Implementation of Perturb & Observe and INC MPPT of PV system with Direct Control method using Buck and Boost Converter

MANJAPPA N[1], DR. MADHUSUDANA J[2]

[1, 2] *Department of Electrical Engineering, UVCE, Bengaluru, India*

Abstract— This paper highlights tracking maximum power points using perturb and observe and incremental conductance methods. MPPT techniques are the most important part of extracting the maximum power from a PV system. In this study, a DC-DC conversion system using a buck and boost converter has been designed for a 5Kw PV system. The MPPT controller communicates tracking data (current, voltage, duty cycle and power at each algorithm step). The controllers are simulated using MATLAB/Simulink.

Index Terms- Photovoltaic, MPPT Techniques, DC-DC Converter.

I. INTRODUCTION

Solar energy is the most important source of renewable energy sources. The main application of photovoltaic systems is in either stand-alone (water pumps, domestic and streetlights, electric vehicle and space applications) or grid-connected configuration (hybrid systems, power plants) [1-5].

Unfortunately, PV generation systems have two major problems. The conversion efficiency in electric power is low (generally less than 17%, especially under low irradiation conditions) and the amount of electric power generated by solar arrays changes continuously with weather conditions [6-9].

Moreover, the solar cell V-I characteristics are non-linear and change with irradiation and temperature. In general, there is a unique point on the V-I or V-P curve called the maximum power point at which the entire PV system (array, inverter etc.) operates with maximum efficiency and produces its maximum output power [10-13]. The location of MPP is not known but can be located either through calculation models or by search algorithm. MPPT techniques are used to maintain the PV array operating point at its MPP.

Many MPPT techniques have been proposed in the literature. Examples are the Perturb and Observe method, the Incremental Conductance method, the Artificial Neural Network Method, the Fuzzy Logic method etc. The P&O and Inc. techniques are the most widely used [14].

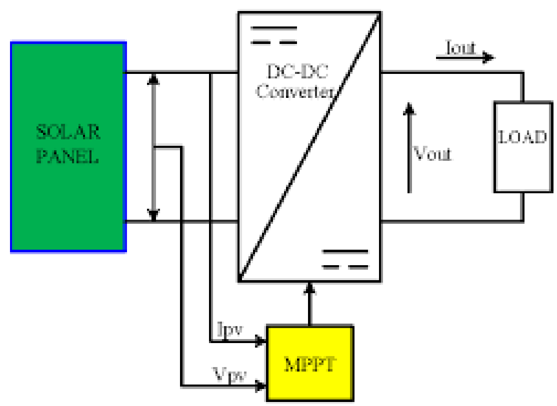

Fig1: PV module and DC-DC Converter with MPPT

Among the various MPPT techniques, P&O and Inc. are the most efficient and widely employed algorithms in PV systems. However, these algorithms require both voltage and current sensors, which results in more implementation costs. The voltage can be Easily censored by a resistive potential divider circuit, but current sensing is difficult, and it has some elements like the presence of undesired signals (i.e., noise) in response, and power loss. Hence an MPPT method by sensing PV module voltage is a good choice for minimizing the power loss and price reduction. MPPT control algorithm can be implemented by using direct duty cycle control or closed-loop control (voltage/current reference). The conventional MPPT methods with direct duty cycle control are generally implemented by considering a fixed perturbation in duty cycle (ΔD) based on the desired tracking system.

II. PV ARRAY MODELING

The PV array block is a five-parameter model using a current source *IL* (light-generated current), diode current *(I0),* series resistance Rs, and shunt resistance *Rsh* to represent the irradiance- and temperature-dependent I-V characteristics of the modules.

