Simulation and Analysis of Perturb & Observe (MPPT Algorithm) using Boost converter

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ABSTRACT

Renewable energy is an alternative way that will hopefully lead us away from petroleum dependent energy sources. Among all renewable energy sources solar energy is the most acceptable solution as it is available in abundant and free of cost worldwide. A typical solar generation system consists of a solar array and a DC-DC converter.

A DC-DC converter acts as an interface between the load and the PV module as it serves the purpose of transferring maximum power from the solar PV module to the load. To develop a photovoltaic (PV) power generation system with a suitable converter topology, it is imperative to analyze the converter.

The DC-DC converters are widely used in photovoltaic systems as an interface between the PV panel and the load and are used to ensure the maximum power point (MPP) operation. Directly connecting the load to the PV panel will give MPP operation only in one load condition.

To extract the maximum power for different load conditions, power processors (power electronic converters) can be used where one can vary the duty ratio and thereby the input impedance as seen by the PV panel can be varied. In this work, DC-DC boost converter are used along with maximum power tracking algorithm (MPPT), Perturb and Observe (P&O). The MPPTs of the PV array are verified by the simulation results.

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CHAPTER 1

1.1 INTRODUCTION

Renewable energy conversion technologies based on solar and wind sources are very interesting for electricity production because they are non-polluting and do not deplete finite fossil fuel resources. Solar photovoltaic (PV) power systems have found numerous applications, ranging from small, standalone systems to utility-scale, grid-connected power plants.

At the end of 2012, the cumulative installed, grid-connected PV capacity in the United States reached approximately 7.4 Gigawatts (GW). Of the nearly 316,000 PV installations which were connected to the grid in 2012, approximately 283,000 (nearly 90%) were residential systems. Solar PV installations tend to be expensive when compared with conventional fossil fuel power generation, but benefit from having no associated fuel cost.

However, in order to maximize the return on investment, it is important to maximize the amount of electricity generated by the PV system. This thesis focuses on the effective power converter which will extract the maximum power from a PV array using a Maximum Power Point Tracking (MPPT) control algorithm with a very efficient circuit topology.

1.2 Objective

The goal of this thesis is to design, build, demonstrate, and evaluate a direct-current (DC) converter for use in for PV power system applications, with several advantages when compared to the current state-of-art. The system designed in this thesis will serve as part of a residential-scale, or small commercial, PV power system.

The interface for the PV modules and inverter will be addressed as part of the design process. A provision for including optional energy storage will be considered as well, although the actual incorporation of energy storage is outside of the scope of this thesis. MPPT capability will be implemented as part of the converter design, in order to maximize energy capture.

The design process will include performing mathematical modeling and simulation, with analysis made with simulation software such as MATLAB-Simulink and PSIM. After completing the modeling and simulation study, the converter will be implemented in hardware and evaluated. Efficiency, size, and cost are the primary advantages of switching power converters when compared to linear converters. The switching power converter efficiencies can run between 70- 80%, whereas linear converters are usually 30% efficient. The DC-DC Switching Boost Converter is designed to provide an efficient method of taking a given DC voltage supply and boosting it to a desired value

1.3 LITERATURE REVIEW

Power for the boost converter can come from any suitable DC source, such as DC generators, batteries, solar panels and rectifiers. The method that changes one DC voltage to a different DC voltage is called DC to DC conversion. Generally, a boost converter is a DC-DC converter with an output voltage greater than the source voltage. It is sometimes called a step-up converter since it “steps up” the source voltage.

For high efficiency, the SMPS switch must turn on and off quickly and have very less losses. The coming of a commercial semiconductor switch such as the boost converter in the 1950s represented a major milestone that made SMPSs possible. The main DC to DC converters were developed in the early 1960s when semiconductor switches were available. Switched systems such as SMPS are a challenge to design since its model depends on whether a switch is opened or closed. R. D. Middlebrook from Caltech in 1977 published the models for DC to DC converters in the market today. He averaged the circuit configurations for each switch state in a technique called state-space average modeling. This simplification resulted in reduction of two systems into one. This model led to insightful design equations which helped SMPS growth [1].

