Mathematical Modelling of PV array and Performance Enhancement by MPPT Algorithm

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Abstract: This paper proposes a mathematical modelling and simulation of photovoltaic array and MPPT algorithm with Boost converter. The photovoltaic array and MPPT algorithm with Boost converter can be simulated with MATLAB Simulator. The mathematical modelling of PV array model gives different PV cell behavior under variant environmental conditions. It is seen that the output characteristics of q PV array changes due to environmental factors. So the maximum power point tracking (MPPT) technique is needed to catch the peak power to maximize the produced energy. In this paper, Perturbation & Observation algorithm is used. This algorithm sets the suitable duty ratio in which the DC/DC converter is operated to MPP. This paper outlines the working of PV array as well as MPPT algorithm.

Keywords: Matlab, Simulation, Solar Cell Model, $\boldsymbol{Vmpp}$, $\boldsymbol{Impp}$, Maximum power Point Tracking, P&O Algorithm, Boost Converter.

I. Introduction

Demand and supply of the energy are vital factors in the economic growth. The global demand of energy is increasing day by day with the economic growth. Renewable energy sources has been increasingly used in order to develop clean and sustainable energy sources as they possess several advantages like their suitability for decentralized use, they are clean source of energy, possess no potential damage to the environment, widely available unlike fossil fuel sources which are concentrated at some locations only. Popular renewable energy sources are solar energy, Tidal energy, geothermal energy, Wind energy, Bio energy, Hydro energy.

Use of Solar Photovoltaic is increasing day by day and it is now preferred as a clean source of energy with no CO_2 emission. Several countries have started ambitious programs in search of renewable energy sources. The obvious choice of a clean energy source, which is abundant and could provide security for the future development and growth, is the solar energy. Solar energy is one of the most important renewable sources of energy. India has high solar insolation. It is an ideal place for using solar power. But the high installation cost of PV system and the low conversion efficiency of PV modules are the major obstacles for using this alternative energy source on a large scale. So several studies are being developed in order to minimize these disadvantages. [1]- [9]. Therefore, a maximum power point tracking (MPPT) control method to achieve maximum power (MP) output at real time becomes necessary in PV generation systems.

There are different techniques used to track the maximum power point. Few of the most popular

Techniques are:

 ⇒Perturb and Observe (hill climbing method)

⇒Incremental Conductance method

⇒Fractional short circuit current

⇒Fractional open circuit voltage

⇒Neural networks

⇒ Fuzzy logic

Among them Perturb and Observe (hill climbing method) method has drawn much attention due to its simply implementation. But the oscillation issues in this method is unavoidable.

II. PV Panel Model

A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array. Typically a solar cell can be modelled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n top junction and parallel resistance is due to the leakage current. Figure 1.1 shows single diode model of a PV cell.

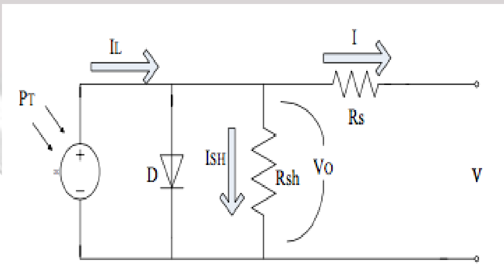


Figure 1.1 Single diode model of a PV cell

In this model we consider a current source (I_L) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected.

The output current from the photovoltaic array is

$I = I_L - I_d - V_0 / R_{sh}$ (1)

Where,

$V = V_0 - R_{sI}$
(2)

The basic equation for the ideal case of the elementary PV cell does not represent the I–V characteristic of a practical PV array, actually Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV Array is expressed by considering one the parameter called "I" which is given by:

$$I = I_l - I_d \left[\exp\left(\frac{q(V + R_s I)}{nktN_s}\right)\right] - 1 \quad (3)$$

In the above mentioned equation, the parameter I_L and I_0 are expressed as:

$$I_l = I_{L(T_r)}(1 + \alpha_{I_{se}}(T - T_r)) \quad (4)$$

$$I_o = I_{0(T_r)} \left(\frac{T}{T_r}\right) \exp\left[\frac{qV_g}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (5)$$

