REALIZATION OF CLASSICAL AND NON LINEAR CONTROLLERS BASED MPPT TECHNIQUES FOR PV SYSTEM

A DISSERTATION

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Submitted by

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CANDIDATE'S DECLARATION

I hereby declare that the Dissertation titled "**REALIZATION OF CLASSICAL AND NON LINEAR CONTROLLERS BASED MPPT TECHNIQUES FOR PV SYSTEM**" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Dissertation titled "**REALIZATION OF CLASSICAL AND NON LINEAR CONTROLLERS BASED MPPT TECHNIQUES FOR PV SYSTEM**" which is submitted by Ms. MANISHA, Roll No. 2K19/C&I/03 Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere

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ABSTRACT

This project presents the collective study of various Maximum PowerPoint Tracking Methods. These methods include widely used MPPT techniques such as Perturb and Observe (P&O), Incremental Conductance (InC) & Sliding Mode Approach (SMC), Backstepping Controller (BSC) with integral action. Maximum Power Point (MPPT) Tracking is essential to obtain the optimum power from a photovoltaic system otherwise a substantial amount of power is wasted. This work is focused on the testing of these methods under varying irradiation conditions. Conventional methods like Perturb and Observe (P&O) and Incremental Conductance (InC) are easy to implement but they show oscillations around Maximum power point under varying irradiations condition, non-linear tools like Sliding Mode Control (SMC) approach and Backstepping Controller (BSC) with integral action are used to ensure the reduction in these oscillations.

ACKNOWLEDGEMENT

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CONTENTS

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LISTS OF ABBREVIATIONS

I_{SC}	Short Circuit Current
V_{oc}	Open Circuit Voltage
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
InC	Incremental Conductance
SMC	Sliding Mode Control
I_{PP}	Peak Point Current
V_{PP}	Peak Point Voltage
P_{max}	Maximum Power
V_{mp}	Voltage at Maximum Power
Imp	Current at Maximum Power
No	Number
BSMC	Backstepping Sliding Mode Controller
F_{sw}	Switching Frequency
V_d	Voltage Drop
MP	Maximum Power
OC	Open Circuit
HC	Hill Climbin

CHAPTER 1

INTRODUCTION

1.1Weather Condition

It is tough to exactly describe all the causes behind the variations in weather conditions because of the complexity of variation in trends. Too much increase in the number of industries tends to increment in usage of fossil fuel. Excessive burning of fossil fuel creates additional pressure on the environment in terms of increment in greenhouse gases amount in the atmosphere in last 10 years. As a result of which excessive heat energy is trapped into the atmosphere so the temperature of the earth is rising continuously which in turn resulting in Global Warming. This excessive heat is not able to go out of the atmosphere due to the presence of gases like Carbon dioxide and chlorofluorocarbons. Continuous burning of Non-Renewable resources for industrial purposes adding more and more greenhouse gases to the environment. Due to too much increment of population and excessive industrialization and modernization, it is forecasted that in upcoming years the temperature of the earth is going to rise more and more and this is going to have very adverse effects on our planet.

1.2 Renewable Resources as an Alternative

Since the economy of a country depends on industrialization and that it mainly depends on the availability and utilization of energy. So, to fulfill energy demands we have to look for different types of energy sources. At present, for most of the energy demands, we are dependent on non-renewable energy sources. But these sources are present in a limited amount so we cannot rely on these sources for long. So, renewable energy sources can act as a better option because of their abundant availability in nature.

Moreover burning of these non-renewable sources causes the emission of greenhouse gases. These above-mentioned reasons conclude that renewable sources can serve as a better replacement to deal with all negative effects renewable sources are having like these sources are having nil carbon components and their derivative emission.

Solar energy is one such alternative solar energy that is convertible to electrical energy using Photo-Voltaic cells consists of two different types of semiconductors. Gallium arsenide is a very high-efficiency material. When solar energy strikes this junction, an electric field is created due to movement of holes and electrons but the efficiency of these photovoltaic cells is very low. So, we require some methods to obtain the utmost power from the solar module.

1.3 Solar Insolation

Sun is a natural and clean source of energy and providing energy to the earth continuously. The energy provided by the sun in one hour is sufficient to fulfill all humans. We quantify radiation in terms of irradiance but mostly used quantity is solar insolation. It is described by the addition of energy at a particular area for a fixed period of an interval; this can be defined in units of the day. Solar energy is present in unlimited amounts, it is a clean source. So, we simply need to find out ways to cultivate this solar energy. So in today's scenario, people are started to focusing on solar energy to cultivating energy and to replace non-renewable energy resources. As per the data from the central electricity authority, total energy cultivated was approximately 4300 MW in 2019 which was risen to 5600 MW means there was a net growth of 1300 MW within one year. Population growth is also the main reason behind the increase in demand for electricity. In 2014, the population of India was 1.2 billion whereas electricity demand was near about 776TWh and according to population forecasting, the population of a country will going to rise to nearly 1.5 billion and electricity demand will go up to 2499TWh.So this gives reason to think about more and more research in the field of solar energy. As per the information available on the internet, till 2015 the installed solar power capacity was 4076 MW. Now, the Indian government has taken the initiative to increase the installed solar capacity up to 100 GW.

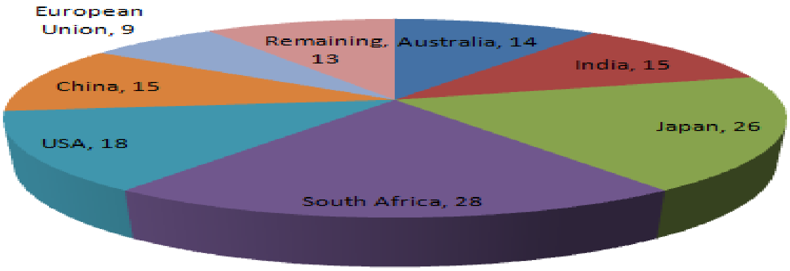

Figure-1.1 Solar Power in Electricity grid in different countries by 2030 (in %)

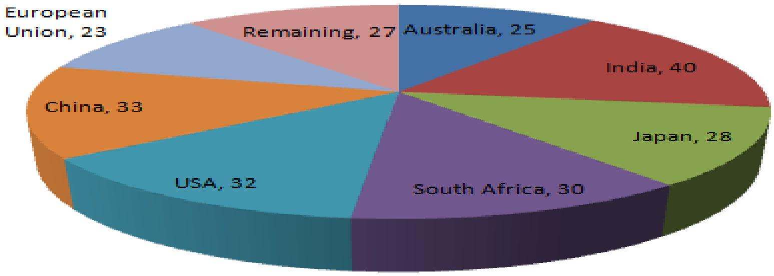

Figure-1.2 Solar Power in Electricity grid in different countries by 2050 (in %)

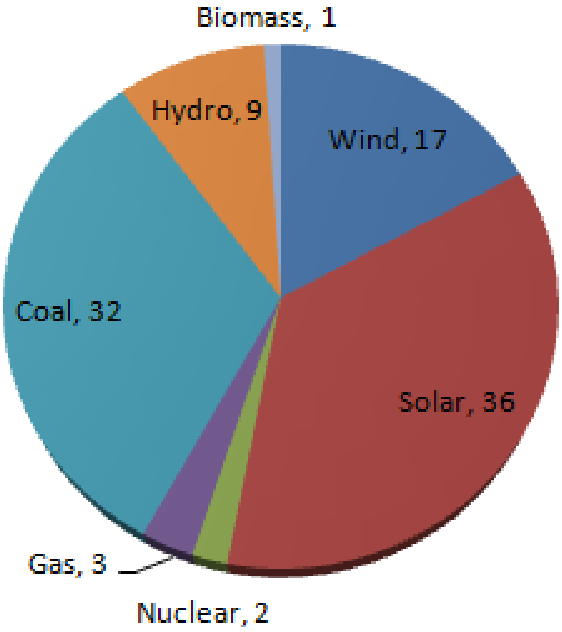

Figure-1.3 Contribution of different sources in energy production

1.4 Motivation

Depletion of fossil fuels and other non-renewable resources and drastic increase in population makes it is very difficult to fulfill our energy demands. We can have so much dependency on non-renewable resources. So, our focus is now shifted towards renewable resources. Cultivation of electricity from solar energy includes the photovoltaic system. But these photovoltaic systems are not having high efficiency and reliability. So we need to figure out the methods to have the maximum solar energy from the PV module for every irradiance and temperature condition. Hill-Climbing algorithms are popular and they become less reliable if the atmospheric conditions like irradiance and temperature are changing often. As a result, some non-linear tools need to design for meeting the control objectives and design specifications.

1.5 Thesis Outline

1. To provide a basic idea about the Photovoltaic effect and Solar Cell Modeling.

2. To understand various components associated with PV systems such as converter, controller.

3. To learn about Nonlinear Characteristics of PV Systems.

4. To understand the working of P&O and InC algorithms.

5. To implement Sliding Mode Controller.

6. To implement Back Stepping Controller with integral action.

7. Analysis of different performance parameters like ideal, PV output power, Converter output power.

1.6 Literature Review

Solar Photovoltaic systems are a vast and relevant topic to be discussed. Many research papers have already been in area of MPPT algorithms. Since solar energy is easily available everywhere and completely free. Due to all these benefits, it is used in many applications. Given that photovoltaic (PV) cells is very important in energy production, many research and development are being carried out to search for the Maximum possible control, as the PV cells feature in nature it is nonlinear[1],[2]. Therefore, the peak point of operation is required, where linear output can be seen. The maximum possible point of operation is known as MPP that ensures the utmost conceivable power generation. There are many approaches available for MPPT [3]. There are many approaches available for MPPT. These methods are P&O, INC, Constant Voltage & Constant Current Methods[5],[6].Here P&O, INC, and SMC methods are discussed In paper [7], [8] P&O MPP Tracking algorithm is studied. In [9] improved perturbation and observation are covered. In Paper [10], the Incremental Conductance Method for MPPT has been studied.[11] An upgraded incremental-resistance MPPT technique which is having changeable step-size for PV systems has been covered.[12] talks photovoltaic pulse charger with very frequency for battery controlled by PI-INC MPPT. In paper [13] Simulation of INC-PIMPPT and this is compared with INC MPPT by direct duty cycle control for photovoltaic covered. In [14] implementation of 'Hill Climbing' and the 'Incremental Conductance' maximum power point tracking techniques for PV power systems has been discussed.In-depth study of P&O and modified InC methodology in solar MPPT has been covered in [15]. [16] Comparison between P & O, Inc and Fuzzy MPPT at various climatic conditions has been covered. Paper [17] talks about the assessment of PV panels connected to Buck-Boost using MPPT & Non- MPPT. Paper [18] covers nonlinear system dynamics and it's controlling with the help of Lyapunov based approach. A relative study between SMC and P&O controlling methodology to MPPT has been discussed thoroughly in [19].Paper [20] talks about SMC for single-phase grid-connected PV system. In [21] design of an SMC for a three-phase grid-connected PV system has been discussed.[22] covers improved design of SMC based on the need for MPPT techniques. A INC MPPT constitute of a variable step-size method for PV Systems has been discussed in [23]. General simulation of SMC in dc-dc converters have been discussed in [24].[25] talks about maximum power point tracker using sliding mode controller for the three-phase grid-connected PV system. An SMC technique for the robust MPPT method for PV cells has been discussed in [26]. SMC with integral action to control the duty cycle of boost converter implemented with the help of microcontroller has been studied in [27]. Discussion of controlling the duty ratio of a boost converter with the help of BSMC has been studied in [28].[29] is having an in-detailed analysis of integral backstepping BSC by using SEPIC. converter.[30]presents the integral backstepping technique for different solar models such as PV with no series & shunt resistance, PV with series and shunt resistance, and PV with constant resistance connected in series.[30]-[31] ameliorate describes the simulation of the nonlinear BSC for the inverter system which is a single-phase grid-connected by the load. The controller is to make correction in the quality factor of the system.[31]also shows the study of the backstepping controller for a single-phase connected grid . A comparative study between two non-linear controllers i.e. sliding mode and backstepping controller has been done in [32].[33]Shows the study of adaptive backstepping methodology for DC-DC buck converter. A comparison is made among different controllers like P&O, proportion integral (PI), neuro-fuzzy, and backstepping controls [34].[35]-[36] discuss the way for searching out the PV reference voltage and after then the extraction of maximum power under various climatic i.e. for different irradiation and temperature conditions and hence improve the performance of the standalone photovoltaic system. A methodology that includes the training of many neural networks and then implementation of the backstepping controller is studied in [37].[38]-[39]describe the backstepping controller connected with a single-phase connected grid system and standalone PV system respectively.[40] describes the control mechanism for a smart grid-connected PV system by using a Backstepping controller. Usage of power obtained from PV panels for pumping of water, the control mechanism was integral sliding mode controller for both ideal and real PV module[41].[42] defines the implementation of the BSC based MPPT technique for solar panels. A grid-connected PV system having a good quality factor controlled by using an advanced backstepping controller is discussed in [43].A discussion about the BSC for standalone PV has been done in [44]-[45].A methodology to provide a non-linear control to a single-phase inverter in a standalone System is described in [46].[48]-[49]describes an effective way for acquiring MPPT. The methodology consists of two loops in cascade first loop is a constitute of changeable step size P&O methods and the second loop is having a robust backstepping controller to eliminate the oscillations. A nonlinear controlling mechanism for single-phase grid connection with PV system has been studied through an LCL filter. The main point of this study is the regulation of DC voltage, supply a sinusoidal current waveform to the grid, and getting maximum power from the PV panel [49].[50] A nonlinear method is studied which comprises of sensor-less MPPT technique for the generation of PWM pulses for induction motor in water pump further backstepping controller with integral action is derived for the maintenance of rotor flux.[51] defines the non-linear controlling mechanism for inverter for backstepping control.[52] In this paper, a non-inverting buck-boost converter is used for interfacing circuit for PV Module & load, and a backstepping approach is used for controlling purposes.

CHAPTER 2

MODELING OF SOLAR CELL AND BOOST CONVERTER

2.1 Introduction

Due to impedance mismatch between the load and PV side, utmost power is not able to be provided to the load. So to get MP, the impedance of PV array can be made equal to load side; a DC-DC converter is required. It has been analyzed that the effectiveness of Boost type converter is higher than Buck-Boost converter. Buck type converter is having minimum efficiency.

Any type of converter is generally used such that intrinsic impedance of PV Panels will be equal to intrinsic impedance of load, so that utmost transfer of power can occur. MPPT controllers achieve this by varying the duty ratio of converters so that the system operating point is always at its MP.

2.1.1 Photovoltaic Phenomenon

Whenever radiation of a particular frequency range which must be greater than threshold frequency falls on the junction of two dissimilar semiconductor materials a terminal potential difference across the junction is generated, this all-over effect is known as the photovoltaic phenomenon.

The photovoltaic effect phenomenon can be described as:

1. When an energy packet which is also known as photons of suitable energy is rivet by material, a junction is formed.
2. The charges are disparate sweeping through the junctions.
3. The assemblage of this charge is collected at terminals which creates a potential difference.
4. A sheet is placed towards the end of the absorber to segregate the charge. The

sheet is required so that it allows the entrance of one type of charge only.

2.2 Solar Cell Equivalent Circuit

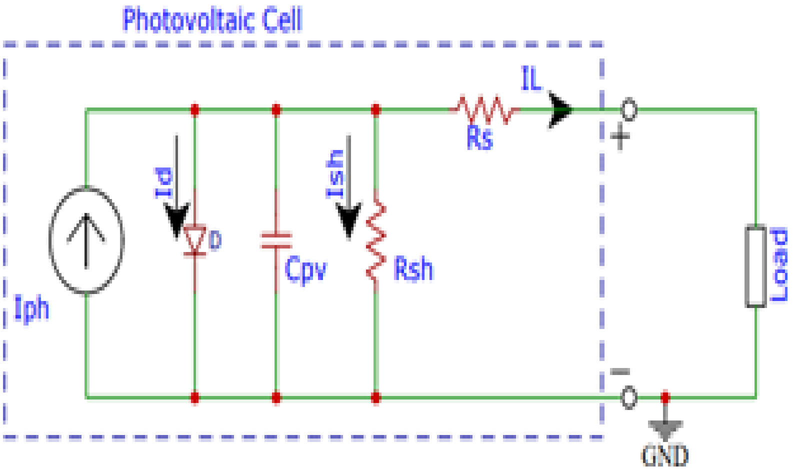

Figure-2.1-Equivalent of PV cell

The above circuitry can be implemented as a single cell. It is having current source (Iph), diode (D), & resistance connected in series (Rs). This is the resistance present inside each cell.