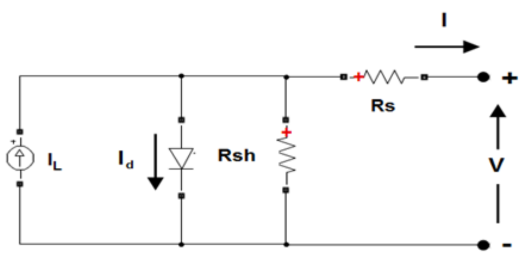

Figure 2: Single diode equivalent circuit of a Solar Cell

The diode I-V characteristics for a single module are defined by the equations

$$I_d = I_o\left[\exp\left(\frac{V_d}{V_T}\right) - 1\right]$$

$$V_T = \frac{kT}{q} \times n_I \times Ncell$$

Where,

I_d = diode current (A)
V_d = diode voltage (V)
I_0 = diode saturation current (A)
n_I = diode ideality factor, a number close to 1.0
k = Boltzmann constant = 1.3806e-23 J.K-1
q = electron charge = 1.6022e-19 C
T = cell temperature (K)
Ncell = number of cells connected in series in a module

III. SOLAR PV MODULE

A solar PV module is a collection of solar cells, connected in series. These combinations of solar cells provide higher power than a single solar cell. The PV modules are available in the power ratings range from 3 watts to 300 watts.

The parameters of the solar PV modules (Voc, ISC, Wp), mentioned by the manufacturer are measured under some standard conditions of temperature 25 degrees Celsius and solar radiations 1000 (W/m2). These test conditions are known as standard test conditions (STC)

The most important parameter of a PV module is its peak output power. The solar PV modules are rated in terms of the peak power *(Wp)* output. It is the most important parameter from a user's point of view. The *Wp* is specified by the manufacturer under so-called standard test conditions (STC). The model rating under STC is widely accepted by the manufacturers and the users.

A PV model is made up of many cells connected, and the electrical behaviour of PV modules is similar to PV cells. Therefore, the PV module parameters are also similar to solar cell parameters, which include open circuit voltage*(Voc),* short circuit current *(Isc),* maximum PowerPoint *(Pm),* voltage at maximum PowerPoint *(Vm),* current at maximum PowerPoint*(Im),* fill factor *(FF)* and efficiency of the cells. A solar cell PV module also has the same set of parameters most of the time all the above parameters are mentioned in the datasheet of the model supplied by the manufacturer.

Maximum Power (W): For TSMC solar TS-110
Power obtained at maximum power point (V_{mp}, I_{mp}). Pmax is computed as $P_{max} = V_{mp} \times I_{mp}$. The default value is 109.871 W.

Cells per module (N_{cell})
Number of cells per module.

Open circuit voltage V_{oc} (V)
Voltage is obtained when array terminals are left open.

Short-circuit current I_{sc} (A)
Current obtained when array terminals are short-circuited.

Voltage at maximum power point V_{mp} (V)
The voltage at the maximum power point.

Current at maximum power point I_{mp} (A)
Current at maximum power point.

Temperature coefficient of V_{oc} (%/deg.C)

Defines variation of V_{oc} as a function of temperature. The open-circuit voltage at temperature T is obtained as

$V_{ocT} = V_{oc} (1 + beta\_V_{oc}(T–25))$,

where V_{oc} is the open-circuit voltage at 25 degrees C, V_{ocT} is the open-circuit voltage at temperature T (in degrees C), $beta\_V_{oc}$ is the temperature coefficient (in %/degrees C), and T is the temperature in degrees C.

Temperature coefficient of I_{sc} (%/deg.C)

Defines variation of I_{sc} as a function of temperature. The short-circuit current at temperature T is obtained as

$I_{scT} = I_{sc} (1 + alpha\_I_{sc}(T–25))$,

where I_{sc} is the short-circuit current at 25 degrees C, I_{scT} is the short-circuit current at temperature T (in degrees C), $alpha\_I_{sc}$ is the temperature coefficient (in %/degrees C) and T is the temperature in degrees C.

The default value is 0.1 %/deg. C

IV. DC-DC CONVERTERS

To implement MPPT, a PV array is operated in configuration with a DC-DC converter. DC-DC converter is the heart of the MPPT hardware. It interfaces the PV source and the DC-AC inverter. The converter must be carefully chosen as the efficiency of the entire system depends on the performance of the converter. Among all the available converter topologies, boost converter topology is most commonly used for MPPT applications. This is because the current drawn by the boost converter from the PV module contains less harmonic distortion as compared to other converters. Also, the PV voltage can be stepped up for grid-connected systems.