Where $IL(Tr)is$:

$$I_{L(T_r)} = G\left(\frac{I_{sc(T_r,nom)}}{G_e}\right) \quad (6)$$

Where $I_0(T_r)$ is a reverse saturation current.

$$I_{0(T_r)} = \frac{I_{sc(T_r)}}{\exp\left(\frac{q(V_{oc(T_r)})}{nkT_r N_s}\right) - 1} \quad (7)$$

Where,

$$\alpha_{I_{sc}} = \frac{dI_{sc}}{dT} \quad (8)$$

Here,

□⇒I_L: light or photo current.

□⇒Io: reverse saturation current of the diode.

□⇒Is, Vs: the output current and voltage of the photovoltaic generator respectively.

□⇒q: charge on electron.

⇒K: Boltzmann’s constant.

⇒Rs: series resistance.

⇒n: Ideality factor for P-N junction.

III. Control Algorithm for MPPT Perturbation & Observation (P & O) method

Perturbation & Observation (P & O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn’t stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm reaches very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method.

The Perturb and Observe is one of the so called ‘hill- climbing’ MPPT methods, which are based on the fact that, on the voltage-power characteristic, on the left of the MPP the variation of the power against voltage $d_P/d_V > 0$, while on the right, $d_P/d_V < 0$.

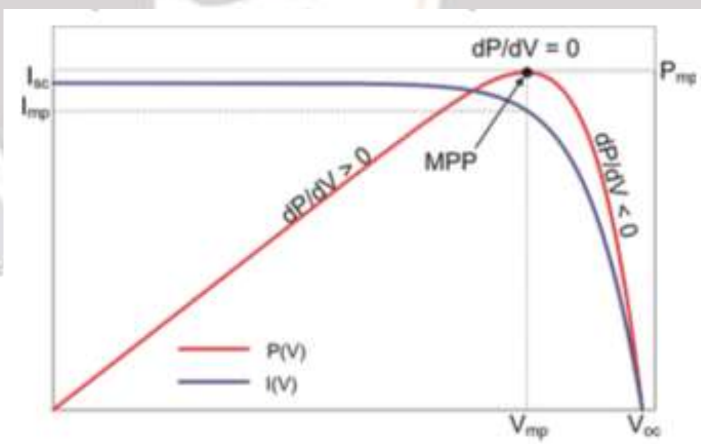


Figure 1.2 Sign of d_P/d_V at different positions on the power characteristic of a PV module

In Fig.1.2, if the operating voltage of the PV array is perturbed in a given direction and $d_P/d_V > 0$, it is known that the perturbation moved the array’s operating point toward the MPP.

The P&O algorithm would then continue to perturb the PV array voltage in the same direction. If $dP/dV < 0$, then the change in operating point moves the PV array away from the MPP, and the P&O algorithm reverses the direction of the perturbation.

The main advantage of the P&O method is that it has low computational demand, easy to implement and is very generic, i.e. applicable for most systems as it do not require any information about the PV array, but only about the measured voltage and current.

The main problems of the P&O is the oscillations around the MPP even in the steady state condition, and poor tracking (possibly in the wrong direction, away from MPP) under rapidly-changing irradiations.

The flowchart for the P&O algorithm is shown in Figure 1.3.