Value of Iph can be calculated by the below equation-

$I_{ph}=I_{pv}-I_D-Ish$

By neglecting the effect of two resistances Rs and R_{sh}, the final equation of current can be written as

$$=I_{PV} - I_o\{\exp(^{e(V_{PV}+\, I_{PV}\, Rs)/\eta KT)}) - 1\} \qquad (1.1)$$

PV module is traditional source. PV cell is having a non-linearity between its current and voltage at output side. These quantities are having a logarithmic relationship. PV panel voltage can be given by-

$$V_{pv} = V_{Thermal} * \ln\,(I_{ph} - I_{pv}/I_{\text{saturation}}\,) \qquad (1.2)$$

Where $V_{Thermal}$ and $I_{saturation}$ are the thermally generated voltage and dark saturation current respectively. $V_{Thermal}$ is preferably estimated by electrical characteristics of the PV module. On avoiding shunt current under OC conditions can be rewritten as:

$$I_{ph} - Io\{\exp\left(\frac{V_{oc}}{n_s V_t}\right) - 1\}=0$$

The open-circuit voltage can be written as

$$V_{oc} = n_s V_t \ln \left\{\frac{\mathrm{I_{ph}+I_{d}}}{\mathrm{I_d}}\right\}$$

Where,

$$\mathrm{V_t}= \frac{AK_bT}{e}$$

$$I_0 = I_{or}\left(\frac{T}{T_{ref}}\right)^3 \exp\ \left\{\frac{\mathrm{qE_g}}{\mathrm{n_s K_b T}}\left(\frac{1}{\mathrm{T_{ref}}} - \frac{1}{\mathrm{T}}\right)\right\} \qquad (1.3)$$

2.3 Dependency on Irradiance and Temperature

Key factors on which is affects performance of PV Cell-

(i). Irradiance

(ii). Temperature

Changes in the I-V graph are observed below the plot for the different values for irradiations. It can be concluded that if irradiation changes, variation in the open circuit is lesser as than short circuit.

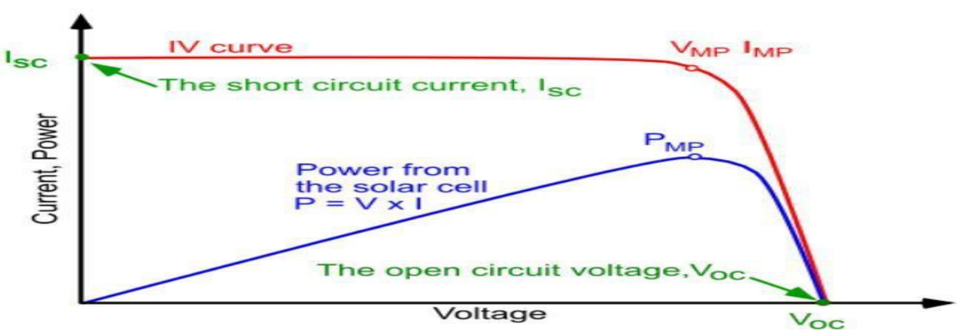

Figure-2.2 Characteristics of PV Cell

The reason behind this is that short circuit current is having a dependency on photo generated current and that is having a dependency on various levels of irradiance.

The relationship between photonic current, short circuit current, and temperature is given by-

$$I_{ph} = (Isc + K_i(T - Tref))\frac{G}{1000}$$

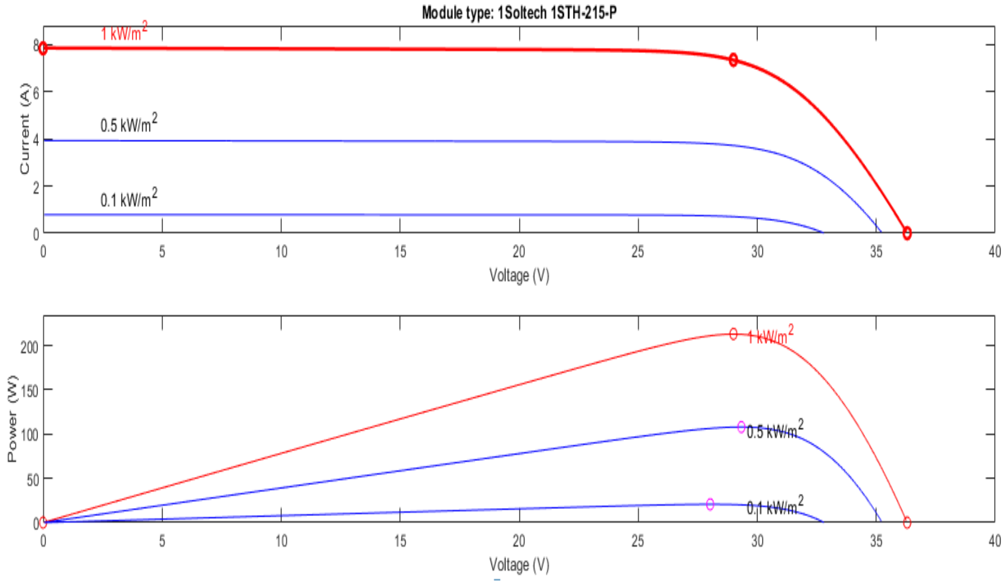

Figure-2.3 Current & Power plot of PV Cell for various irradiation level

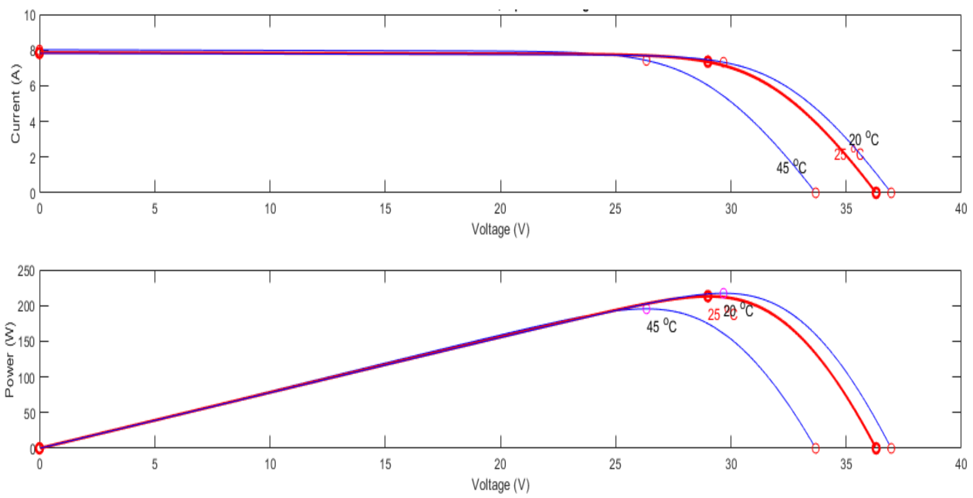

Figure-2.4 Current & Power curve of PV Cell for various temperature

2.4 Requirement of Converter for PV System

There is always an impedance mismatch between load and PV side so a transfer of maximum power doesn't take place to load. According to MPT for the transfer of utmost power from a source to load, impedance of source should be equal to load (in case of resistive load). There are several kinds of a converter like a boost, buck, buck-boost type converter, etc. In these, the efficiency of boost converter is higher than that of a buck converter. So, we can connect a solar panel to these converters for matching of source and load impedance i.e. PV panel impedance can be matched to load impedance. This entirely can be obtained by making variations in the duty ratio of the converter.

The basic controlling schematic is given below-

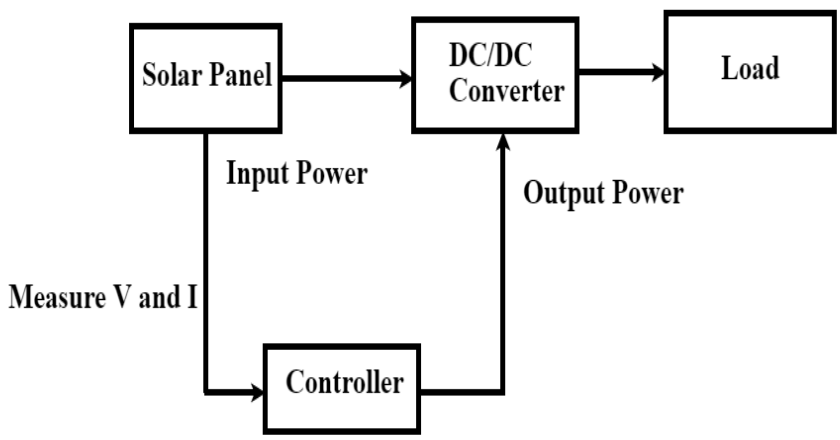

Figure-2.5 Basic Schematic of Controlling Mechanism

2.5 PV with Boost Converter

Input of DC/DC converter is DC and output is also a DC value of different level so as a result it converter DC input voltage of one level into a DC voltage of another level. For the safer operation of several equipments, one voltage level is converted to another by DC/DC converter.

Among the different converter topologies, the converter used in this project is a boost, because it is higher efficiency.

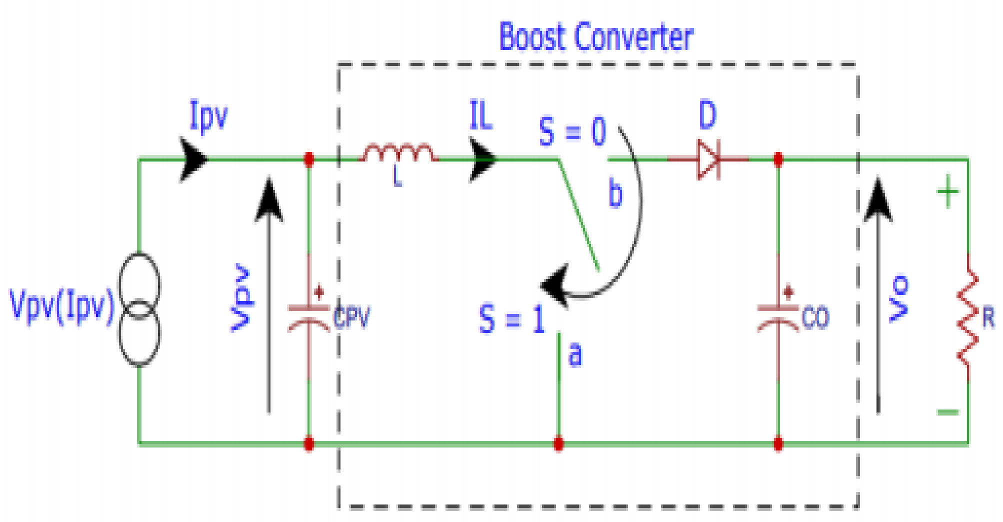

Figure-2.6 PV with Boost Converter

The state-space technique is used to carry out mathematical modeling of the system.

2 sets of state-space equations can be used to express the system which is entirely based od switch S's position.

When position of switch is at b i.e. S=0(OFF) system dynamics is:

$$\frac{dI_L}{dt} = \frac{V_{pv}}{L} - \frac{V_o}{L} \tag{2.2}$$

Time rate of change of voltage at output side of boost converter

$$\frac{dV_o}{dt} = \frac{I_L}{C_o} - \frac{V_0}{C_0 R} \tag{2.3}$$

According to theory of PWM, the ratio of switch position at point a to total time is defined as duty ratio.

If we "d" is considered as the duty ratio for the signal "u" has given to switching MOSFET, system dynamics is described as-

$$\frac{dI_L}{dt} = \frac{V_{pv}}{L} - (1 - d)\frac{V_o}{L} \tag{2.4}$$

$$\frac{dV}{dt} = \frac{I_L}{C_o}(1 - d) - \frac{V_o}{C_o R} \quad (2.5)$$

Where $0<d<1$

CHAPTER 3

PERTURB AND OBSERVE TECHNIQUE FOR MPPT

3.1Introduction

P&O technique is a very simple to implement and most generally applied method. This MPPT technique is also coming under the category of the Hill-Climbing (HC) algorithm. This is one among the old and popular methods which indeed very fine weather condition is stable i.e. when there is minimal variation in irradiation levels or if irradiation level is constant. The key distinction between P&O and HC algorithms is that HC requires a variation in duty cycle of converter. Other side around, P&O interrupts the operating voltage of PV module.

3.1.1 Working

P&O algorithm includes the continuous and periodic perturbation of panel voltage increasingly. Then the power is determined and the distinction between the magnitude of power at a present instance and a previous instance is observed. If the power difference between two consecutive cycles is positive then a small amount of perturbing value is added and then again the value of power is calculated.

The process of addition of small perturbing value is done until the difference between two consecutive powers negative. If the difference value comes out to be negative then the perturbing direction is changed. When an operating point is on left side of MPP then the P&O methodology results in increasing voltage value, which in turn increases in output power.

When the operating voltage at right side of MPP, the working direction of P&O is changed i.e. by subtracting the small perturbing value, thus the voltage value decreases. This perturbing concludes in an increased value of $dp/dv > 0$, which implies that operating point is goes apropos MPP. Successive disturbance will be in corresponding direction to make the operating point move towards MPP until it is obtained.

Now, if these perturbing shows decrement such that dp/dv < 0, it means that the operating point is moving away from MPP, then direction of perturbation will be in opposite direction. This algorithm regulates Panel voltage which corresponds to MPP. This MPP is under tracking to update and ensuring the power expression and voltage slope curve such that dp/dv < 0. The dp/dv is obtained by sampling the panel voltage and current at current (i) and antecedent (i-1) instances. The dP/dV can be defined by-

$$\frac{dp}{dv}(i) = \frac{p(i) - p(i-1)}{v(i) - v(i-1)}$$

P&O methodology uses two sensors so that we can find the value of voltage and the current value of the module.

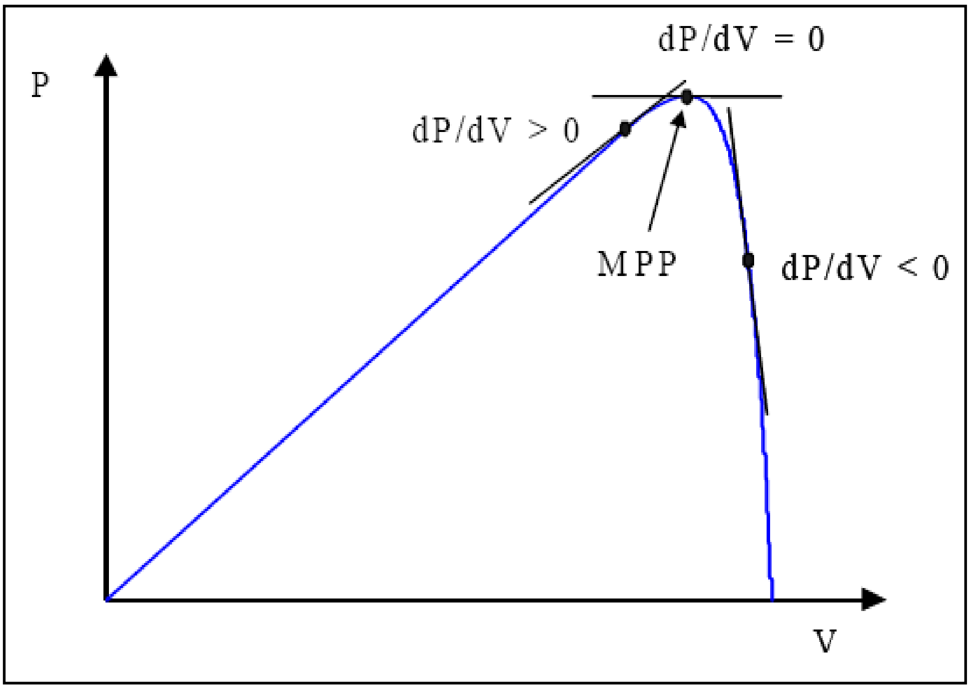

Figure 3.1: Graph of PV Panel power

A complete summarization of the above-described algorithm can be done in following below given table which is further perturbation steps corresponding to the value infinitesimally disturbance in voltage value which also indicate the corresponding variation in power.