V. BUCK CONVERTER

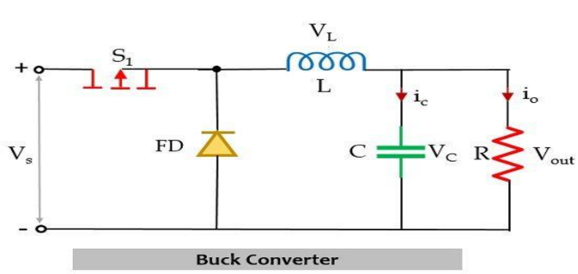

Figure 3: Buck Converter

DC to DC buck converter is a converter in which DC voltages are stepped down to the desired level by high-frequency switching of semiconductor switches such as MOSFET or IGBTs. This type of converter is also called a step-down converter. If we talk about regulated supply, then it is not so difficult on the AC side but on the DC side it is so much difficult, and this is only possible with high-frequency switching of semiconductor switches. This type of converter is mainly used in switch mode power supplies and DC motor control systems.

The MPPT controller determines the maximum power point according to the irradiation level and temperature after measuring the voltage and current of the PV. The controller generates the pulse width modulation (PWM) switching signal to control the PV system to operate at its maximum power.

Equation demonstrates the mathematical relations between PV's voltage Vs, load voltage Vo, and duty cycle D. To achieve the accurate Vs at the maximum power, a tracking system is necessary.

The relation between the output and input voltage of the converter is as follows.

$$V_o = D \times V_s$$

Or

$$D = \frac{V_o}{V_s}$$

Inductance (L) and Capacitance (C) are calculated from the formula given by:

$$L_{min} = \frac{(1-D)R}{2f}$$

$$L = 1.25\, L_{min}$$

$$C = \frac{1-D}{8L\left(\frac{\Delta V_o}{V_o}\right)f^2}$$

Where,

V_s = PV voltage,

V_o = Output voltage,

f = Switching frequency,

$\Delta V_o / V_o$ = Ripple voltage

VI. BOOST CONVERTER

A step-up converter is necessary to increase the level of the PV voltage. The DC-DC converter can be employed as a switching mode regulator used for modifying uncontrolled DC voltage to a controlled DC output voltage. At fixed frequency controlling is normally accomplished by PWM and the switching device. In general, the DC-DC converter for the PV system is used in conjunction with the MPPT controller to control the input voltage and current from the PV to reach its maximum power point.

The boost converter operates in two modes. During Mode I when the switch is closed, the current rises gradually through the inductor and the diode D is off during this interval.

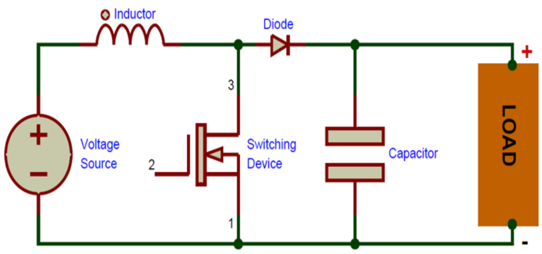

Fig 4: Boost Converter

During Mode II when the switch is opened, the current flows through the inductor, diode, capacitor, and load. The switch has a duty ratio of D which is defined as

$$D = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T}$$

The MPPT controller determines the maximum power point according to the irradiation level and temperature after measuring the voltage and current of the PV. The controller generates the pulse width modulation (PWM) switching signal to control the PV system to operate at its maximum power.

Equation demonstrates the mathematical relations between PV's voltage Vs, load voltage Vo, and duty cycle D. To achieve the accurate Vs at the maximum power, a tracking system is necessary.