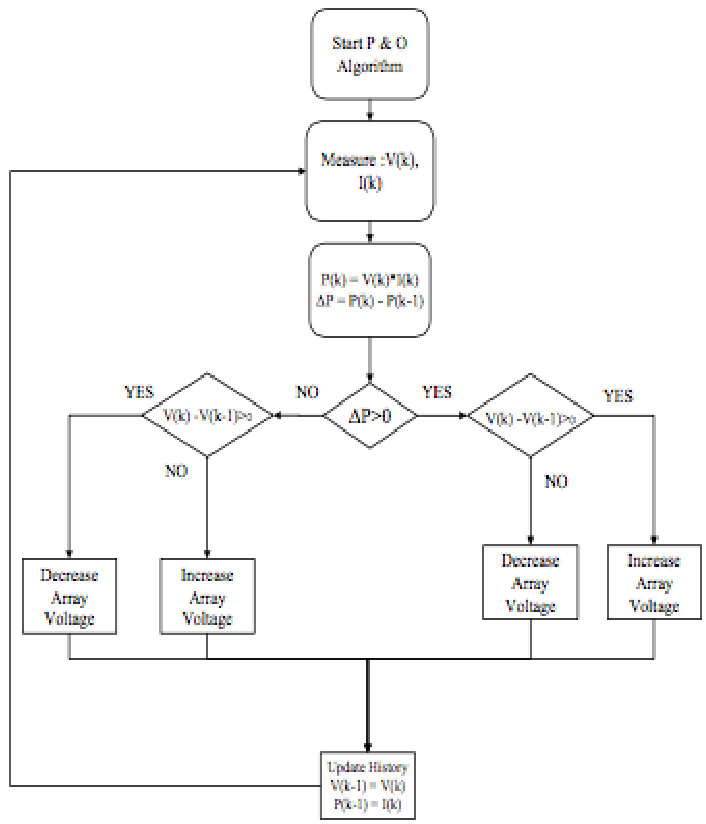


Figure 1.3: Flowchart of Perturb & Observe Algorithm

IV. Simulation Setup and Results

➢PV Array simulation

All of the model parameter can be determined by examining the manufacturer's specifications of the PV products. The important parameters used for the penal electrical performance is the open circuit voltage (V_{OC}) and short circuit current (I_{SC}).

Parameters	Specifications
I_{mp}	7.61 A
V_{mp}	26.3 V
P_{max}	200.143 W
I_{sc}	8.21 A
V_{oc}	32.9 V
K_v	-0.1230 V/K
$\alpha_{I_{sc}}$	0.00032 V/K
N_s	54
$Io_{(Tr)}$	$9.2825*10^{-8}$ A
n	1.3
R_p	415.405
R_s	0.221

Table 1:- Solar array KC200GT Specification (1000 W/m^2, 25^o C)

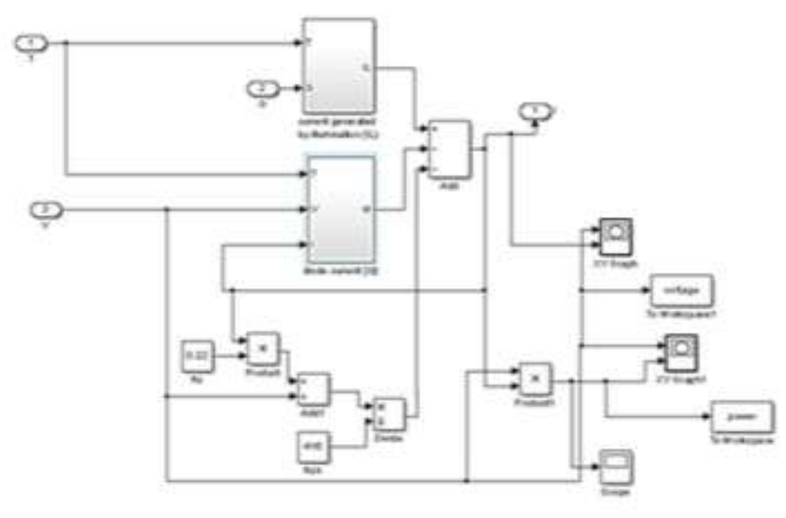


Figure 1.5 PV panel model

Fig 1.5 shows the mathematical simulation of the Solar panel with different subsystem.