Table I Summary Table

Serial no	Disturbance in Voltage *dv*	Power Variation *dp*	Further Perturbation
I	$dv > 0$	$dp > 0$	Forward
Ii	$dv > 0$	$dp < 0$	Backward
Iii	$dv < 0$	$dp > 0$	Backward
Iv	$dv < 0$	$dp < 0$	Forward

Case1 shows that when a change in voltage is positive, resultant power is also positive. A smaller positive perturbation value is added in a further direction. Case 4 shows that when variation in operating voltage is negative, which concludes decrement of power at output side so further required action must be the forward direction, i.e. to increment the voltage. In detailed information of P&O methodology can be analyzed according to the below flowchart -

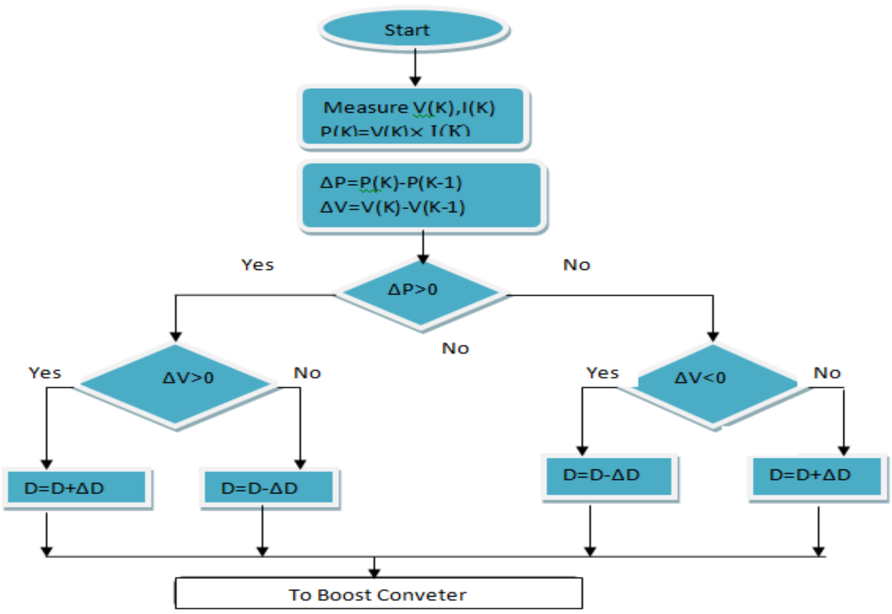

Figure-3.2 Flowchart of P&O Methodology

As per the P&O methodology, the power value is calculated for each cycle with the help of multiplication obtained by the output of current and voltage sensors. Now, we check these calculated values if power & voltage difference is coming out to be a positive value then this technique increases the operative voltage but if the value of the difference is coming out to be negative the process is reversed.

3.2 Analysis of P&O Methodology

Specificity of technique lies in point that the voltage must be changed by a small amount in every cycle to extract the maximum power. But when MPP is achieved, it is continuously showing oscillations around the reference voltage. Power loss, is caused by these oscillations that is in turn depending on step value of perturbation.

If step size is chosen to be a large value, the P&O execution is happening at a high speed but more fluctuations and oscillations are observed. But if the smaller value of step size is chosen then the oscillation is reduced to a greater level. Hence but this makes the dynamics of a system becomes very slow especially when the system undergoes expeditious variations. It can be observed that small step size hampers speed of the system i.e. makes the system sluggish while large step size leads to bad steady-state performance.

The acceptable step size can be selected as per the system and is found experimentally, as discussed by Xiao.

However, P&O methodology may fail in the case when the system is subjected to sudden variations in atmospheric conditions and stops working precisely. But in the case of relatively small variation in irradiation condition and the region of irradiation curve which is not changing or remain constant, the p& O work in an appropriate manner.

But in region of irradiation curve which is having step variation or very sudden and large variations, the suitability of P&O decreases. Output of P&O power curve is having noticeable oscillations. This observation can be made by graphical analysis done in the results section by P&O methodology.

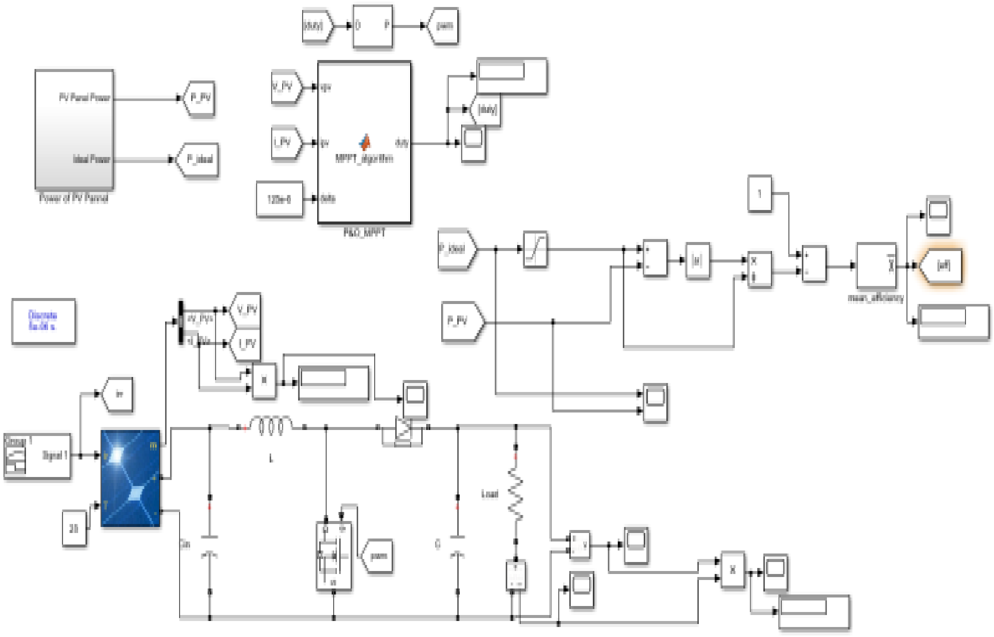

Figure-3.3 Simulink Diagram of P&O Methodology

3.3.1 Advantages of P&O Methodology -

1. P&O Circuitry is straightforward to implement.

2. It is of low cost and it needs to be knowledge of voltage and current of module.

3. It is effective when the insolation variations are slower.

3.3.2 Disadvantage of P&O Methodology –

1. When Circuit with P&O reaches MPP, it starts to oscillate around that point which results in the power losses in PV.

2. P&O works are suitable for low variations and constant irradiation only.

3. Its accuracy is decreased when the MPP is reached.

4. A lower value of step size used for perturbing results in high correctness but affect the dynamic performance.

5. Large step size results in lesser time tracking of MPP but steady-state performance is decreased.

3.3 Observation with P&O

3.3.1 Input Signal to PV Module

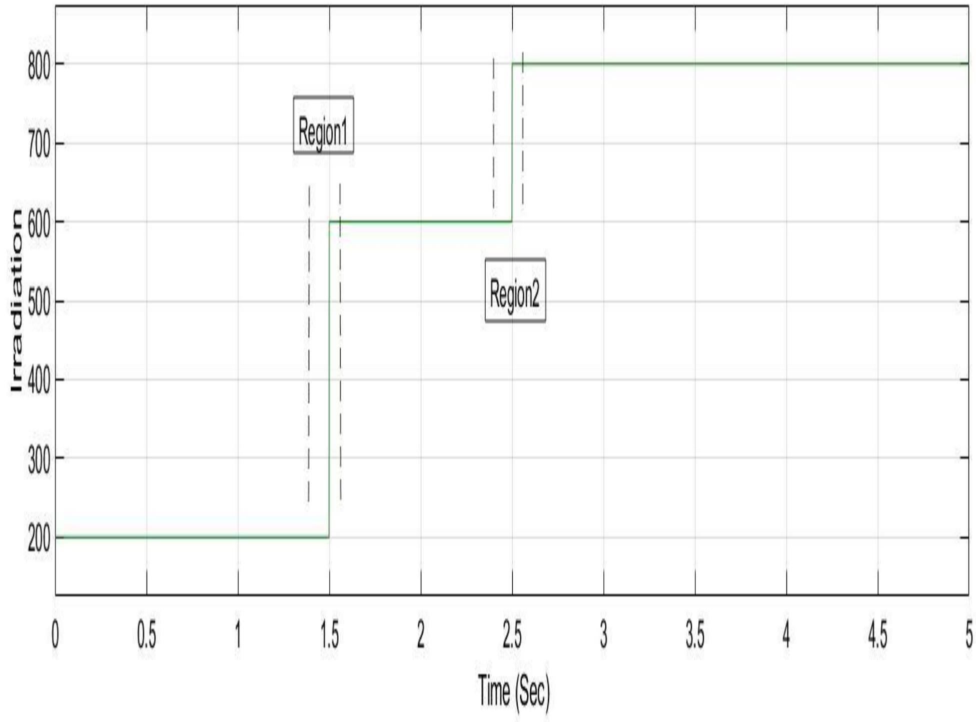

Figure-3.4 Input irradiation Curve

Region1: Sudden and large change in irradiation

Region2: Sudden and Comparatively small change in irradiation

3.3.2 PV and Boost converter Output Current

Fig.3.5 presents PV & Boost Converter current values under various region of irradiation. A clear observation is made in region 1 of the irradiation curve (Figure 3.4), where the irradiation is having sharp and large increment, the oscillations in PV current is also high whereas, in region 2 of irradiation Curve where there is a sharp but relatively small change in irradiation value, the oscillation is less as compared to the previous case of irradiation.

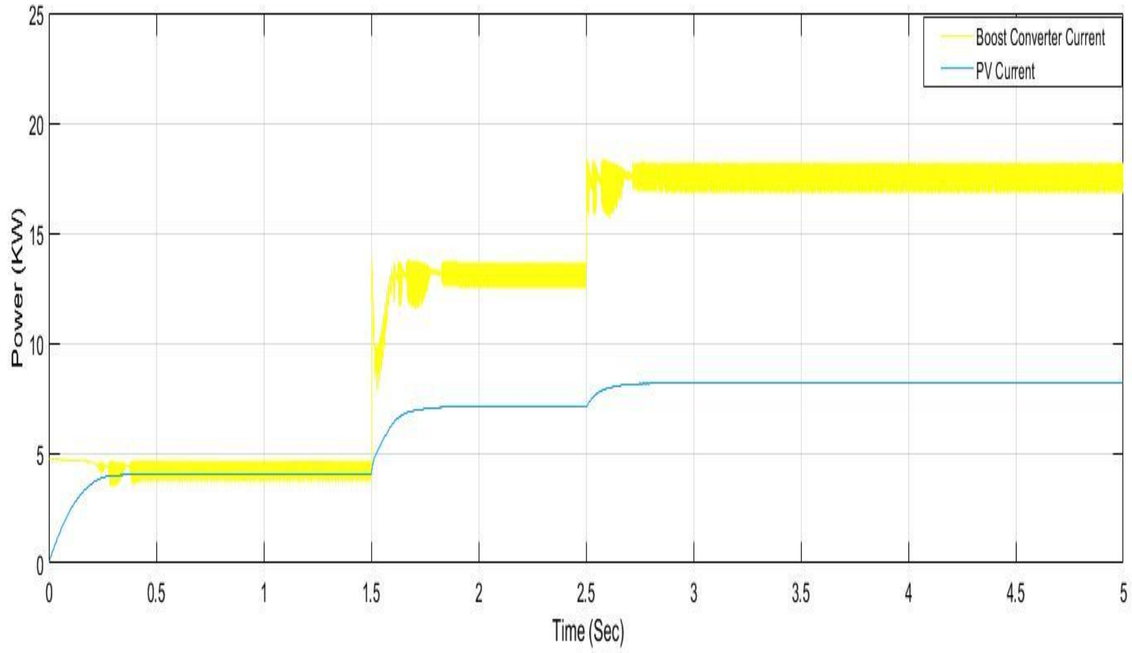

Figure-3.5 PV and Boost converter Output Current

3.3.3 PV and Boost converter Output Voltage

Fig.3.6 presents PV and Boost Converter Voltage values under various regions of irradiation. The input voltage to the converter is around 120 V which is boosted to a level such that power at input side of the boost converter can be made equal to its power at output side.

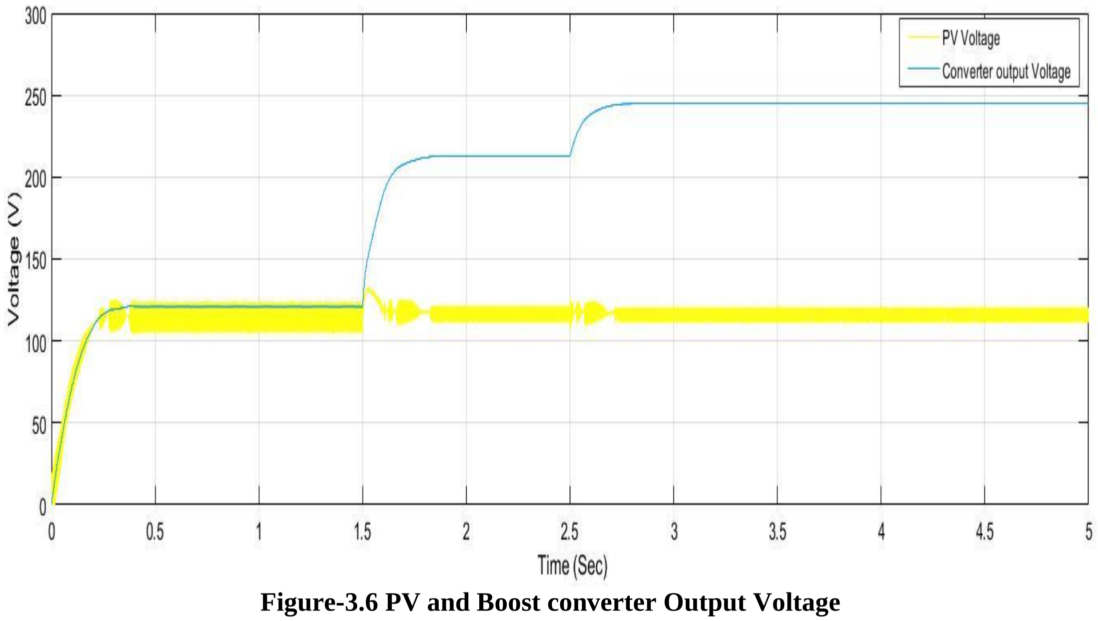

Figure-3.6 PV and Boost converter Output Voltage

3.3.4 PV and Boost converter Output Power

Fig.3.7 presents PV & Boost Converter Power values under the various regions of irradiation. A clear observation is made in region 1 of the irradiation curve (from fig 3.4), where the irradiation is having sharp and large increment, the oscillations in PV power is also high whereas, in region 2 of irradiation Curve where there is a sharp but relatively small change in irradiation value, the oscillation is less as compared to previous case .

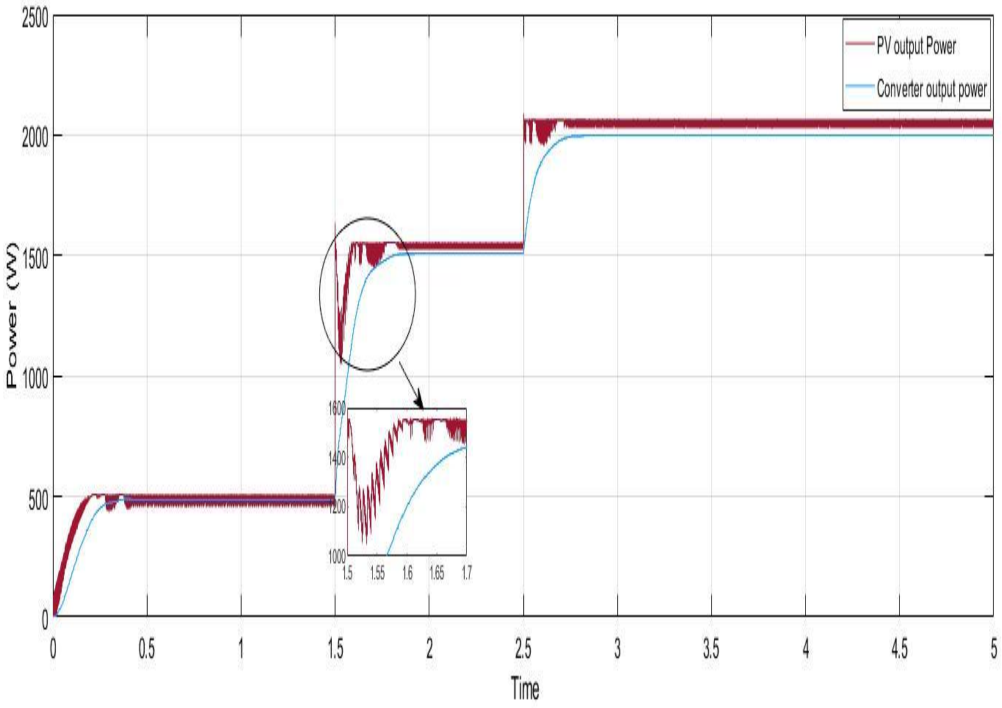

Figure-3.7 PV and Boost converter Output Power

CHAPTER 4

INCREMENTAL CONDUCTANCE METHOD

4.1 Introduction

The InC technique is used to bridle of P&O methodology when it is operating in rapidly varying atmospheric conditions. With the help voltage and current sensors, value of voltage-current would be found out, conductance is a ratio of current to voltage, and incremental change in conductance *dI/dV* is obtained so that we can be decide whether operating voltage and current are to be incremented or decremented by the position of the operating point is being left or the right of the MPP respectively.

