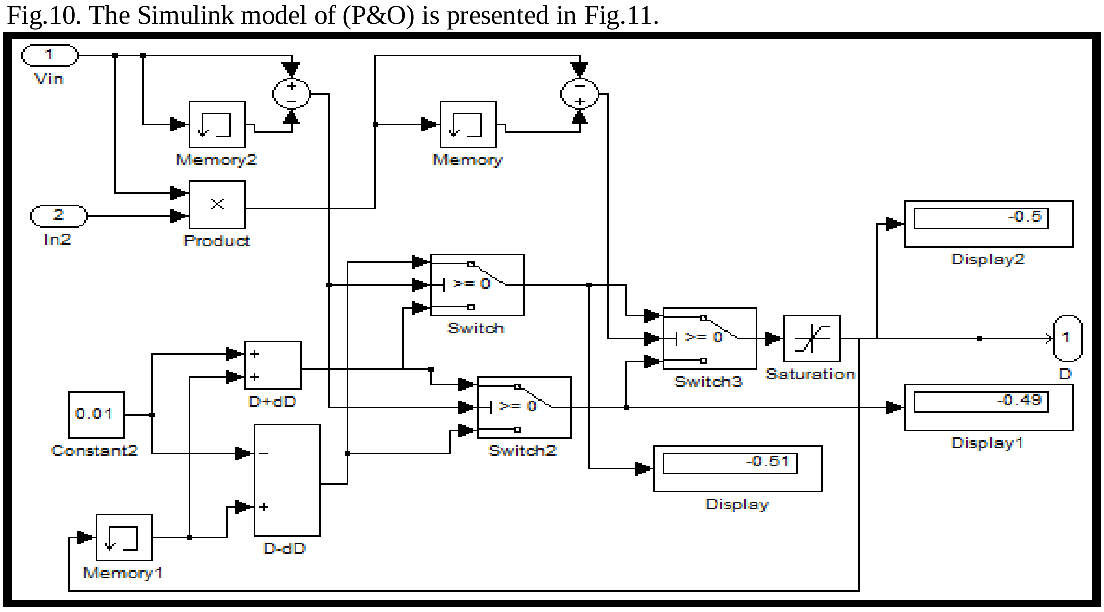

Fig. 11 Simulink model of Perturbation and Observation (P & O) MPPT algorithm

In this MPPT, technique algorithm, I_{in} and V_{in} are considered as input for MPPT and duty cycle is obtained as the output. The detailed Simulink model for PV system with Perturbation and Observation (P&O) MPPT system is presented in Fig.12. and the result of MPPT PV system is demonstrated in Fig.13.