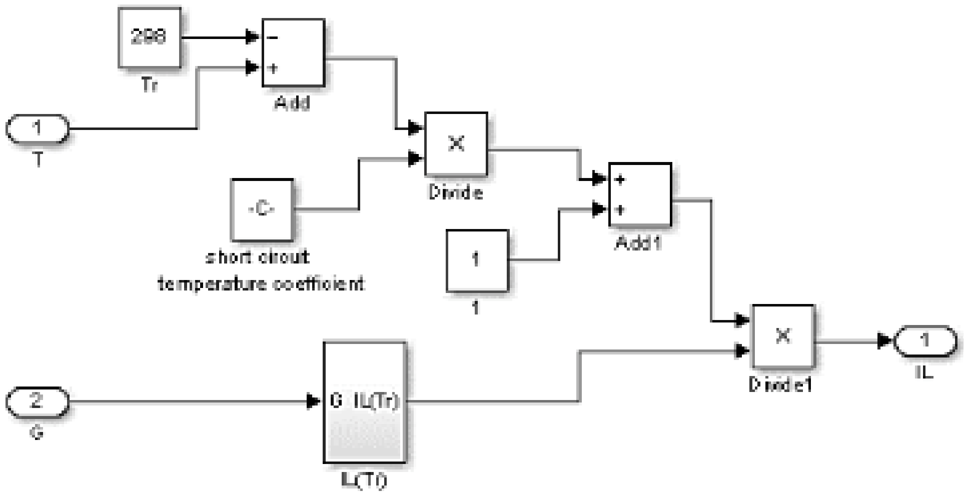


Figure 1.6 Subsystem of Current generated by illumination (I_L)

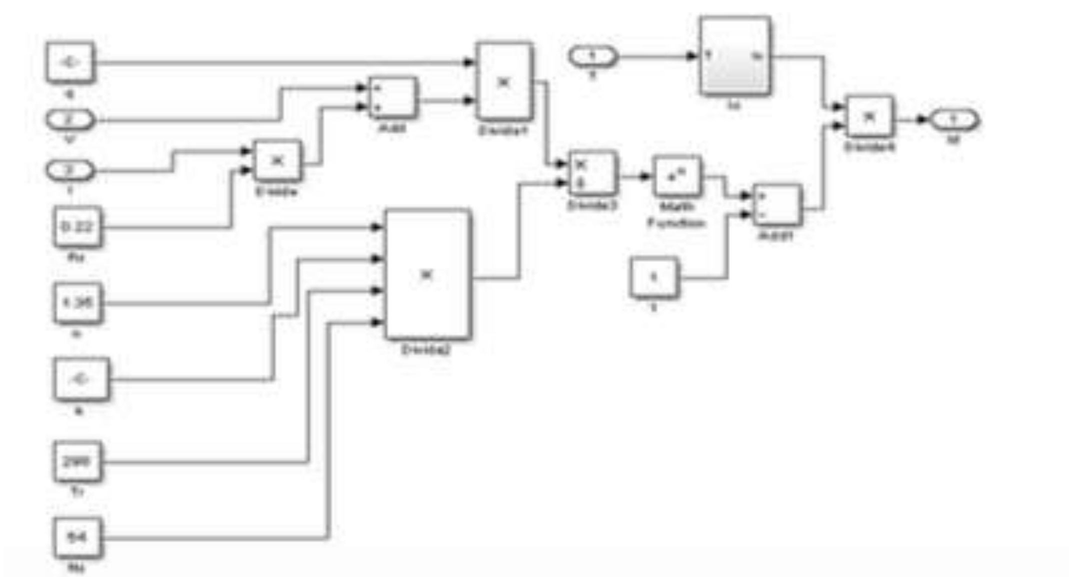


Figure 1.7 Subsystem of Diode current (Id)