The relation between the output and input voltage of the converter is as follows.

$$V_o = \frac{V_s}{1 - D}$$

Or

$$D = 1 - \frac{V_s}{V_o}$$

Inductance (L) and Capacitance (C) are calculated from the formula given by:

$$L_{min} = \frac{D(1-D)^2 R}{2f}$$

$$L = 1.25\, L_{min} C = \frac{D}{R(\frac{\Delta V_o}{V_o})f}$$

Where,
V_s = PV voltage,
V_o = Output voltage,
f = Switching frequency,
$\Delta V_o / V_o$ = Ripple voltage

The inductance and capacitance are calculated to maintain the inductor current ripple and capacitor voltage ripple values within 10% and 5% respectively. The boost converter is designed to operate at a switching frequency of 50kHz. The switching of the DC-DC is regulated by using different MPPT techniques. The most widely used maximum power point tracking method is the Perturb and Observe (P&O) or hill climbing method which has been considered in this work.

VII. MAXIMUM POWER POINT TRACKING

Maximum PowerPoint Tracking (MPPT) techniques are very significant, as one can improve the efficiency of the PV model through them. There are many methods of MPPT, such as Perturbation and Observation (P&O), the incremental conductance, the Fractional Open-Circuit Voltage, the Fractional Short-Circuit Current, the fuzzy logic control and the Ripple Correlation Control. All the above vary in complexity, cost, popularity, convergence speed, hardware requirements and efficiency levels. In this section, we examine the Perturbation and Observation (P&O) and Incremental Conductance algorithms.

VIII. PERTURB AND OBSERVE ALGORITHM.

The perturb and Observation algorithm, also known as the hill climbing method, is one of the most used methods due to its ease of implementation. The slope of the curve is zero at the maximum power point (MPP), positive on the left side of the MPP (increasing power region) and negative on the right side of the MPP (decreasing power region). Therefore, the algorithm is repeated and oscillated until the MPP is reached. The oscillation can be minimized by reducing the step size of the perturbation, but this slows down the process of reaching the MPPT.

The control variable of the P&O algorithm is the Duty cycle *(D)*. The algorithm aims to extract maximum power in the solar panel by varying the duty cycle in step size until the optimal operating point is reached. To do this, three possible actions can be performed; either D stays the same, D is increased, or D is reduced. A 'Switch' block is used to implement the required 'if' cases. First, the algorithm checks if $\Delta P > 0$. Then it checks if $\Delta V > 0$. If the algorithm detects that the operating voltage is lower than $VMPP$, it adjusts the duty cycle by adding a fixed value ΔD to get a higher voltage. It keeps adjusting until the condition is no longer true and the operating voltage is higher than $VMPP$ it subtracts ΔD from the duty cycle. In the conventional P&O MPPT developed, the step size ΔD is fixed for all input voltages. These changes are then applied to the PWM Generator which controls the switching of the converter. The fixed step size is set as 0.01.

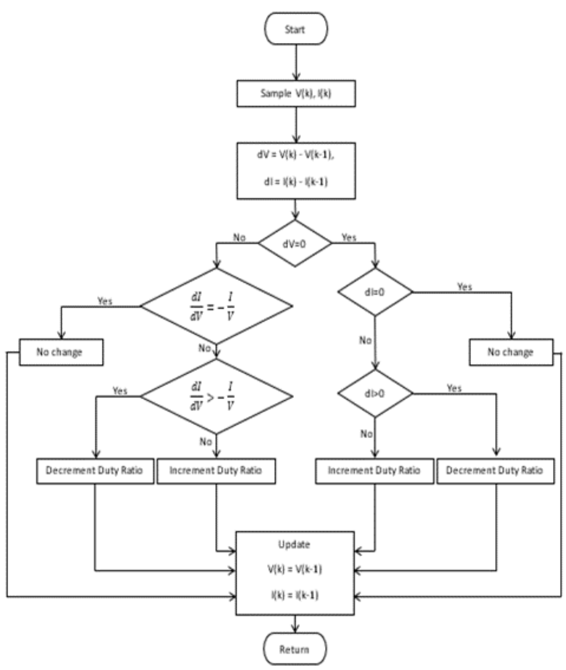

Fig5: Flowchart of P&O algorithm

IX. INCREMENTAL CONDUCTANCE ALGORITHM

The time complexity of the perturb & observe algorithm is much less but on reaching very close to the MPP it does not stop at the MPP and keeps on perturbing in both directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or use a wait function which ends up increasing the time complexity of the algorithm. [5] However, the method does not consider 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 MPPT.