4.1.1Working

Principle of InC technique depends on magnitude of the slope of module power plot is negative on the right of MPP, 0 at MPP, and positive on the left of MPP as shown below-

dp/dv > 0 left of MPP ($V< V_{MPP}$)

dp/dv = 0 at MPP ($V=V_{MPP}$) (2.3)

dp/dv < 0 right of MPP ($V<V_{MPP}$)

since P=VI, Power plot slope is

$$\frac{dP}{dV} = \mathrm{I}\frac{dV}{dV} + V\frac{dI}{dV} = \mathrm{I} + \frac{\mathrm{dI}}{\mathrm{dV}} = 0$$

$\frac{dI}{dV} < -\frac{I}{V}$ right of MPP

$\frac{dI}{dV} = \frac{-I}{V}$ at MPP

$\frac{dI}{dV} > \frac{-I}{V}$ left of MPP

Incremental conductance (InC) technique gives enough detail to define the location of MPP. All over procedure is done utilizing the measurement and comparison of *dI/dV* & *I/V* so that module can be operated at a set reference voltage corresponding to the MPP The detailed working principle of InC technique can be achieved employing the following flow chart.

Complete Schematic of implementation InC method is given below-

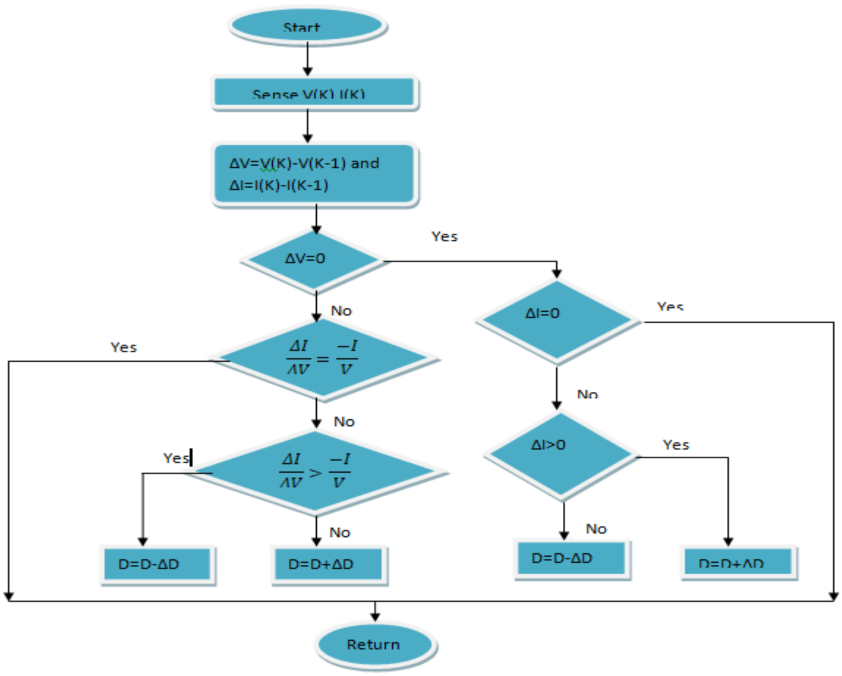

Figure-4.1 Flow Diagram of InC Technique

As per the InC technique, the voltage and current values are observed at this and old state, then a test is done to balancing the condition *dI/dV* + *I/V* = 0 at MPP. Main work of InC algorithm is to increase and decrease the voltage value as per the difference in the currency according to *dI/dV* + *I/V* is superior or inferior at zero respectively.

4.2 Analysis of InC Technique-

InC technique works finer than P&O under varying weather conditions. Its major advantage is that it shows relatively fewer oscillations when MPP is reached. As per the above flowchart. If the condition *dI/dV* = *-I/V* is satisfied there will be no changes needed in operating voltage and current, the MPP is already reached. The condition dI=0 makes it bypass the process of adjusting the perturbation of step cycle ruled out. According to the INC principle $|\frac{dI}{dV}+\frac{I}{V}| > 0$ & dI > 0 decide the location of MPP.

This methodology ensures that initial corrections must be in the proper direction to rule out the case of trial and error as observed in the P&O algorithm.

Fast and right output from the system can be expected from this methodology and this is having higher efficiency when a collation is made concerning the P&O method. If the subtraction of two consecutive values of currents is not resulting in zero as per the flow chart, in this case, a test condition is established such that if the difference value of two currents value is coming out to be positive, the system is working at the left or right of MPP and more modification in voltage has been done.

A number of experiments concluded that there are always some oscillations are present in weather and the condition that the differentiation of power with respect to zero is not achievable in practical cases. These oscillations are because of assumption for dV, dI difficulty in maintaining the V to exactly at V_{MPP} while considering a perturbing step size. There is adjudication between tracking in lesser time & accuracy which is entirely dependent on the selection of step size. An effective solution can be carried out by generating an error signal with the help of dI/dV and I/V. An error can be used by I/V + dI/dV. The magnitude of difference can be optimized by considering the oscillation around MPP.

4.2.1 Advantage of InC Method -

1. It shows more effectiveness at higher solar irradiation levels when a comparison is made with respect to P&O methodology.

2. It shows lesser oscillations when compared with P&O methodology.

3. Have more reliability when compared to P&O method.

4.2.2 Disadvantages of InC Method -

1. Implementation wise it is more complicated when compared with the PO.

2. It is mandatory to have information about PV voltage & current.

3. If magnitude of fixed-step is made to decrease to achieve effectiveness of hounding, performance hampers due to which system becomes sluggish resulting in adjudication.

Complete Schematic of Implementation of Incremental Conductance is given below-

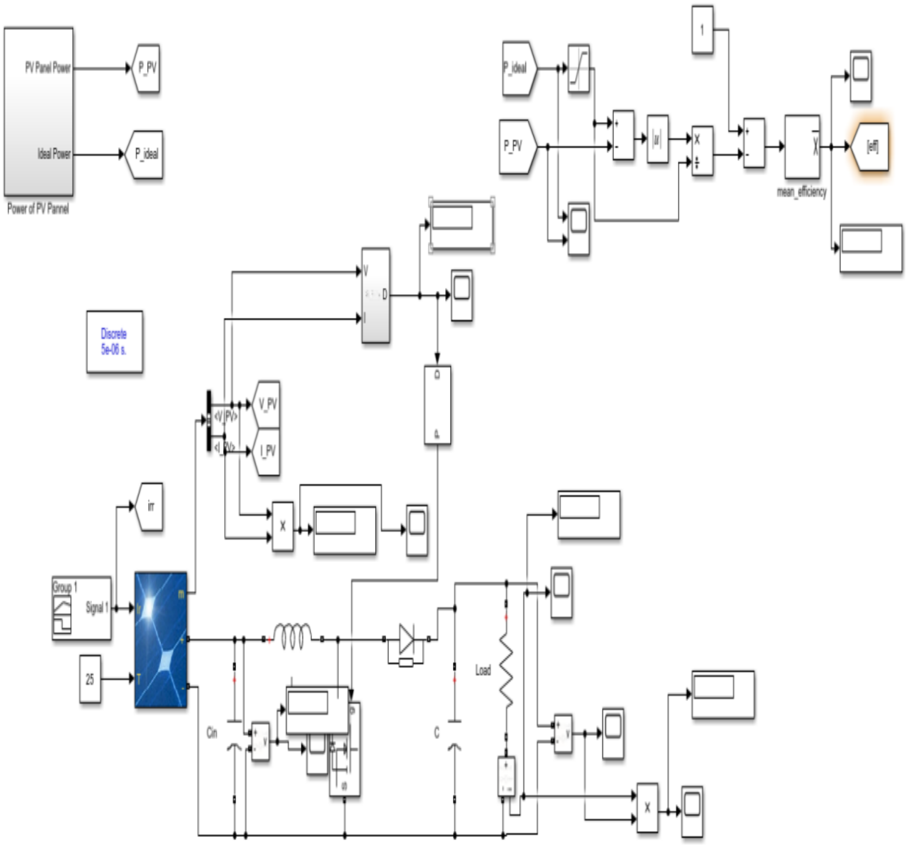

Figure-4.2 Simulink model With InC MPPT

4.3.1 PV and Converter Output Current

Fig.4.3 presents PV & Boost Converter current values under a various region of irradiation. A clear observation is made in region 1 of the irradiation curve (from fig 3.5), where the irradiation is having sharp and large increment, the oscillations in PV current is also high but lesser than that of P&O outputs whereas, in region 2 of irradiation Curve where there is a sharp but relatively small change in irradiation value, the oscillation is less as compared to the previous case.

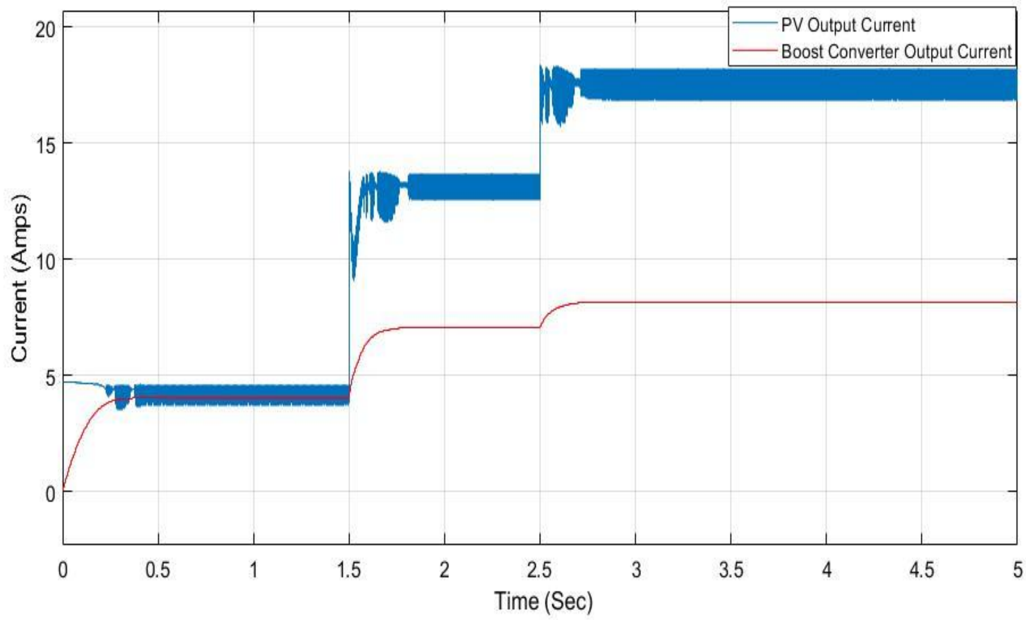

Figure-4.3 PV and Converter Output Current

4.3.2 PV and Converter Output Voltage

Fig.4.4 presents PV & Boost Converter Voltage values under a various region of irradiation. The input voltage to the converter is around 120 V which is boosted to a level such that power at input side of boost converter can be made equal to its power at output side.

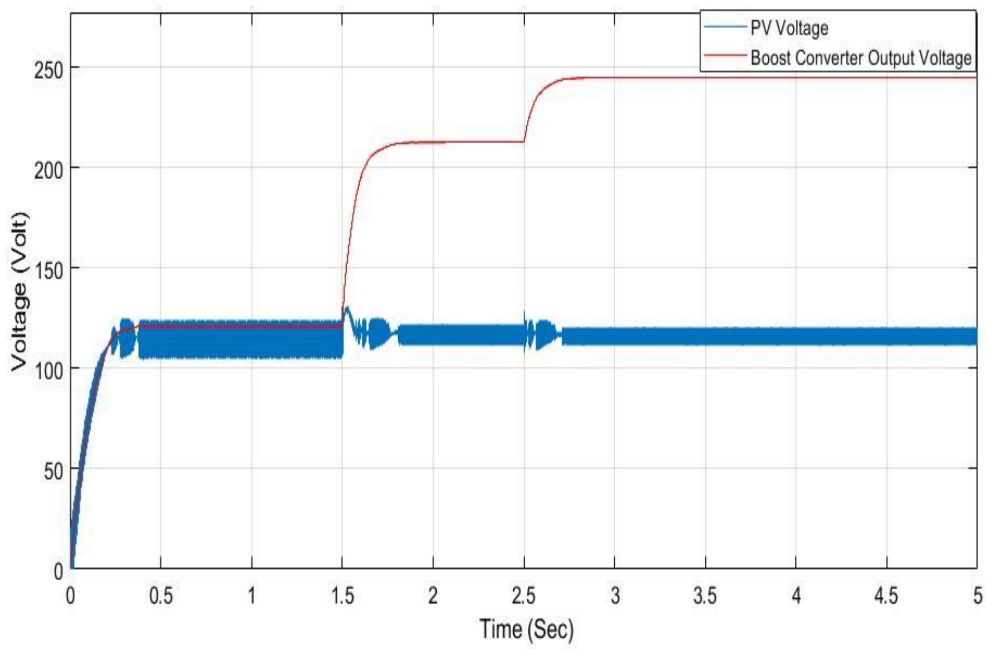

Figure-4.4 PV and Converter Output Voltage

4.3.2 PV and converter output power

Fig.4.5 presents PV and Boost Converter Power values under a different region of irradiation. A clear observation is made in region 1 of the irradiation curve (from fig 3), where the irradiation is having sharp and large increment, the oscillations in PV power is also high but lesser than that of oscillations in P&O whereas, in region 2 of irradiation Curve where there is a sharp but relatively small change in irradiation value, the oscillation is less as compared to previous case.

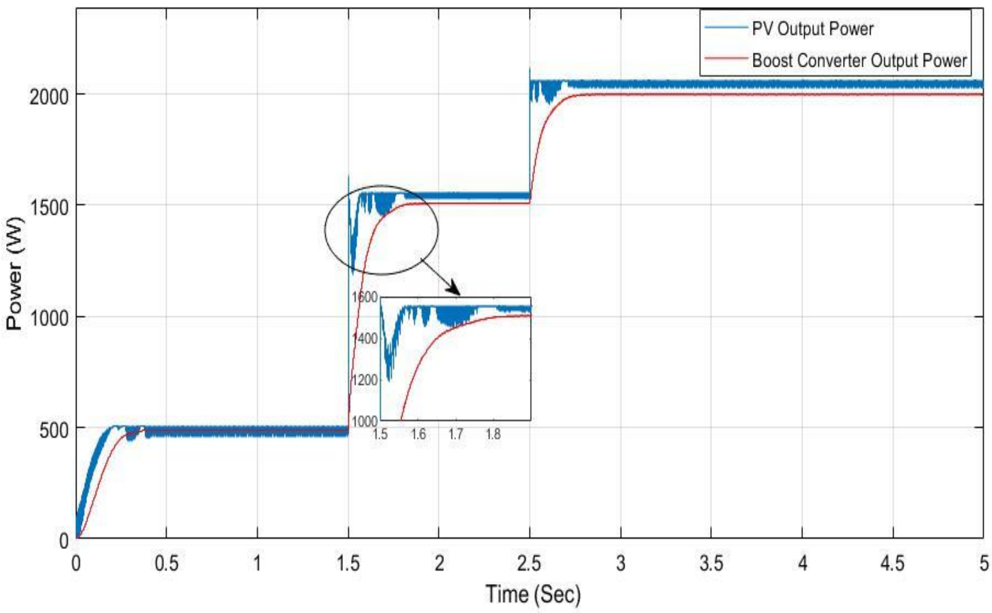

Figure-4.5 PV and converter output power

CHAPTER 5

SLIDING MODE CONTROL METHOD

5.1 Introduction

In earlier lesson, we discussed the P&O methodology & InC methodology for MPP tracking and here in this chapter, we are describing the implementation of a SMC to make the system work near the operating point so that utmost power will be obtained. SMC is a non-linear controller i.e. it is based on non-linear control theory. Implementation of sliding mode includes two key steps of determination of sliding surface and a proper controller which makes the system follow the predefined sliding surface such that the system can work properly and can achieve the required output from the system.

5.2 System Modeling

PV module is connected at input side of boost converter as shown below figure 5.1.

PV with Boost type converter schematic is presented in the Figure. Irradiation and temperature are 2 key points upon which power to PV array is depends.