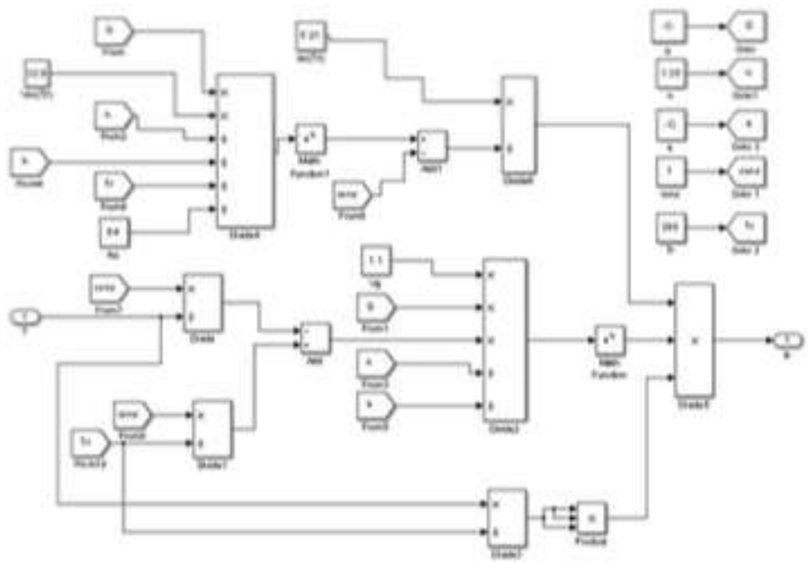


Figure 1.8 Subsystem of Saturation current Io

Simulation Results of the PV

A) I-V curve

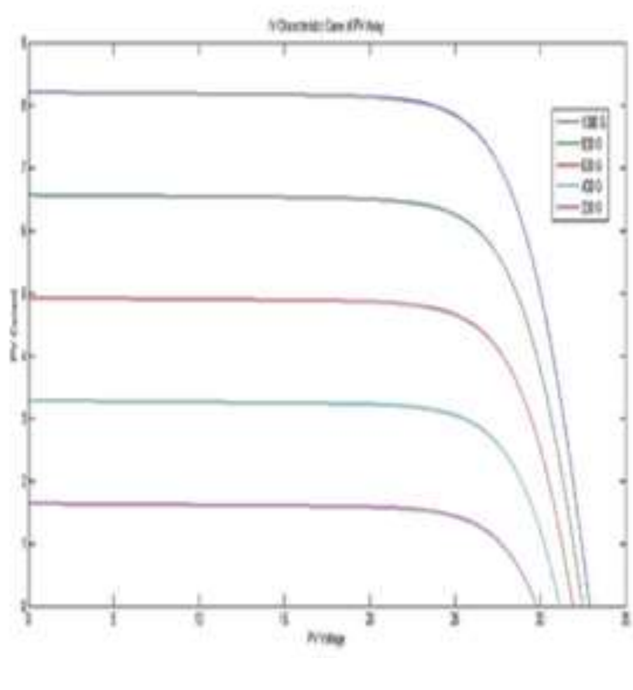


Figure 1.9 I-V curve.
P-V curve

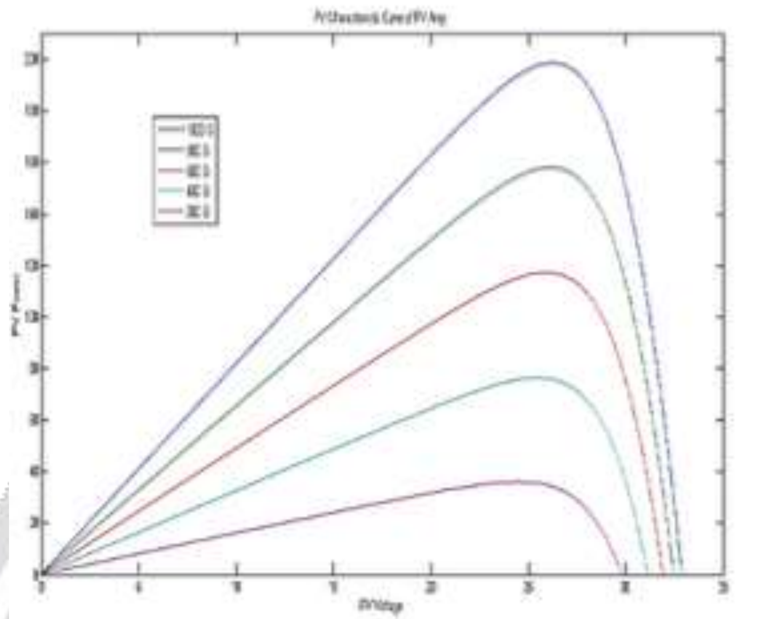


Figure 1.10
P-V curve.