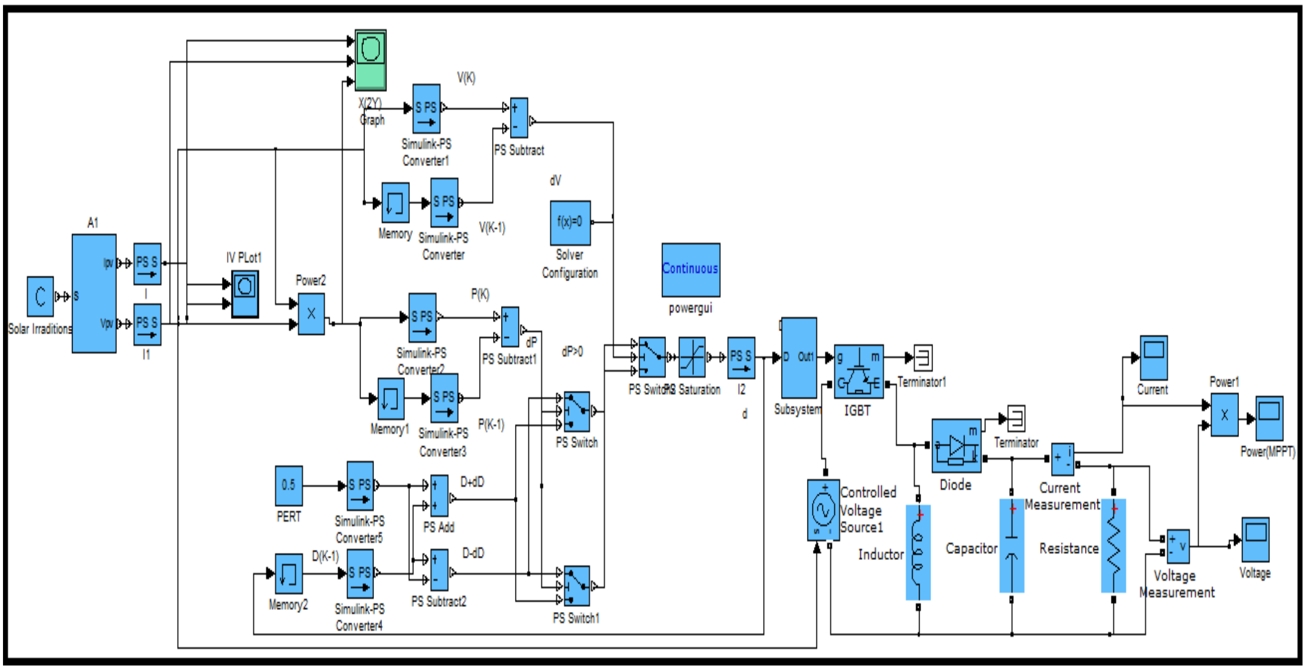

Fig. 12 MPPT System

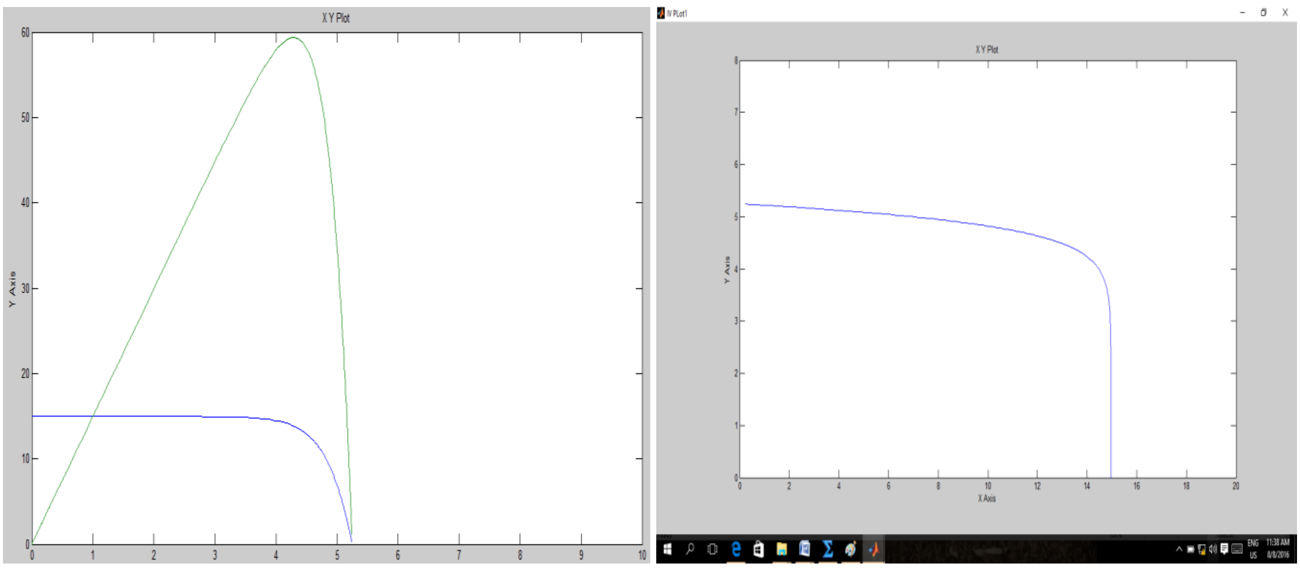

Fig. 13 MATLAB/SIMULINK based maximum power point tracker output

It has been observed that maximum power of the PV system is increasing as the solar irradiance increase. Further, the comparison has been made between the output power by varying temperature and irradiance, when it is connected with MPPT or without MPPT, which has been tabulated in TABLE VI and TABLE VII.

Table VI Output power for different irradiance and constant temperature 25˚c

Sr. No.	**Irradiance**	**Output power (W) (Without MPPT)**	**Output power (W) (With MPPT)**	**% Increase**
1.	100	2.92	19.7	89.9%
2.	200	5.841	24.12	50.2%
3.	300	8.761	26.93	35.4%
4.	400	11.68	29.03	25.6%
5.	500	14.6	30.71	20.1%

6.	600	17.52	32.13	16.1%
7.	700	20.44	33.35	13.1%
8.	800	23.36	34.42	10.8%
9.	900	26.28	35.39	90.6%
10.	1000	29.2	36.26	75.3%

Table VII Output power for different temperature and constant irradiance 600 W/m^2

Sr. No	**Temperature ˚c**	**Output power (W) (Without MPPT)**	**Output power (W) (With MPPT)**	**% Increase**
1.	15	17.38	25.65	47.5%
2.	20	17.45	27.15	55.6%
3.	25	17.52	29.70	69.5%
4.	30	17.59	31.35	78.2%
5.	35	17.66	32.60	84.6%
6.	40	17.73	34.25	93.2%
7.	45	17.80	34.85	95.7%
8.	50	18.07	35.80	98.1%

It has been observed from TABLE VI that the output power is increasing uniformly with increase in irradiance at constant temperature of 25˚. From TABLE VII, it has been revealed that output power does not change so much from maximum value by changing temperature.

IV. CONCLUSION

In this paper, the mathematical equation of PV module with their (I-V) and (P-V) characteristics are presented at various temperature and irradiance. Further, PV system has been developed with DC/DC boost converter using Perturbation and Observation (P&O) algorithm based maximum power point tracker (MPPT) technique performed at various irradiance and temperature. Result shows that P&O based MPPT is effectively and efficiently extract the maximum power from PV model with changing temperature and irradiance.

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