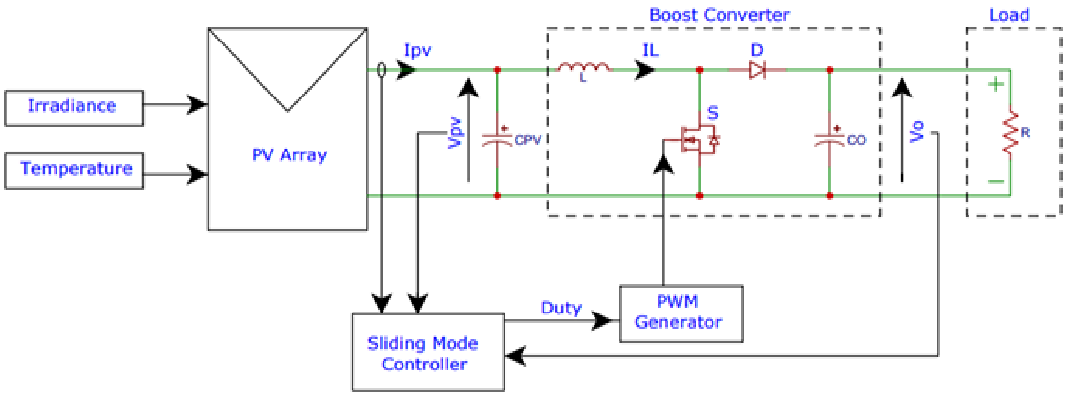

Figure 5.1 PV system with Boost Control Schematic

5.2.1 Controller Design

The first main step is involving the selection of a surface that ensures the trajectories of a system to strike that surface. Firstly, it includes selection a surface which will guarantee move system trajectories to be on the surface and produces hence utmost power can be obtained continually. The surface can be chosen such that maximum power can be acquired.

Selection of sliding surface is made so as the utmost power can be obtained as shown in Fig 3.2. So the surface of sliding can be obtained through-

$$\frac{\partial \mathrm{P_{PV}}}{\partial \mathrm{I_{PV}}} = 0 \qquad (5.1)$$

Now,

$$\frac{\partial P}{\partial I} = \frac{\partial\left(I_{PV}^{2} * R\right)}{\partial I_{pv}} = I_{pv}\left(2R_{pv} + I_{pv}\frac{\partial R_{pv}}{\partial I_{pv}}\right)$$

Here $Rpv = Vpv/Ipv$ define the load-connected PV system. So, the surface can be defined as-

$$\sigma = 2R_{pv} + I_L\frac{\partial R_{pv}}{\partial I_L} \qquad (5.2)$$

$R_{pv} =$ Dynamic resistance of the system

Here an assumption is made $\boldsymbol{Ipv} \cong \boldsymbol{I_L}$The below diagram defines that a switching surface can be selected such that the utmost power can be acquired productively.

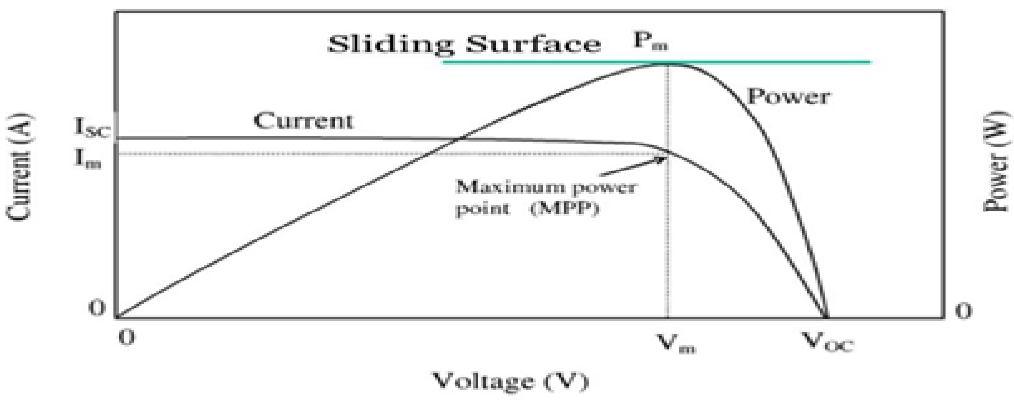

Figure-5.2 Selection of sliding surface

Duty cycle updation can be done for govern operation as depicted in Fig. 3.3, can be expressed below-

$$\text{dupdate}=\begin{cases} d-\Delta d & ,\sigma<0 \\ d+\Delta d & ,\sigma>0 \end{cases} \tag{5.3}$$

The equivalent control can be determined from -

$$\sigma^{\cdot}=\frac{d\sigma}{dt}=0$$

$$=\frac{d\sigma}{dt}\frac{dI_{pv}}{dt}=0$$

$$=\frac{d\sigma}{dt}*\dot{I}_L=0$$

$$=\frac{d\sigma}{dt}*\left[\frac{V_{pv}}{L}-(1-deq)\frac{V_o}{L}\right]=0$$

The solution for duty cycle can be derived as-

$$d_{eq}=1-\frac{V_{pv}}{V_o} \tag{5.4}$$

The actual control signal can be described-

$$d'=\begin{cases} 1 & d_{eq}+Ksign(\sigma)\geq 1 \\ d_{eq}+Ksign(\sigma), & 0<d_{eq}+Ksign(\sigma)<1 \\ 0 & d_{eq}+ksign(\sigma)\leq 0 \end{cases} \tag{5.5}$$

5.3 Observations with SMC

5.3.1 PV and converter output current

Fig.5.3 presents PV & Boost current values under the various regions of irradiation. It can be observed is made in region 1 of irradiation curve (from fig 3), where the irradiation is having sharp and large increment, the oscillations in PV current is also high whereas, in region 2 of irradiation Curve where there is a sharp but relatively small change in irradiation value, the oscillation is less as compared to the previous case.

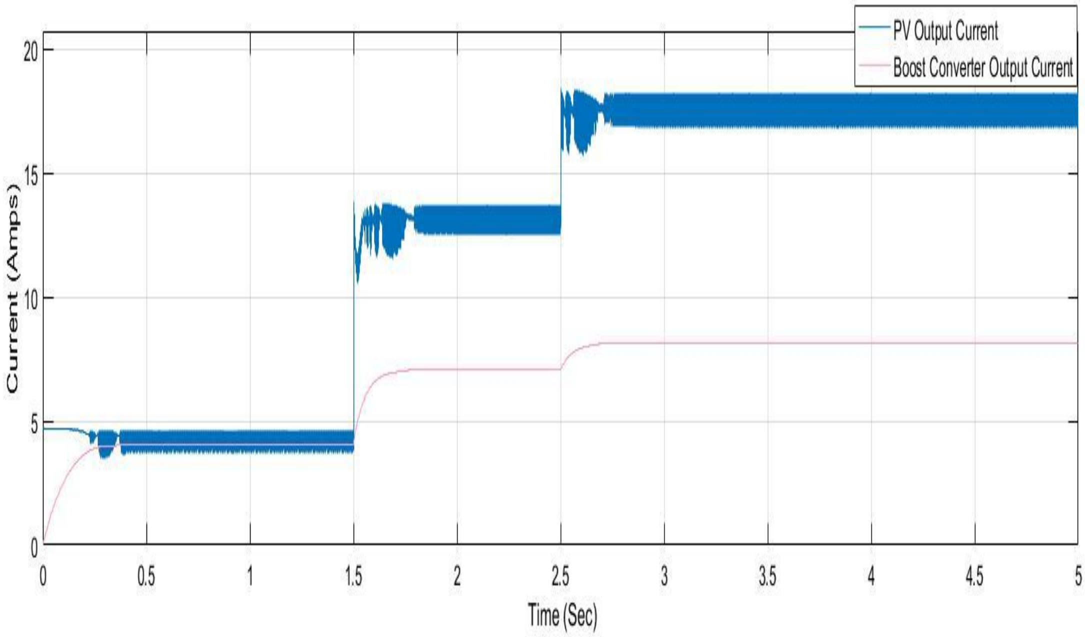

Figure-5.3 PV and converter output current

5.3.2 PV and converter output voltage

Fig.5.4 presents PV & Boost Converter Voltage values under various regions of irradiation. The input voltage to the boost is approximately 120 V which is boosted to a level such that power at the input side of the boost converter can be made equal to power at the output side.

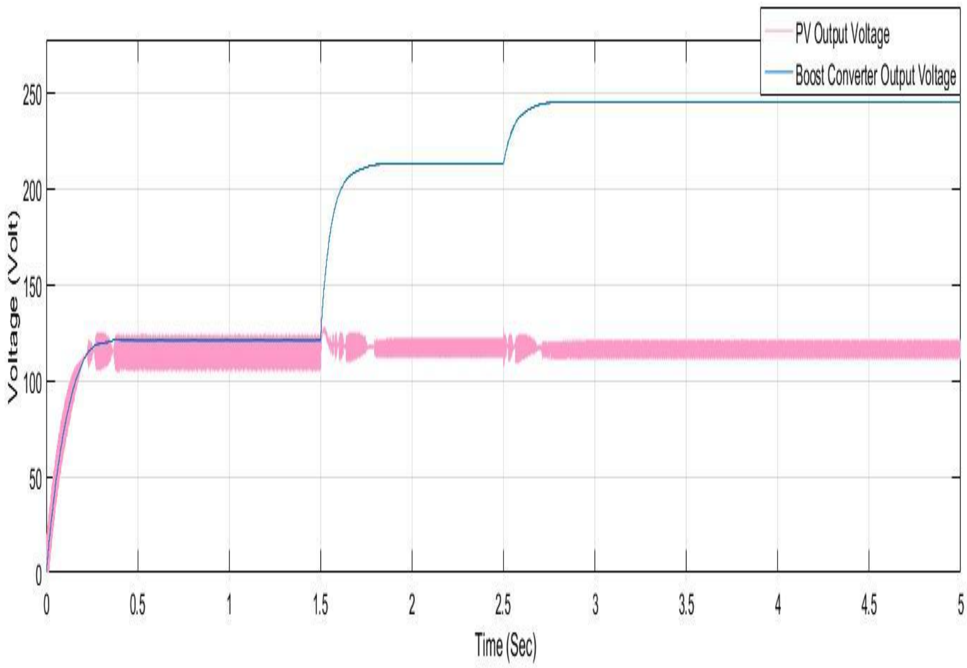

Figure-5.4 PV and converter output voltage

5.3.3 PV and Converter Output Power

Fig.5.5 presents PV & Boost Converter Power values under the various regions of irradiation. A clear observation is made in region 1 of the irradiation curve (from fig 3), where the irradiation is having sharp and large increment, the oscillations in PV power is high (but lower when compared with P&O) whereas in region 2 of irradiation Curve where there is a sharp but relatively small change in irradiation value, oscillation is less as compared to previous case.

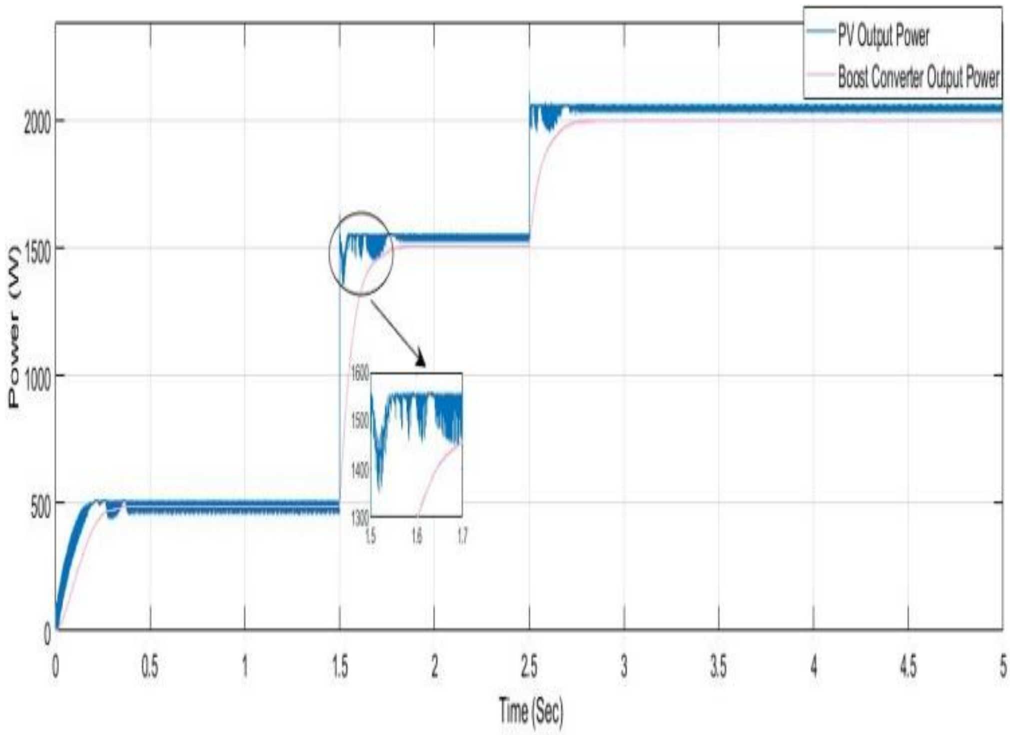

Figure-5.5 PV and converter output Power

CHAPTER -6

BACKSTEPPING CONTROLLER WITH INTEGRAL ACTION

6.1 Introduction

We have already discussed the implementation of a conventional sliding mode controller which comes under non–linear control theory-based controller to have utmost power from PV. Here in this chapter, we are going to deal with the theory and implementation of the integral backstepping controller. The most primary step in designing this controller is the selection of the proper Lyapunov function which provides the non-linear feedback control action. This controller provides robust control to the entire system. The second major steps involving in this simulation are the selection of stabilization function which is taken as a reference to minimize the tracking of maximum power from the panel. The control action is done with the help of the development of suitable control law. For a controller, to exist the first derivative of the previously chosen function must be negative ($\dot{V} \leq 0$).

Designing of Integral Backstepping controller involves the selection of Lyapunov function and then deriving a suitable control law to make first differentiation of scalar energy Lyapunov function negative.

These steps are followed while designing the controller-

1. Incremental Conductance method is used to find the error dynamics which is associated with voltage.

2. Based on the above-calculated error dynamics a suitable Lyapunov function in selected.

3. Examine the first differentiation of Lyapunov function, it must be negative.

4. Ensure the final Control law depends on the Lyapunov function.

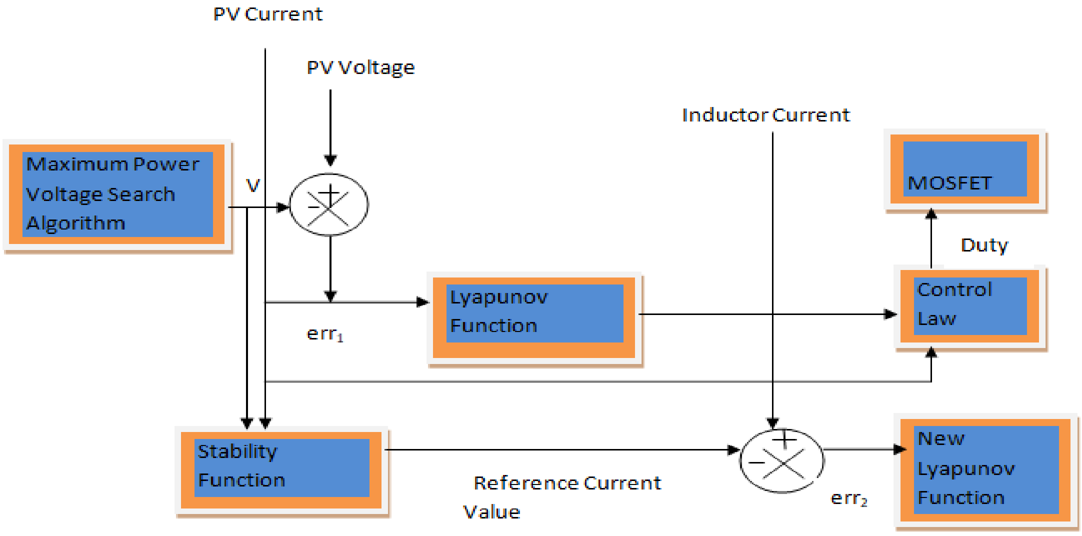

Figure-6.1 Diagram of Backstepping Controller with integral action

From Equation (2.1) and (2.2), (2.3),(2.4)System-

$$\frac{dI_L}{dt} = \frac{V_{pv}}{L} - \frac{V_o}{L}$$

$$\frac{dV_o}{dt} = \frac{I_L}{C_o} - \frac{V_0}{C_0 R}$$

$$\frac{dI_L}{dt} = \frac{V_{pv}}{L} - (1-D)\frac{V_o}{L}$$

$$\frac{dV}{dt} = \frac{I_L}{C_o}(1-D) - \frac{V_o}{C_o R}$$

6.2 Stability Function

V^*_{PV} be reference voltage obtained from MPV searching technique, the error in PV voltage can be defined as