V. Simulation of PV Array, DC/DC boost Converter with MPPT Algorithm

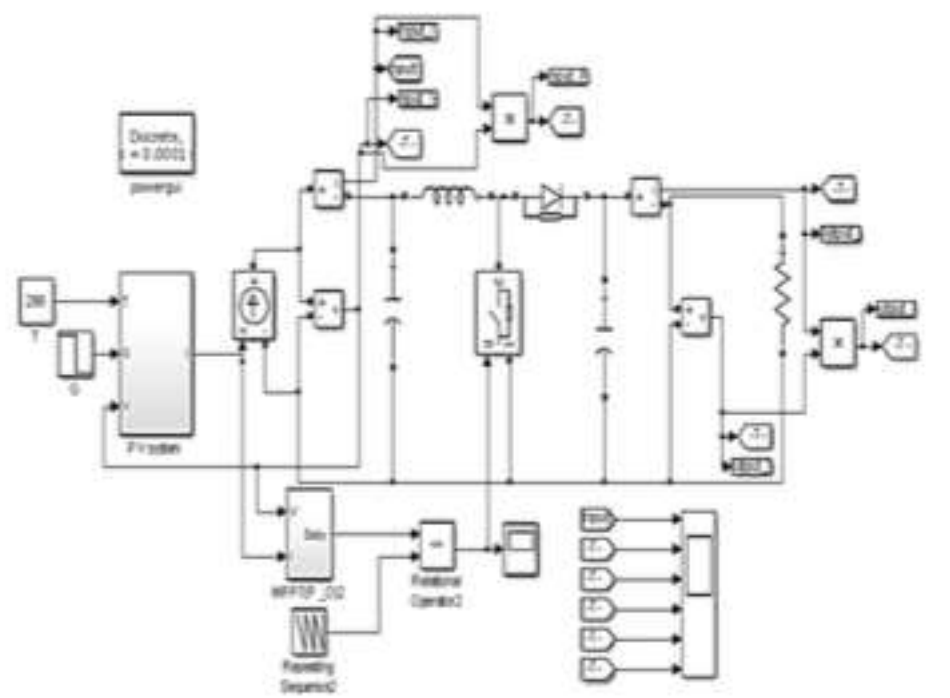
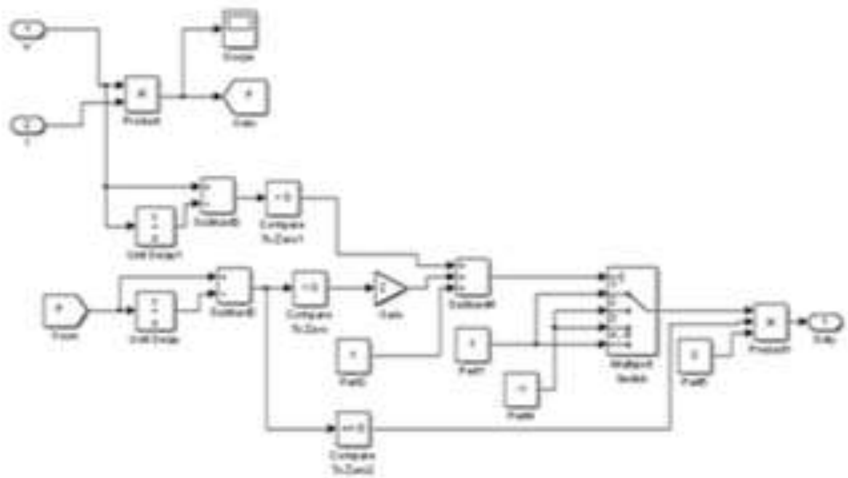


Figure 1.11 DC/DC Converter with MPPT Algorithm.

Figure 1.12 P & O Algorithm.

By using the Step block in the MATLAB one can change the irradiation level. Figure 1.12 and figure 1.13 shows I-V and P-V Curve of the PV array and also the changes in the irradiation level 1000 G to 800 G.