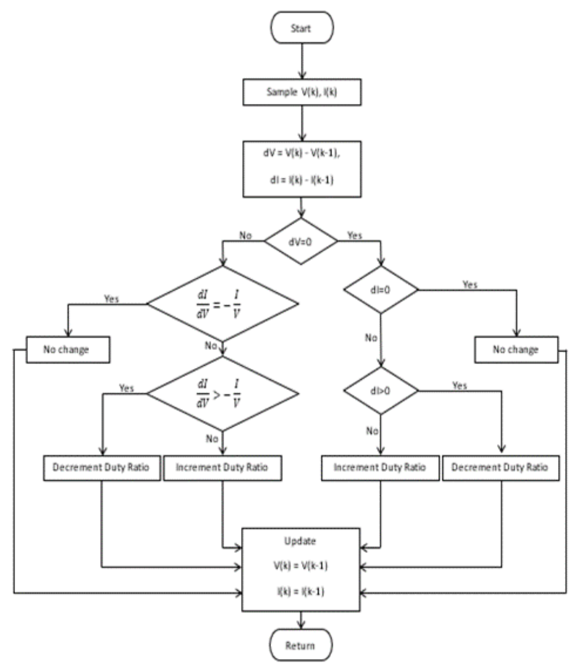

Figure 6: Flowchart of the implemented P&O algorithm

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric conditions is overcome by the INC method. The INC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than P and O.

X. DESIGN OF CONVERTERS FOR 5KW

Solar panel: TSMC Solar TS-110C
N_{cell}: 100
V_{oc}: 51.6 V
V_m: 39.1 V
I_{sc}: 3.36 A
I_m: 2.81 A
MPP: 109.871 W
(i)Buck converter
5 kW solar panel
The total number of modules used is 48 (8 series and parallel) Therefore, total power = 5.273 kW
Input and output parameters
V_{in} = 372V
In = 7.5A
V_o = 230V
$\Delta V_o/V_o$=0.005
f=10 kHz
Duty cycle

$$D = \frac{V_o}{V_{in}} = \frac{230}{372} = 0.618$$

Inductor Design
Let R=10 Ω

$$L_{min} > \frac{(1-D)R}{2f}$$
$$= \frac{(1-0.6182)\times 10}{2\times 10000}$$
$$= 1.909\times 10^{-4} H$$
$$L = 1.25 L_{min}$$
$$= 1.25\times 1.909\times 10^{-4}$$
$$= 2.375\times 10^{-4} H$$

Capacitor Design

$$C = \frac{1-D}{8L\left(\frac{\Delta V_o}{V_o}\right)f^2}$$
$$= \frac{1-0.6182}{8\times 2.375\times 10^{-4}\times 0.005\times 10000^2}$$
$$= 4\times 10^{-4} C$$

(ii) Boost converter
Five kW solar panel
The total number of modules used is 46 (2 series and 23 parallel)
Therefore, total power = 5.054 kW

Input and output parameters
V_{in} = 90 V
In = 35.37 A
V_o = 230V
$\Delta V_o/V_o$=0.005
f=10 kHz
Duty cycle

$$D = 1 - \frac{V_{in}}{V_o}$$
$$= 1 - \frac{90}{230} = 0.6086$$

Inductor Design
Let R=10 Ω

$$L_{min} > \frac{D(1-D)^2 R}{2f}$$
$$= \frac{0.6086(1-0.6086)^2\times 10}{2\times 10000}$$
$$= 4.6617\times 10^{-5} H$$
$$L = 1.25 L_{min}$$
$$= 1.25\times 4.6617\times 10^{-5} H$$
$$= 5.8271\times 10^{-5} H$$

Capacitor Design

$$C = \frac{D}{R\left(\frac{\Delta V_o}{V_o}\right)f}$$
$$= \frac{0.6086}{10\times 0.005\times 10000}$$
$$= 1.2172\times 10^{3} C$$