$$e_{rr1} = V_{PV} - V^*_{PV} \tag{6.1}$$

Taking the first derivate of the tracking error

$$e_{\dot{r}r1} = V_{\dot{P}V} - V_{PV}^{*}{}^{\cdot} \tag{6.2}$$

$$= \frac{1}{\mathrm{Cpv}}(\mathrm{I}_{PV} - I_L) - V_{PV}^{*}{}^{\cdot}$$

Lyapunov function can be defined as-

$$V_1 = \frac{1}{2} e_{rr1}^2 \tag{6.3}$$

On differentiating the above function-

$$V_{\dot{1}} = e_{rr1} - e_{\dot{r}r1} \tag{6.4}$$

$$= e_{rr1}[\frac{1}{\mathrm{Cpv}}(\mathrm{I}_{PV} - I_L) - V_{PV}^{*}{}^{\cdot})]$$

$$e_{\dot{r}r1} = \mu_1 \mathrm{e}_{\mathrm{rr1}} \tag{6.5}$$

as per the stability theory, for the controller to exist, the differentiation of the above-defined function must be negative

$$V_{\dot{1}} = -\mu_1 e_{rr1} < 0 \tag{6.6}$$

Where μ_1 should be chosen so that the first differentiation of function will be negative so it is chosen as a positive value and hence we chosen $e_{\dot{r}r1} = \mu_1 e_{rr1}$

$$\mathrm{V}_{\dot{\mathrm{P}}\mathrm{V}} = \frac{dV_{PV}}{dt} \frac{1}{\mathrm{Cpv}}(\mathrm{I}_{PV} - I_L) \tag{6.7}$$

$$\mathrm{V}_{\dot{\mathrm{P}}\mathrm{V}} C_{PV} = \mathrm{I}_{\mathrm{PV}} - \mathrm{I}_{\mathrm{L}}$$

$$\mathrm{I}_{\mathrm{L}} = \mathrm{I}_{\mathrm{PV}} - \mathrm{C}_{\mathrm{PV}} \mathrm{V}_{\dot{\mathrm{P}}\mathrm{V}}$$

$$\mathrm{I}_{\mathrm{L}} = \mathrm{I}_{\mathrm{PV}} - \mathrm{C}_{\mathrm{PV}} \mathrm{V}_{\dot{\mathrm{P}}\mathrm{V}}$$

$$\mathrm{I}_{\mathrm{L}} = \mathrm{I}_{\mathrm{PV}} + \mathrm{C}_{\mathrm{PV}} (\mathrm{C}_1 \mathrm{e}_{\mathrm{rr1}} - \mathrm{V}_{\dot{\mathrm{P}}\mathrm{V}}^{*}) \tag{6.8}$$

The above equation can be summarized as Stability function β

$$\beta = \mathrm{I}_{\mathrm{PV}} + \mathrm{C}_{\mathrm{PV}}(\mathrm{C}_1 \mathrm{e}_{\mathrm{rr1}} - \mathrm{V}_{\dot{\mathrm{P}}\mathrm{V}}^{*}) \tag{6.9}$$

The stability function value is used as a base value for defining the next error

$e_{rr2} = I_L - \beta$ (6.10)

on defining the differentiation of the above equation

$$\dot{e_{rr2}} = \dot{I_L} - \beta \quad (6.11)$$

$$\dot{e_{rr2}} = \frac{V_{pv}}{L} - (1-D)\frac{Vo}{L} - \dot{\beta}$$

Selection of new Lyapunov function can be done as-

$$V_2 = V_1 + \frac{1}{2} e_{rr2}^2 \quad (6.12)$$

$$\dot{V_2} = \dot{V_1} + e_{rr2}\dot{e_{rr2}} \quad (6.13)$$

From 4.6 and 4.10

$$\dot{e_{rr1}} = \dot{V_{PV}} - \dot{V_{PV}^*} = \frac{1}{Cpv}(I_{PV} - I_L) - \dot{V_{PV}^*} \quad (6.14)$$

$e_{rr2} = I_L - \beta$ (6.15)

on combining equations (4.14) and (4.15)

$$\dot{e_{rr1}} = \frac{1}{Cpv}(I_{PV} - (e_{rr2} + \beta)) - \dot{V_{PV}^*}$$

(6.16)

$$\dot{e_{rr1}} = \frac{1}{Cpv}(I_{PV} - (e_{rr2} + \beta)) - \dot{V_{PV}^*}$$

$$\dot{e_{rr1}} = \frac{-e_{rr2}}{C_{pv}} + \frac{1}{C_{pv}}(I_{PV} - \beta) - \dot{V_{PV}^*} \quad (6.16)$$

The stability function now cab be defined as

$$\beta = I_{PV} + C_{PV}\left(C_1 e_{rr1} - \dot{V_{PV}^*}\right)$$

(6.18)

$$-C_{PV}(\mu_1 e_{rr1} - \dot{V_{PV}^*}) = I_{PV} - \beta$$

$$-\mu_1 e_{rr1} + \dot{V_{PV}^*} = \frac{1}{C_{pv}}(I_{PV} - \beta)$$

$$-\mu_1 \, e_{rr1} = \frac{1}{C_{pv}}(I_{PV} - \beta) - V_{PV}^{*\cdot}$$

$$\dot{e_{rr1}} = \frac{-e_{rr2}}{C_{pv}} - C_1 e_{rr1} \quad (6.17)$$

Where μ_2 must be a positive value. Substituting equation , we get

$$\dot{V_2} = e_{rr1}\left(\frac{-e_{rr2}}{C_{pv}} - \mu_1 e_{rr1}\right) + e_{rr2}\left(\frac{V_{pv}}{L} - (1-D)\frac{V_o}{L} - \beta^{\cdot}\right) \quad (6.18)$$

Now for satisfying the stability condition i.e. $\dot{V_2} < 0$

$$(-\frac{1}{C_{PV}} e_{rr1} + \frac{V_{pv}}{L} - (1-D)\frac{V_o}{L} - \beta^{\cdot} = -\mu_2 e_{rr2}$$

$$\dot{V_2} = -\mu_1 e_{rr1}^2 - \mu_2 e_{rr2} < 0$$

6.3 Defining of Control Law

By (4.20)

$$(\frac{1}{C_{pv}} e_{rr1} + \frac{V_{pv}}{L} - (1-D)\frac{V_o}{L} - \beta^{\cdot}) = -\mu_2 e_{rr2}$$

On making a proper arrangement the duty cycle can be defined as-

$$d = 1 - \frac{1}{V_o}[V_{PV} - L\beta^{\cdot} - L(\frac{1}{C_{pv}} e_{rr1} - \mu_2 e_{rr2}) \quad (6.19)$$

The above equation is defined as a control equation to change the duty ratio for having required output from setup. This duty cycle provided to the MOSFET to generate the pulse width modulating function

6.4 Observation Backstepping Controller with Integral Action

Fig.6.2 presents PV & Boost Converter current values under a various region of irradiation. A clear observation is made in region 1 of the irradiation curve (from fig 3), where the irradiation is having sharp and large increment, the oscillations in PV current are greatly reduced to a larger extent whereas, in region 2 of the irradiation Curve where there is a sharp but relatively small change in irradiation value, the oscillation is also reduced as compared to P&O and InC.

6.4.1 Graph of PV and Converter Current

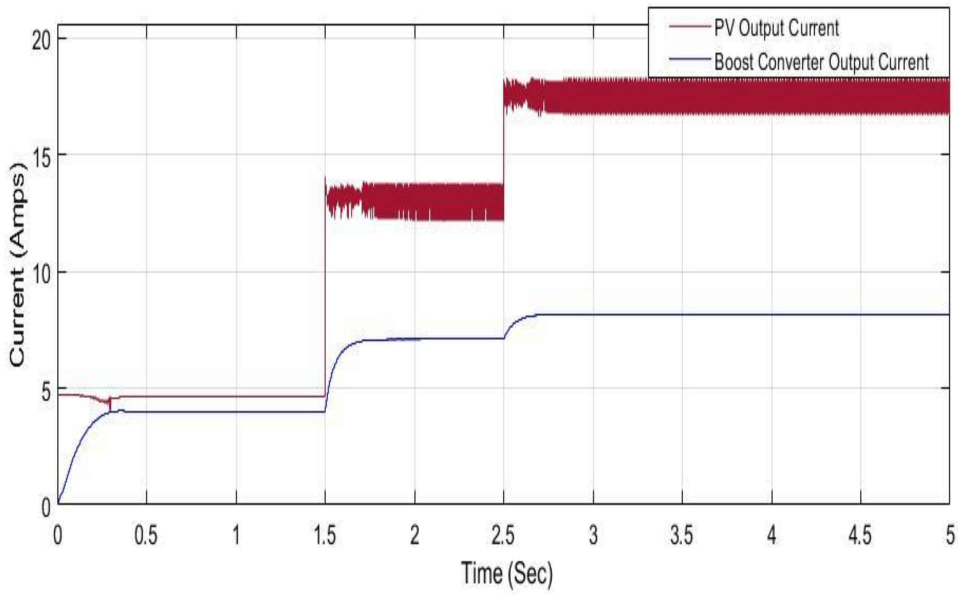

Figure-6.2 Graph of PV and Converter Current

Fig.6.3 presents PV & Boost Voltage values under the various regions of irradiation. The input voltage to the boost is around 120 V which is boosted to a level such that the input power of boost converter can be made equal to output .

6.4.2 Graph of PV and Converter Voltage

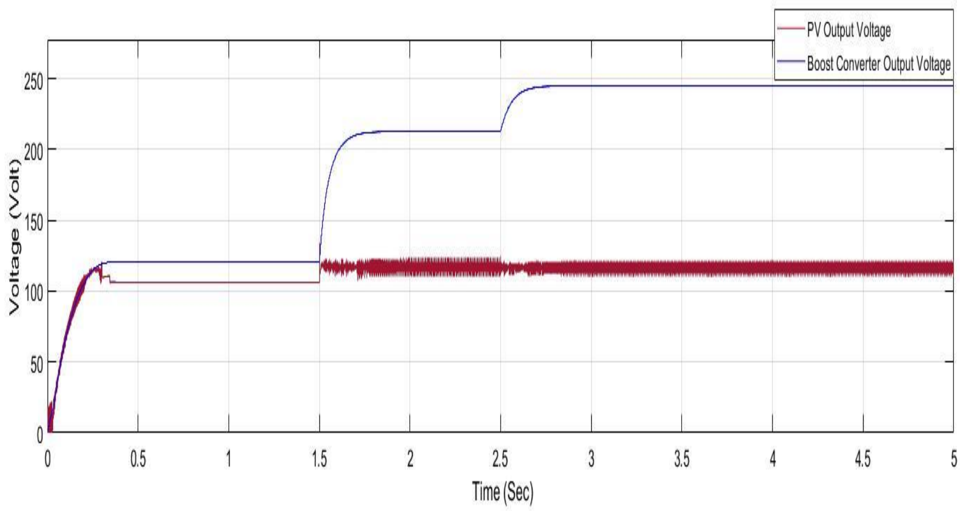

Figure-6.3 PV and Converter Voltage

Fig 6.4 shows the tracking of desired ideal power with the help of the integral backstepping method. It can be observed that during the unexpected variations in irradiation, the PV output power oscillations are reduced to a greater extent.

6.4.3 Graph of PV and Converter Power

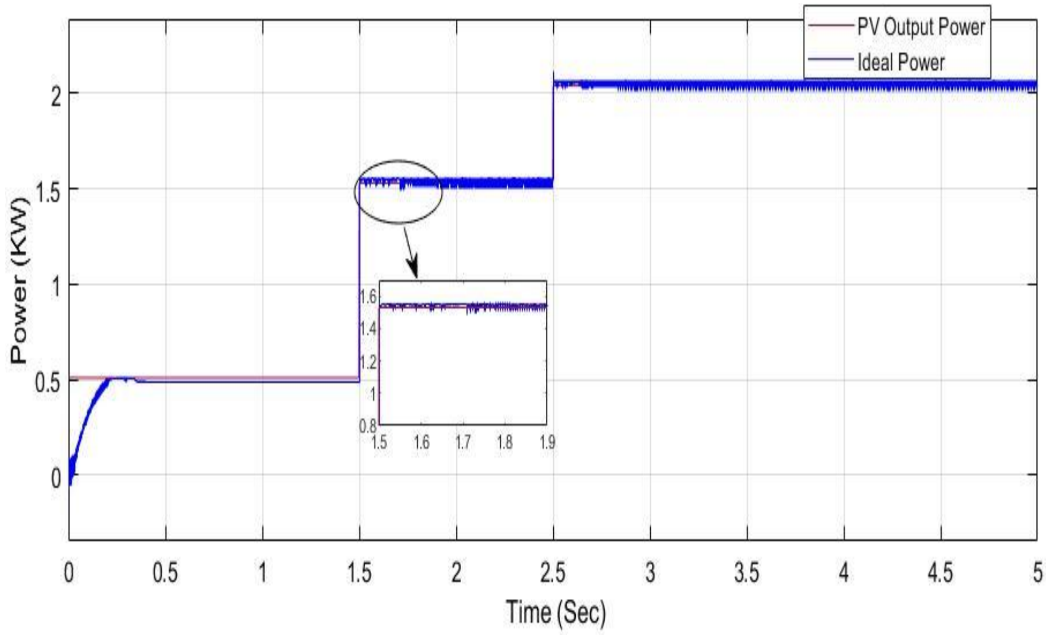

Figure-6.4 Graph of PV and Converter Power

CHAPTER-7

SIMULATION RESULTS & DISCUSSION

7.1 Result obtained by P&O Method

7.1.1 Ideal and PV power

Fig. 7.1 shows the tracking of desired ideal power with the help of the P&O methodology. It can be observed during the accidental variations in irradiation, output power has a greater extent of oscillations.

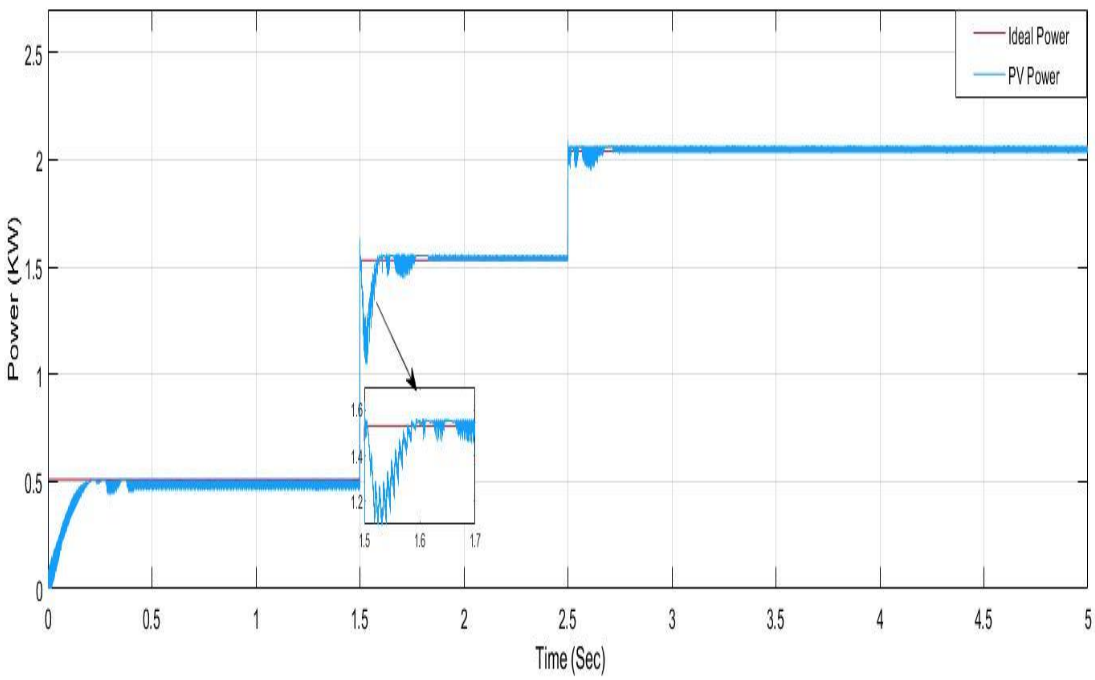

Fig.7.1 Ideal and PV power

7.1.2 TE of P&O Technique

Fig7.2 shows that Perturb and Observe technique works fine under normal conditions or relatively small changes in irradiation but at the point of unexpected and large variations in irradiation (for region 1 in irradiation curve) the tracking efficiency drops down to a large extent.