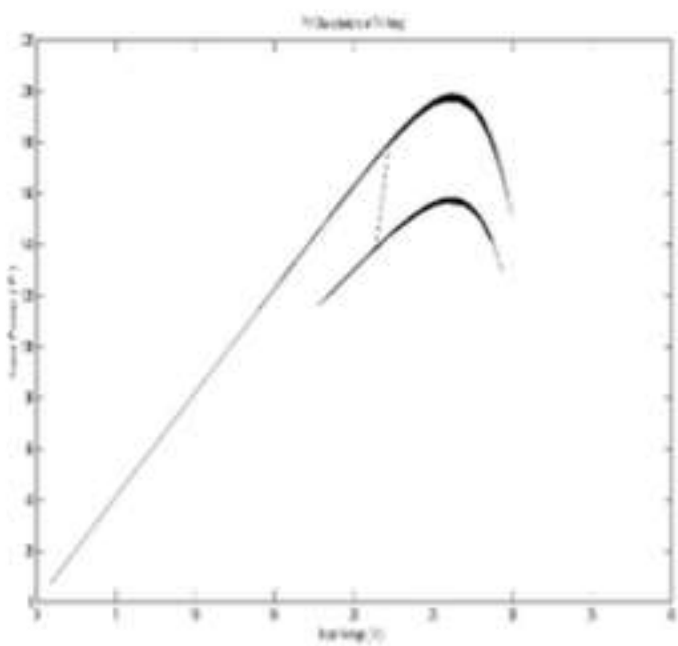


Figure 1.13 I-V curve for 1000 G to 800 G

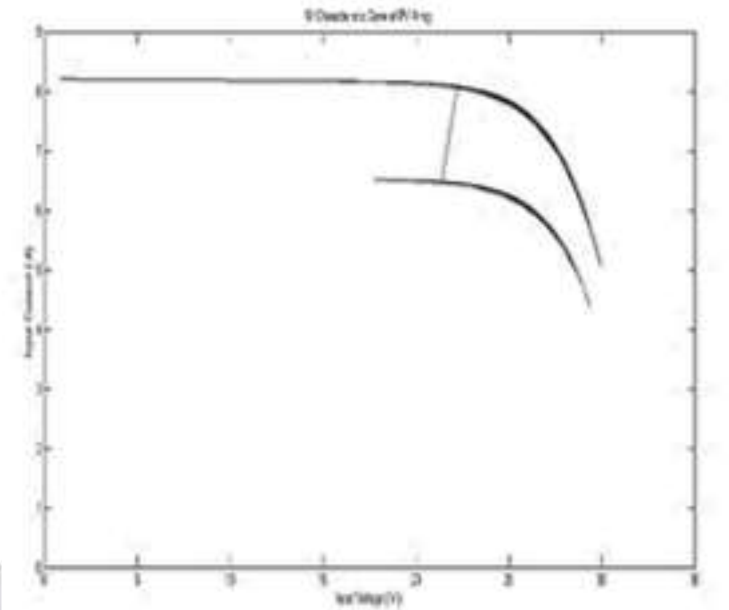


Figure 1.14 P-V curve for 1000 G to 800 G

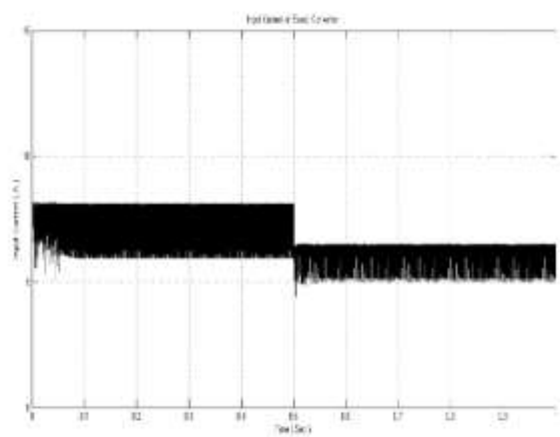


Figure 1.15 Input Current of DC/DC Converter for 1000 G to 800 G

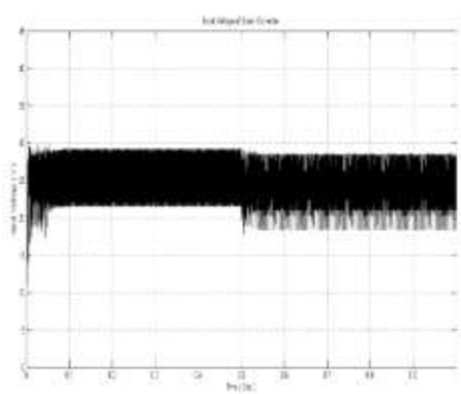


Figure 1.16 Input Voltage of DC/DC Converter for 1000 G to 800 G

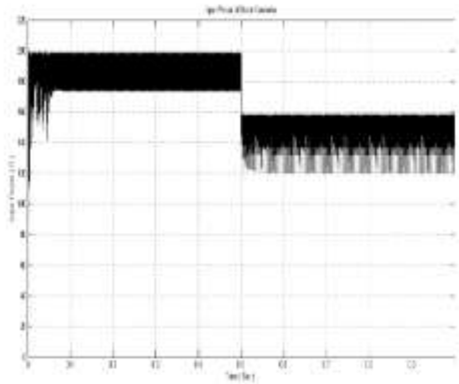


Figure 1.17 Input Power of 1000 G to 800 G

DC/DC Converter for

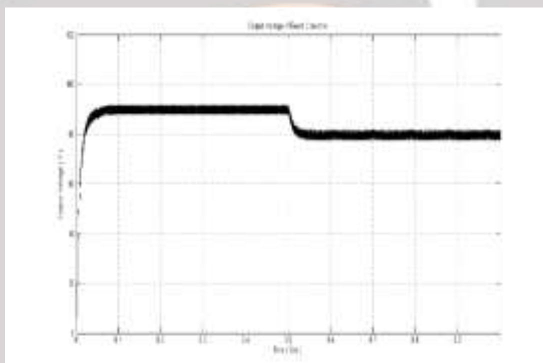


Figure 1.18 Output Current of DC/DC Converter for 1000 G to 800 G

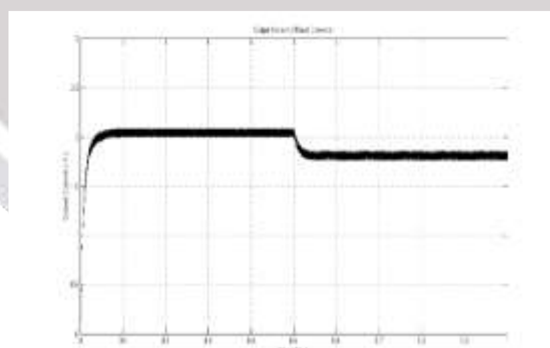


Figure 1.19 Output Voltage of DC/DC Converter for 1000 G to 800 G

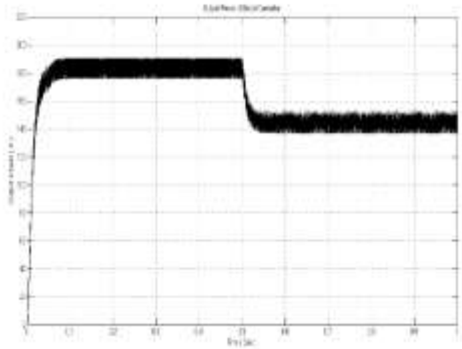


Figure 1.20 Output Power of DC/DC Converter for 1000 G to 800 G

VI. Conclusion

This paper shows the development of a method for the mathematical modelling of the PV array and simulation model of DC/DC boost converter with MPPT algorithm. The objective of the method is to satisfy the mathematical I-V equation with the experimental remarkable points of the I-V curve of the practical Array. The method obtains the parameters of the I-V equation by using following nominal information like open circuit voltage, short- circuit current, maximum output power, voltage and current at the MPP, current/temperature and voltage temperature coefficients from the array datasheet. This paper also presents the simulation of DC-DC boost converter with MPPT algorithm. Figure 1.11 shows the implementation of the DC-DC Converter with MPPT. Figure 1.12 to Figure 1.20 shows the input Current and Voltage, output Current and Voltage, Input Power, Output Power as well as P & O algorithm. Simulation shows how the MPP is tracked using Perturbation & Observation (P & O) algorithm to maximize the power output of the PV array.

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