XI. OUTPUTS

The simulation is run for one simulation time for a 5kW solar array with the above-mentioned design values of buck converter without MPPT, with P&O, and INC algorithm and output is observed.
PV output with a buck converter
Simulation Diagram
Without MPPT

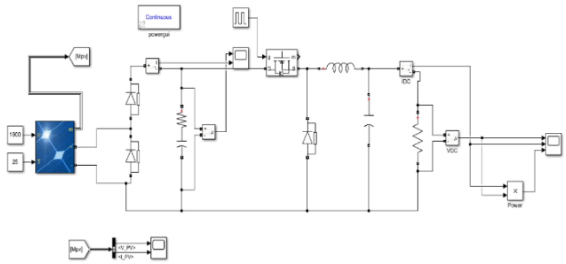

Figure 7: Simulation diagram of PV system with Buck converter without MPPT

With P&O Algorithm

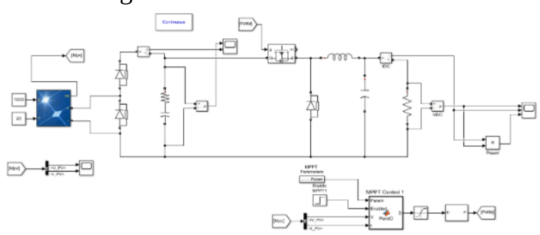

Figure 8: Simulation diagram of PV system with Buck converter with P&O Algorithm

5kW
Without MPPT

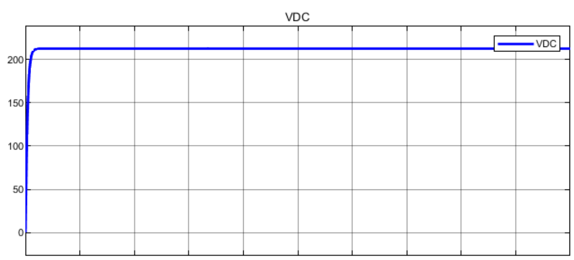

Figure 10: Voltage output of the Buck converter without MPPT

With P&O Algorithm

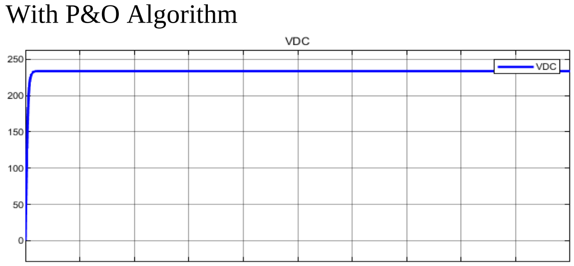

Figure 11: Voltage output of the Buck converter with P&O Algorithm

With INC Algorithm

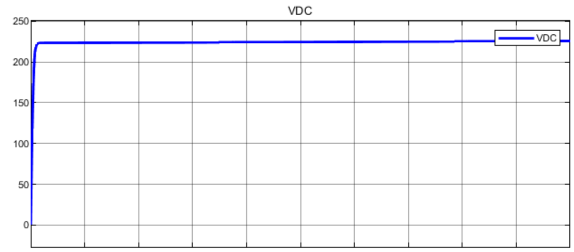

Figure 12: Voltage output of the Buck converter with Inc. Algorithm

Table: Output comparison of 5kW PV array with Buck converter without MPPT, with P&O, and with INC Algorithms (Insolation: 1000W/m^2, Temperature: 25^{0}c)

	V_{pv} (V)	I_{pv} (A)	V_o (V)	I_o (I)	Power (kW)
Without MPPT	392	5.8	212.2	10.61	2.252
P&O Algorithm	392	5.8	233.7	11.69	2.732
InC Algorithm	378	9.14	223.6	11.18	2.5