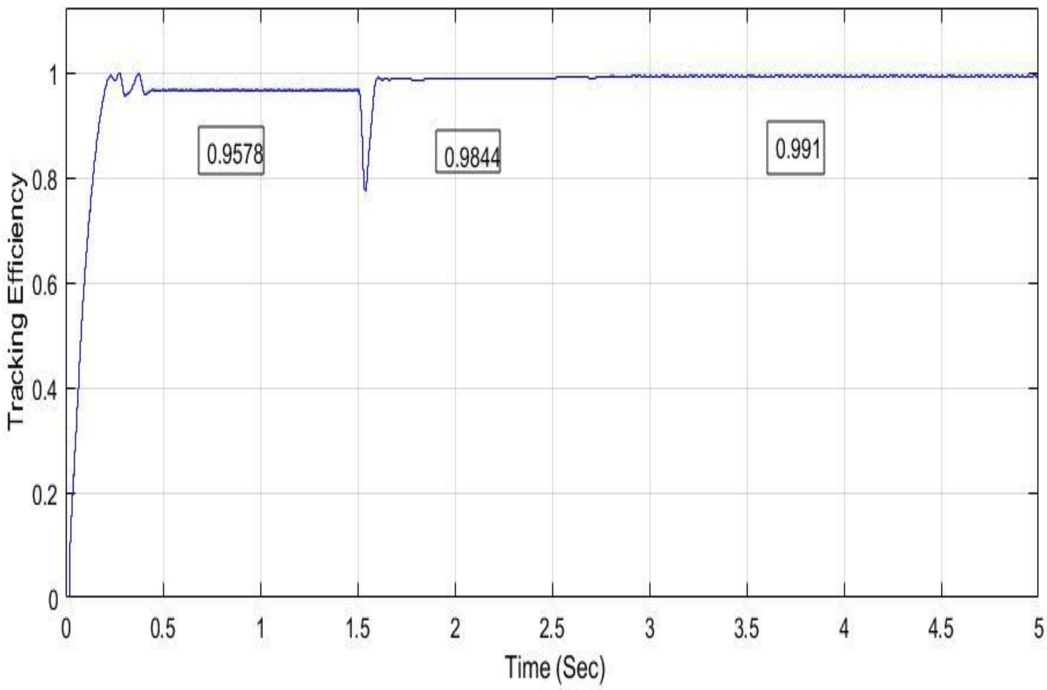

Figure 7.2 TE of P&O Technique

TABLE II TE of P&O Technique

Region	**TE**
Prior to Region 1	95.78%
After Region 1	98.44%
After Region 2	99.1%

7.2 Result obtained by Incremental conductance

7.2.1 PV and Ideal power curve

Fig. 7.3 shows the tracking of desired ideal power with the help of InC method. It can be observed that during the accidentally large variation in irradiation, output power has a greater extent of oscillations.

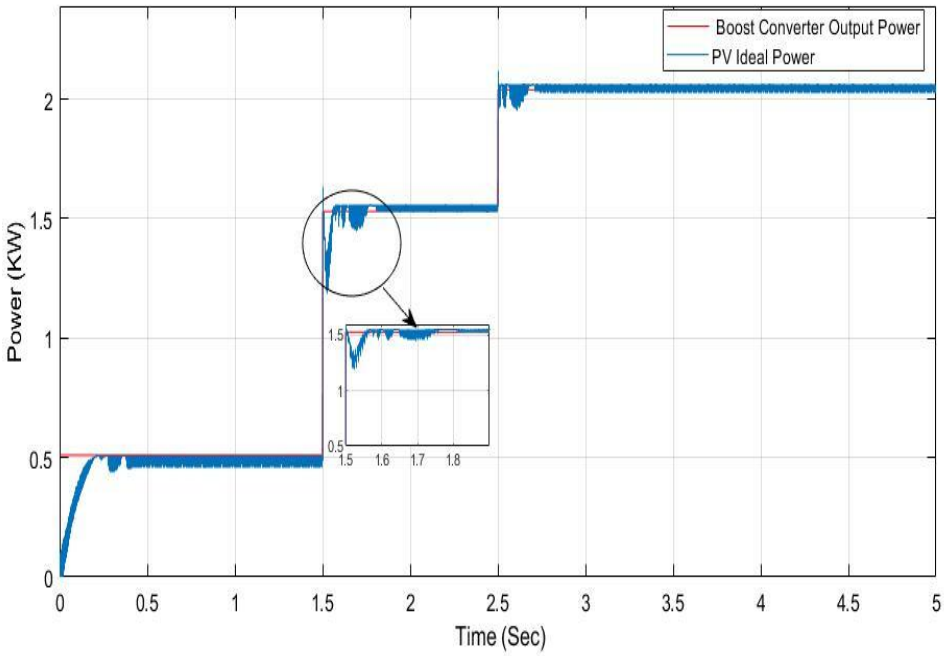

Figure 7.3 PV and Ideal power curve

7.2.2 Tracking Efficiency

Fig7.4 shows that InC technique works fine under normal conditions or relatively small changes in irradiation but at the point of unexpected and large variations in irradiation (for region 1 in irradiation curve) the tracking efficiency drops down to a large extent.

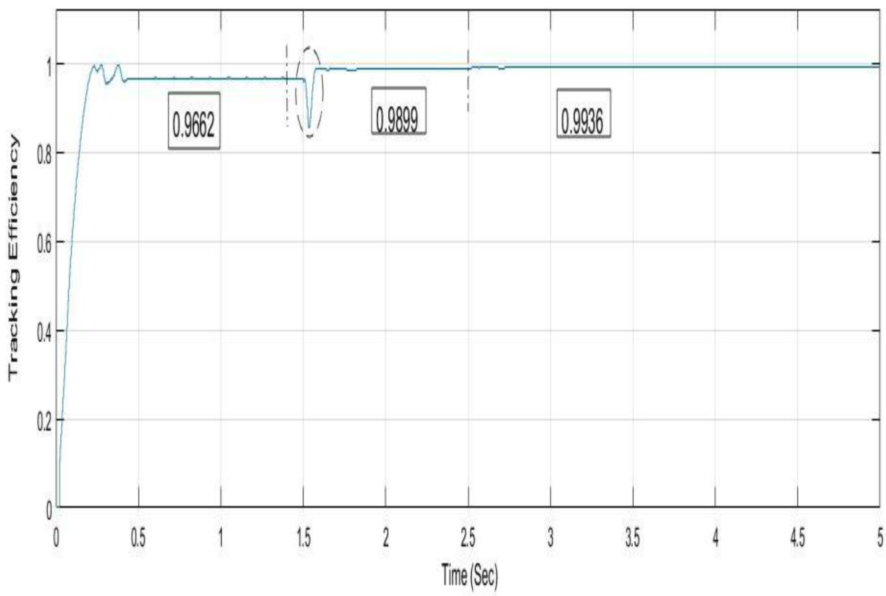

Figure 7.4 Tracking Efficiency

TABLE III TE of InC Technique

Region	TE
Prior to Region 1	96.62%
After Region 1	98.99%
After Region 2	99.36%

7.3 Results from Sliding Mode Controller

7.3.1 PV and Ideal power curve

Fig. 7.5 shows the tracking of desired ideal power with the help of SMC method. It can be observed that during the accidentally large change in irradiation, the PV output power has the greater extent of oscillations (But lesser when compared to P&O and InC)

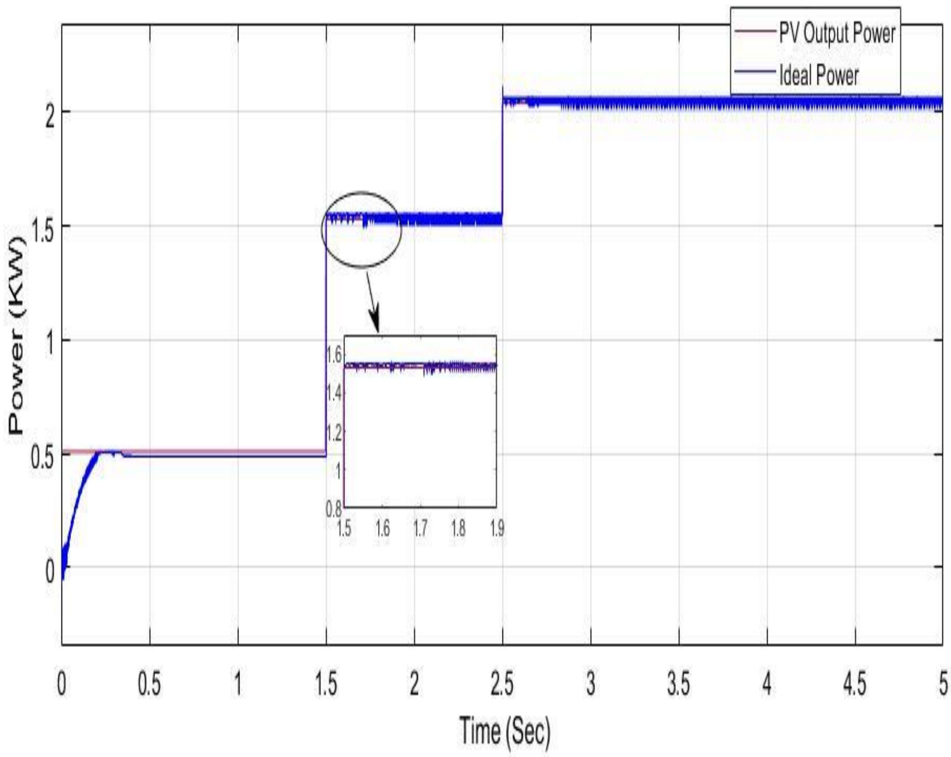

Figure 7.5 PV and Ideal power curve

7.3.2 Tracking Efficiency

Fig 7.6 shows that InC technique works well under normal conditions or relatively small changes in irradiation but at the point of unexpected variations in irradiation (for region 1 in irradiation curve) the tracking efficiency drops down.

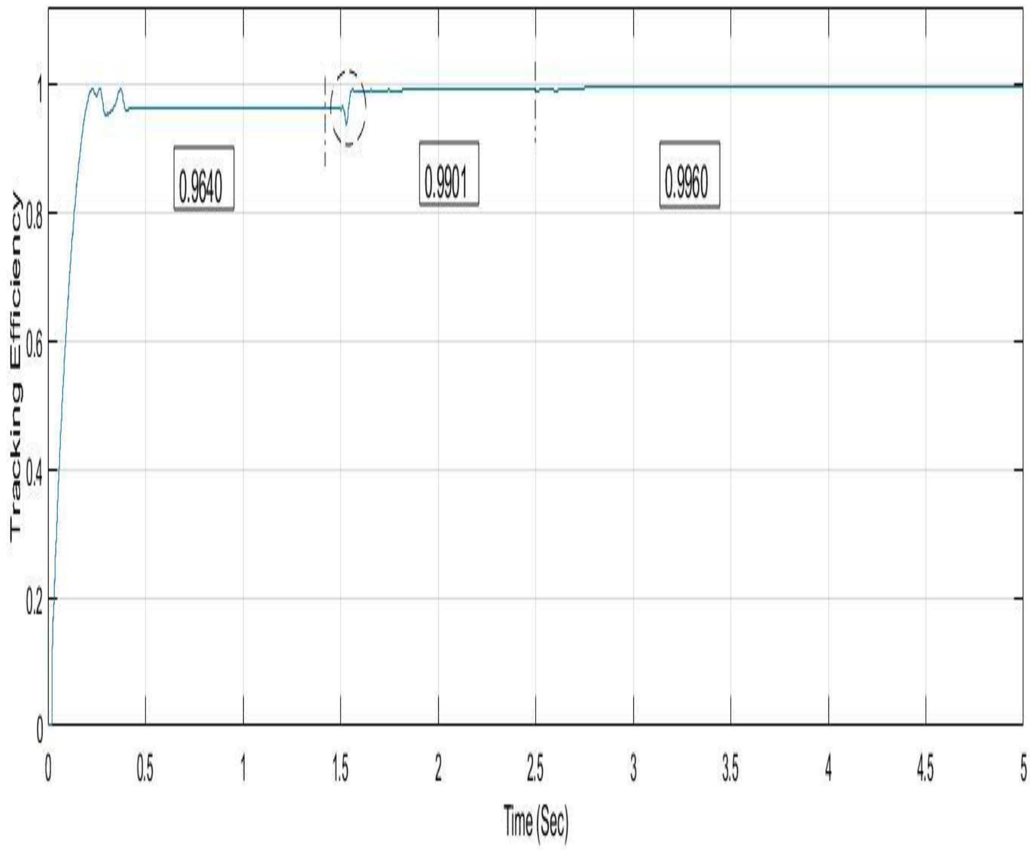

Figure 7.6 Tracking Efficiency

TABLE IV TE of BSC with integral action Techinque

Region	TE
Prior to Region 1	96.40%
After Region 1	99.01%
After Region 2	99.60%

7.4 Results from Backstepping Controller with Integral Action

7.4.1 PV and Ideal power curve

Fig 7.7 shows the tracking of desired ideal power with the help of Backstepping method. It can be observed that during the unexpected variations in irradiation, the PV output power oscillations are reduced to a greater extent.

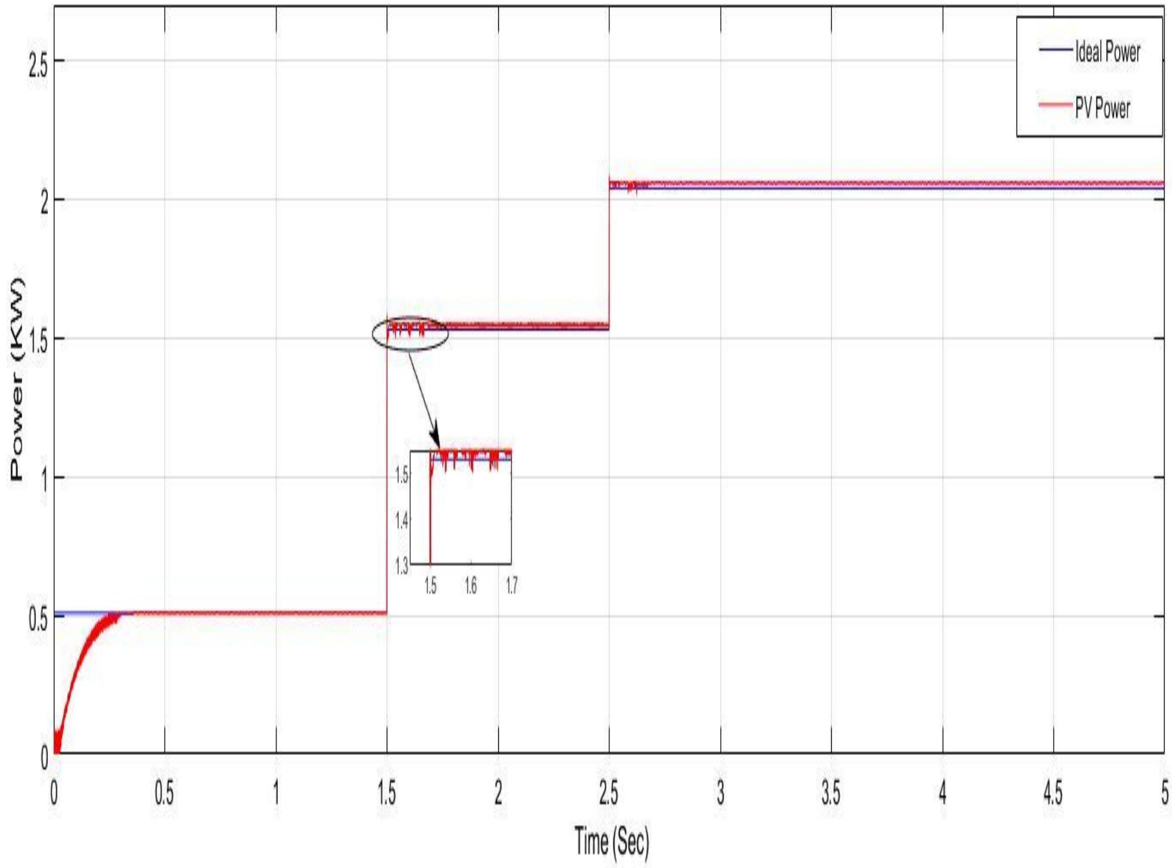

Figure 7.7 PV and Ideal power curve

7.4.2 Tracking Efficiency

The Fig7.8 shows that Backstepping technique works fine under normal conditions or relatively small changes in irradiation as well as at the point of the sudden and large change in irradiation (for region 1 in irradiation curve) the tracking efficiency does not get adversely affected.