PV output with boost converter

i.Simulation Diagram

a) Without MPPT

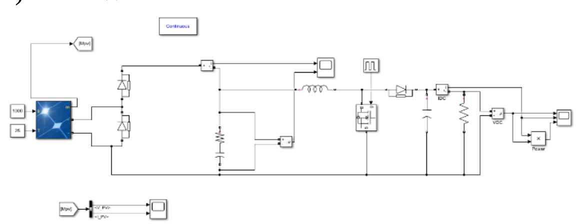

Figure 13: Simulation diagram of PV system with Boost converter without MPPT

b) With P&O Algorithm

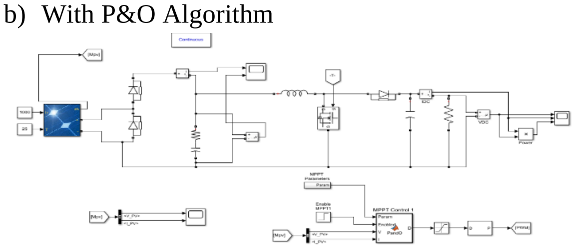

Figure14: Simulation diagram of PV system with Boost converter with P&O Algorithm

c) With INC Algorithm

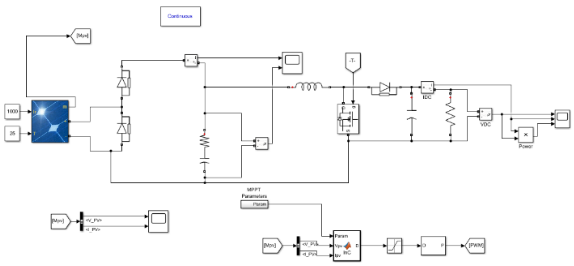
Figure 15: Simulation diagram of PV system with Boost converter with Inc. Algorithm

ii.5kW

a) Without MPPT

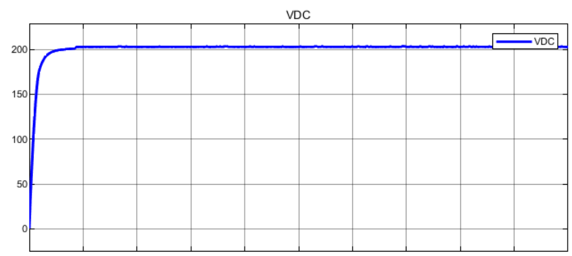

Figure 16: Voltage output of the Boost converter without MPPT

b) With P&O Algorithm

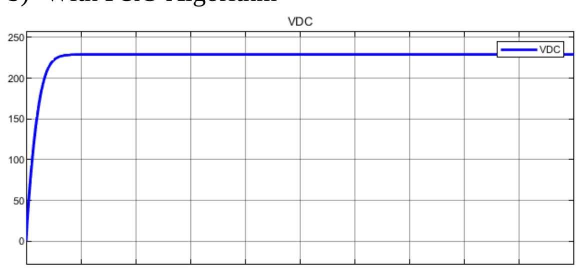

Figure17: Voltage output of the Boost converter with P&O Algorithm

c) With INC Algorithm

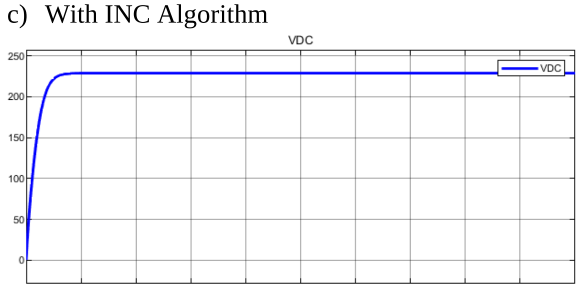

Figure18: Voltage output of the Boost converter with Inc. Algorithm

Table: Output comparison of 5kW PV array with Boost converter without MPPT, with P&O, and with Inc. Algorithms (Insolation: 1000W/m^2, Temperature: 25^{0}c)

	V_{pv} (V)	I_{pv} (A)	V_o (V)	I_o (I)	Power (kW)
Without MPPT	92	34	203	13.5	2.741
P&O Algorithm	81	51	229	15.27	3.495
InC Algorithm	80	51	229	15.26	3.494

CONCLUSION

From the simulation result, it is observed that there is an increment in the power obtained when both P&O and INC MPPT are applied, but output using INC MPPT is partially better than P&O. Above results are obtained for standard test conditions of isolation 1000w/m^2 and temperature of 25-degree centigrade. By increasing in insolation level, we will be able to achieve higher output. The above design and analysis will be done for the Buck-Boost Converter with higher insolation.

REFERENCES

[1] Ariya Sangwongwanich, “Mitigation of Interharmonics in PV Systems With Maximum Power Point Tracking Modification,” IEEE Trans. Power Electronics, Vol 34, NO.9, Sept.2019.

[2] 2. Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo, Massimo Vitelli, “Optimization of Perturb and Observe Maximum Power Point Tracking Method”, IEEE Trans. Power Electronics, Vol.20, NO.4, July.2005.

[3] Ahmed M Atallah, Almoataz Y. Abdelaziz, and Raihan S. Jumah, “Implementation Of Perturb And Observe MPPT Of PV system with direct control method using Buck and Buck-Boost converters”,” Emerging Trends in Electrical, Electronics &Instrumentation Engineering. An international Journal (EEIEI), Vol.1, No 1, Feb.2014.

[4] B. Pakkiraiah and G. Durga Sukumar, “Research Survey on various MPPT Performance Issues to Improve the Solar PV System Efficiency” Journal of Solar Energy, Feb 2016.

[5] Tekeshwar Prasad Sahu, T.V. Dixit and Ramesh Kumar, “Simulation and Analysis of Perturb and

Observe MPPT Algorithm PV Array Using CUK Converter." Vol 4, NO 2, pp, (2014).

[6] Omar Diouri, Najia Es-Sbai, Fatima Errahimi, Ahmed Gaga, and Chakib Alaoui, "Modelling and Design of Single-Phase PV Inverter with MPPT Algorithm Applied to the Boost Converter Using Back-Stepping Control in Standalone Mode," Hindawi, International Journal of Photoenergy, Vol 2019.

[7] Saeed H Hanzab, Samana Gori and Mehran Ektesabi, "A Scheme-Based Review of MPPT Techniques with Respect to Input Variables Including Solar Inradiance and PV Arrays Temperature," Sept 2020.

[8] Ajay Patel, Vikas Kumar, Yogendra Kumar, "Perturb and Observe Maximum Power Point Tracking for Photovoltaic Cell," Innovative Systems Design and Engineering, Vol.4, NO.6, 2013.

[9] Manel Hlaili and Hfaiedh Mechergui "Comparision of Different MPPT algorithm with a proposed One using a power Estimator for grid Connected PV Systems" Hindwai Publishing Corporation, International Journal of Photoenergy, Vol 2016, Received 4 April; Accepted 17 May 2016.

[10] Omar Diouri, Najia Es-Sbai, Fatima Errahimi, Ahmed Gaga, and Chakib Alaoui "Modeling a design of single-phase PV inverter with MPPT algorithm applied to the boost converter using backstepping control in stand-alone mode" Hindawi, International Journal of P photo energy, Volume 2019, published 6 Nov 2019

[11] Saeed H. Hanzer, Saman A. Gorji, Mehran Ektesbi "A Scheme -based review of MPPT techniques with respect to input variables including solar irradiance and PV array Temperature" IEEE Access, Date of publication: October 5 2020

[12] S. Sankar, Madhusmita Mohanty, K. Chandrasekaran, Sishaj P Simon and Y. R Sood "High-speed maximum PowerPoint tracking module for PV system "2018 IEEE Transactions on Industrial Electronics

[13] Vidhya K Viswambaran, Dr Arfan Ghani and Dr Erping Zhou "Modelling and simulation of maximum PowerPoint tracking algorithms & Review of mppt techniques for PV application" Publication: IEEE, 2016 5th International Conference on the Electronic devices, systems and Applications. Date of Conference: 6-8 December 2016

[14] Mohammad Alqarni, Mohammad K Darwish "Maximum PowerPoint tracking for photovoltaics system modified perturb and observe algorithm" 2012 47th International Universities Power Engineering Conference. Publisher: IEEE. Date of Conference: 4-7 Sept 2012.