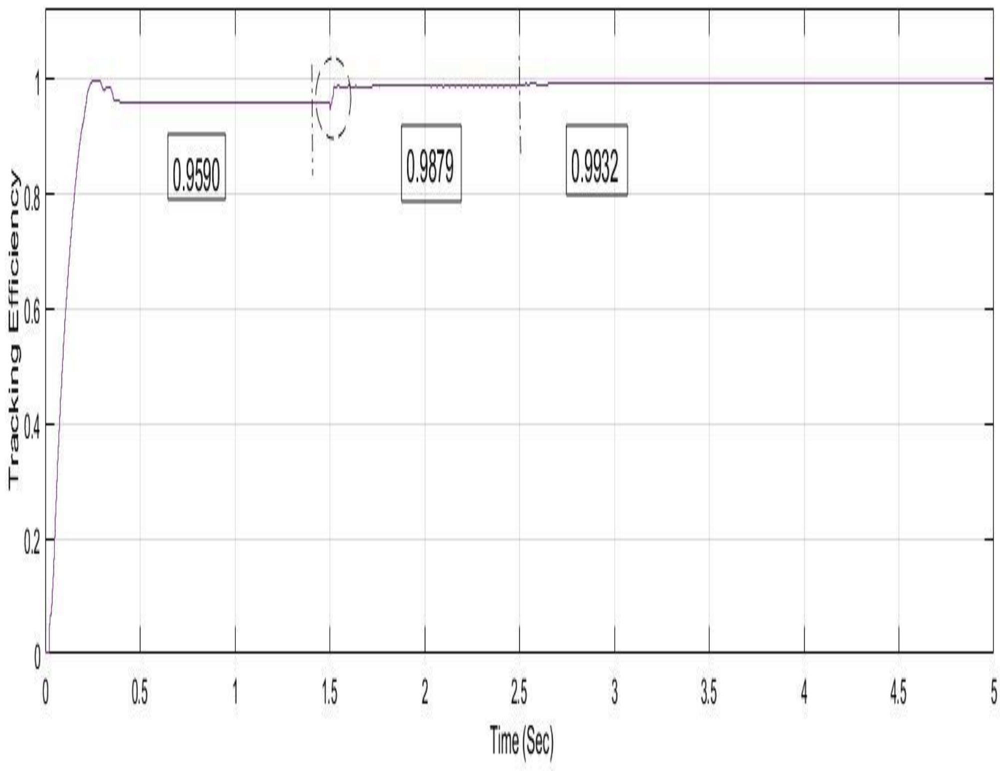

Figure 7.8 Tracking Efficiency

TABLE V TE of Backstepping Technique With Integral action

Region	TE
Prior to Region 1	95.90%
After Region 1	98.79%
After Region 2	99.32%

Chapter-8

Conclusion and Future Scope

8.1 Conclusion

This project explains four methods namely P&O, InC, and sliding mode approach, and backstepping controller with integral action to get utmost power from the solar module. These four types of techniques are developed and studied in MATLAB/Simulink. The output of the PV system is fed to the DC-DC boost converter and switching of the boost converter is done by these four methods. The MPPT tracking. algorithm operates for various climatic conditions. The main drawback of perturb and observation method is oscillations around MPP which are reduced in incremental conductance method to some extent. The oscillations about the utmost power point are very less in the Sliding mode Control Approach and those oscillations are reduced to a much higher extent with the help of an backstepping controller with integral action. Although the design complexity of P & O method is lower than InC and Sliding mode method and integral backstepping controller

Table VI Comparative Analysis of MPPT Techniques

Performance Criteria	P&O	InC	SMC	BSC with integral action
No of Sensing Parameter	2	2	3	4
Sensing Parameter	Vpv,Ipv	Vpv,Ipv	Vpv,Ipv,Vo	I_L,I_{PV},Vpv,Ipv
Design Complexity	Less	More	Higher	Much Higher

Accuracy of MPPT (at point of sudden and large irradiation changes)	Low(more oscillation)	More than P&O (Less Oscillations)	High (Less Oscillations)	Greater than previously designed methods

8.2 Future Scope

This Project is mainly focused on the various types of approaches modeled to hound utmost power from solar modules. Further research in this field can be achieved with the help of another non-linear controller like terminal sliding mode controller, feedback linearization, and LQR controller. Hardware implementation can also be done to study the comparative study between simulation and hardware implementation analysis.

APPENDIX I

Table VI. Converter Parameter

Parameters	Value
Cpv	100 µF
L	1.37mH
Co	4.233mF
R	30 Ω
Fsw (Switching Frequency)	5KHz
Vd(Diode Voltage drop)	0.82V

Table VII. PV Module Parameter

Parameters	Value
Series Cells	3
Parallel Cells	4
Voc	36.3V
Ioc	7.84A
Vmp	29V
Imp	7.35A
Maximum Power (MP)	2.5KW

REFERENCES

[1]T. Salmi, M. Bouzguenda, A. Gagtli, “MATLAB/Simulink based modeling of solar photovoltaic cell,” *International Journal of Renewable Energy Research,* vol.2, no.2, pp. 55-59, March, 2012.

[2] X. H. Nguyen and M. P. Nguyen, “Mathematical modeling of photovoltaic cell/module/arrays with tags in Matlab/Simulink,” Environ. Syst. Res., 2015.

[3] B. Subudhi and R. Pradhan "Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems ",Sustainable Energy, IEEE Transactions On 4(1), pp. 89-98, (2013)

[4]K. Ding, X. Bian, H. Liu, T. Peng, “A MATLAB-Simulink-Based PV Module Model and Its Application under Conditions of Non-uniform Irradiance”, *IEEE Transactions on Energy Conversion,* vol.27, no. 4, pp. 864-872**,** September, 2012.

[5]D. P. Hohm M. E. Ropp "Comparative study of maximum power point tracking algorithms using an experimental programmable maximum power point tracking test" Proc. IEEE Photovoltaic Spec. Conf. pp. 1699-1702, 2000

[6]Shubham and A. Swarup, "Comparative Study and Simulation of Different MPPT Techniques in MATLAB/Simulink," 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT), Coimbatore, 2018, pp. 1524-1528.

[7] L. Piegari and R. Rizzo, “Perturb and observe algorithm for photovoltaic maximum power point tracking,” IET Renew. Power Gener., Vol. 4, Issue 4, p. 317 – 328 July 2010.

[8]L. Egiziano, N. Femia, D. Granozio, G. Spagnuolo and M. Vitelli "Photovoltaic inverters with Perturb & Observe MPPT technique and one-cycle control" Proc. IEEE Int. Symp. Circuits Syst. vol. 4 pp. 3721, 2006

[9] X. Liu and L. A. C. Lopes, “An improved perturbation and observation maximum power

point tracking algorithm for PV arrays," IEEE 35th Annual Power Electronics Specialists Conference, Aachen, Germany, Vol.3 pp. 2005-2010, 2004.

[10] R. I. Putri, S. Wibowo, and M. Rifa'i, "Maximum power point tracking for photovoltaic using incremental conductance method," Energy Procedia, vol. 68, pp. 22–30, 2015

[11] Q. Mei, M. Shan, L. Liu, and J. M. Guerrero, "A novel improved variable step-size incremental-resistance MPPT method for PV systems", IEEE Transactions on Industrial Electronics, vol. 58, no. 6, pp. 2427-2434, 2011.

[12]H. Hsieh, Sheng-Fang Shih, Jen-Hao Hsieh and G. Hsieh, "A study of high-frequency photovoltaic pulse charger for lead-acid battery guided by PI-INC MPPT," 2012 International Conference on Renewable Energy Research and Applications (ICRERA), Nagasaki, 2012, pp. 1-6.

[13] A. Patel, H. Tiwari, "Implementation of INC-PIMPPT and its comparison with INC MPPT by direct duty cycle control for solar photovoltaics employing zeta converter ICICIC,2017, pp.24-26

[14]S. B. Kjaer "Evaluation of the 'Hill Climbing'and the 'Incremental Conductance' maximum power point trackers for photovoltaic power systems" IEEE Trans. Energy. Convers. vol. 27 no. 4 pp. 922-929, Dec. 2012.

[15] T. M. Chung, H. Daniyal, M. H. Sulaiman, M. S. Bakar, "Comparative study of P&O and modified incremental conductance algorithm in solar maximum power point tracking 4th IET Clean Energy and Technology Conference (CEAT 2016)

[16] N. Hussein Selman, "Comparison Between Perturb & Observe, Incremental Conductance and Fuzzy Logic MPPT Techniques at Different Weather Conditions," Int. J. Innov. Res. Sci. Eng. Technol., vol. 5, no. 7, pp. 12556–12569, 2016.

[17]W. M. Haddad and V. S. Chellaboina, Nonlinear dynamical systems and control: A lyapunov-based approach. 2011.

[18]M. Farhat, O. Barambones, J. A. Ramos, and J. M. G. De Durana, "Maximum Power Point Tracking Controller Based on Sliding Mode Approach," Actas las XXXV Jornadas

Automática, pp. 3–5, 2014.
Ss
[19]H. Afghoul, D. Chikouche, F. Krim, and A. Beddar, “A compararative study between sliding mode controller and P and O controller applied to MPPT,” Proc. 2013 Int. Renew. Sustain. Energy Conf. IRSEC 2013, pp. 112–117, 2013.

[20]S. Kim, “Sliding mode controller for the single-phase grid-connected photovoltaic system,” Appl. Energy, Vol. 83, Issue 10, pp. 1101-1115 2006.

[21] S. S. Pradhan, R. Pradhan, and B. Subudhi, “Design of sliding mode controller for three phase grid connected photovoltaic system,” International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), pp. 1317-1322, 2016.

[22]Daniel Gonzalez Montoya, Carlos Andres Ramos-Paja, Roberto Giral, "Improved design of sliding mode controllers based on the requirements of MPPT techniques", IEEE Transactions Power electronics, January, 2015.

[23]Fangrui Liu, Shanxu Duan, Fei Liu, Bangyin Liu, Yong Kang, "A Variable Step Size INC Variable Step Size INC MPPT Method for PV Systems", IEEE Travs. Electron, Vol. 55, Jul. 2008.

[24]S. Tan, Y. M. Lai, and C. K. Tse, “General design issues of sliding mode controllers in dc-dc dc-dc converters,” IEEE Transactions on Industrial Electronics, vol. 55, no. 3, pp. 1160–1174, 2008.
[25]Song Kim, "Robust maximum power point tracker using sliding mode controller for three phase grid connected photovoltaic system", Solar Energy ,vol. 81,2007,pp 405-414.

[26]Chen-Chi Chu, Chieh-Li Chen, "Robust maximum power point tracking method for photovoltaic photovoltaic cells : A sliding mode control approach", Solar Energy, vol. 83,2009, pp. 1370-1378.

[27]H. Maker, H.Gualous, R.Outbib, "Sliding Mode Control with Integral of Boost Converter by Microcontroller”,Proceedings of the 2006 IEEE, International Conference on Control Applications Munich, Germany, October 4-6, 2006

[28] F. Lamzouri, E. Boufounas and A. El Amrani, "A Robust Backstepping Sliding Mode

Control for MPPT based Photovoltaic System with a DC-DC Boost Converter,"International Conference on Control, Automation and Diagnosis (ICCAD), pp. 1-6,2018

[29] R. A. Shirazi, I. Ahmad, M. Arsalan and M. Liaquat, "Integral Backstepping based MPPT controller for photo-voltaic system using SEPIC converter," International Conference on Control, Mechatronics and Automation (ICCMA), 2019, pp. 62-67

[30] S. Marhraoui, A. Abbou, A. Ziouh, N. E. hichami and S. e. Rhaili, "Robust Integral Backstepping Approach for MPPT in Different Models of Solar Panel, International Conference on Renewable Energy Research and Applications (ICRERA), 2018, pp. 371-376

[31] M. Alqatamin and M. L. McIntyre, "Nonlinear Backstepping Controller for Single-Phase Grid-Connected Inverters," Workshop on Control and Modeling for Power Electronics (COMPEL), 2019, pp. 1-6

[32] A. Tiga, C. Ghorbel and N. Benhadj Braiek, "Performance comparison of backstepping and sliding mode controllers,"International Conference on Advanced Systems and Electric Technologies (IC_ASET), 2018, pp. 461-466

[33] O. Boutebba, S. Semcheddine, F. Krim and B. Talbi, "Adaptive Nonlinear Controller Design for DC-DC Buck Converter via Backstepping Methodology," International Conference on Advanced Electrical Engineering (ICAEE), 2019, pp. 1s7

[34] H. Abouobaida, M. Cherkaoui and M. Ouassaid, "Robust maximum power point tracking for photovoltaic cells: A backstepping mode control approach," International Conference on Multimedia Computing and Systems, 2011, pp. 1-4

[35] A. D. Martin and J. R. Vazquez, "MPPT algorithms comparison in PV systems: P&O, PI, neuro-fuzzy and backstepping controls, "IEEE International Conference on Industrial Technology (ICIT), 2015, pp. 2841-2847

[36] F. Zaghar, E. M. Karami, H. E. Chakir, M. Rafi and A. Ridah, "Development of sRobust, Efficient Control and State Estimation Strategy for the Photovoltaic System using Nonlinear Backstepping Controller,"International Renewable and Sustainable Energy Conference (IRSEC), 2019, pp. 1-6

[37] O. Boutebba, A. Laudani, G. M. Lozito, F. Corti, A. Reatti and S. Semcheddine, "A Neural Adaptive Assisted Backstepping Controller for MPPT in Photovoltaic Applications,"IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2020, pp. 1-6

[38] C. Aouadi, A. Abouloifa, A. Hamdoun and Y. Boussairi, "Nonlinear controller design for single-phase grid-connected photovoltaic systems,"3rd International Renewable and Sustainable Energy Conference (IRSEC), 2015, pp. 1-5

[39] H. Abouobaida, M. Cherkaoui and Abd Elmonim El magri,"Nonlinear controller for stand-alone PV system, "International Conference on Multimedia Computing and Systems, 2012, pp. 1136-1140

[40] A. D. Martin, J. M. Cano, J. F. A. Silva and J. R. Vázquez, "Backstepping Control of Smart Grid-Connected Distributed Photovoltaic Power Supplies for Telecom Equipment," in IEEE Transactions on Energy Conversion,2015,pp. 1496-1504

[41] S. Marhraoui, A. Abbou and B. Fahil, "Modeling and simulation for ideal and real photovoltaic module which fed water pumping system with nonlinear integral Backstepping Controller,"International Conference on Electrical and Information Technologies (ICEIT), 2016, pp. 474-479

[42]U.u. Rehman, "Design and Simulations of Backstepping Based Nonlinear Control for MPPT in PV Systems," 2018 5th International Multi-Topic ICT Conference (IMTIC), 2018, pp. 1-8

[43] Khaldi, Naoufel & Zazi, Malika & Mahmoudi, Hassane.Grid-connected photovoltaic system using an advanced backstepping approach International Renewable and Sustainable Energy Conference,2015, pp.330-337.

[44] Martin, A. D., & Vazquez, J. R. (2014). Backstepping Controller Design to Track Maximum Power in Photovoltaic Systems. Automatika, 2014,pp. 22–31

[45] A. Latif, L. Khan and S. Ahmad, "Nonlinear Backstepping Based Control of Single-

phase Inverter in a Standalone Photovoltaic System," 2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST), 2021, pp. 636-641

[46]U. u. Rehman, "Design and Simulations of Backstepping Based Nonlinear Control for MPPT in PV Systems," 2018 5th International Multi-Topic ICT Conference (IMTIC), 2018, pp. 1-8

[47]N. Khan, S. F. Rabbi, M. J. Hinchey and M. A. Rahman, "Adaptive backstepping based MPPT control for a variable speed marine current energy conversion system," 2013 26th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), 2013, pp. 1-5.

[48] N. Benbaha, F. Zidani, M. Nait-Said, S. E. Zouzou, S. Boukebbous and H. Ammar, "dSPACE Validation of Improved Backstepping Optimal Energy Control for Photovoltaic Systems," 2018 6th International Renewable and Sustainable Energy Conference (IRSEC), 2018, pp. 1-6.

[49] C. Aouadi, A. Abouloifa, A. Hamdoun and Y. Boussairi, "Advanced nonlinear control of photovoltaic system connected to the grid," 2014 Second World Conference on Complex Systems (WCCS), 2014, pp. 61-66

[50] M. Madark, A. Ba-Razzouk, E. Abdelmounim and M. El Malah, "Backstepping with Integral Action Controller for a Solar Photovoltaic Powered Induction Motor," 2018 Renewable Energies, Power Systems & Green Inclusive Economy (REPS-GIE), 2018, pp. 1-6

[51] A. Latif, L. Khan and S. Ahmad, "Nonlinear Backstepping Based Control of Single-phase Inverter in a Standalone Photovoltaic System," 2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST), 2021, pp. 636-641

[52]U. u. Rehman, "Design and Simulations of Backstepping Based Nonlinear Control for MPPT in PV Systems," 2018 5th International Multi-Topic ICT Conference (IMTIC), 2018, pp. 1-8

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