Battery powered systems often stack cells in series to obtain higher voltage. However, sufficient heaping of cells is not possible in many high voltage applications due to insufficient space. Boost converters can increase the voltage and reduce the cell numbers. Two battery-powered applications that use boost converters are hybrid electric vehicles (HEV) and lighting systems. The NHW20 model Toyota Prius HEV utilizes 500 V. If there is no boost converter, the HEV would need nearly 417 cells to power its motor. In reality, a Prius actually uses only 168 cells and boosts the battery voltage from 202 V to 500 V.

On a smaller scale application, boost converters also power devices such as portable lighting systems and emergency lights. A white LED typically 3 requires 3.3 V to function, and a boost converter can step up the voltage from a single 1.5 V alkaline cell to power the light. It can also produce higher voltages to operate cold cathode fluorescent tubes (CCFL) in devices such as LCD backlights and some flashlights. A boost converter is used as the voltage increase mechanism in the circuit known as the 'Joule thief', which is a circuit topology used with low power battery applications and is purposed at the ability of a boost converter to 'steal' the remaining energy in a battery.

The energy remaining would otherwise be wasted since the low voltage of a nearly depleted battery makes it unusable for a load. The remaining energy would otherwise remain untapped because many applications do not allow enough current to flow through a load when voltage degrades. This occurs as batteries are degraded, and is a characteristic of a normal battery. [2][3] There are a range of uses for a DC-DC boost converter. Travelers need to carry such devices when they want to bring electronics from home and the supply of current in a foreign country differs from that which is present at their home.

Sometimes only a plug converter is required, but in other cases, plugging electronics directly into the power supply could damage the devices. A boost converter provides a bridge to allow travelers to access electricity safely. Such devices are also used with systems that require high voltage, ranging from theatrical lighting to scientific apparatus. The boost converter may in some cases be wired directly into the electrical supply because of a permanent requirement.

In other instances, it becomes necessary to plug the device in as required, especially in the case of traveling equipment like that used by bands on concerts. As with other electrical devices, it is advisable to inspect a boost converter before use to confirm it is in good working condition and to check for any issues that might impair functionality or safety.

1.4 CONCLUSION

The solar panel has a variety of applications, it can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Power produced by a single solar panel is limited. Solar panel uses light energy from the sun to produce electricity through the photovoltaic effect. Solar Photovoltaic (PV) is used to convert solar energy into electrical energy.

The continuous consumption of fossil fuels has caused the fossil fuel deposit to be reduced and has adversely affected the environment depleting the biosphere and cumulatively adding to global warming. With the non-renewable sources becoming increasingly deficient, solar power provides a likely replacement for the non-renewable resources. The climatic condition of India where, about 300days of clear sunny sky provides a large scope for the use of solar power. The solar power can be developed for long term use and can provide a potential of 20 MW per sq. km. A solar panel is a connected assembly of solar cells, also known as photovoltaic cells.

The complete solar energy conversion system consists of Solar PV, Power electronics converters [2] and control unit to regulate the power extracted from solar PV. Solar PV cells have nonlinear characteristics. Its efficiency is very low and the DC power output varies with solar irradiation and ambient temperature [2]. Recent literature reveals that research efforts target to augment the power output of the solar PV module in terms of MPPT.

The I–V (current–voltage) and P-V (Power-Voltage) characteristics of photovoltaic module is non-linear and it indicates that there exists only one point where the module delivers maximum power [3]. This point also varies with the change in insolation and temperature. Thus, the mismatch between load and source characteristics restricts the availability of maximum possible accessible power delivery to load which causes a significant power loss. The characteristic of load and source matching or impedance matching is done with the help of DCDC converter and the duty cycle of the converter is decided by the MPPT algorithm. In any tracking scheme converter design is very essential part.

CHAPTER 2: - MODELLING OF PV CELL

2.1 Introduction

Photovoltaics (PV) or solar cells are semiconductor devices that convert sunlight into direct current (DC) electricity. A photovoltaic cell absorbs the photons emitted by the sun and generates a flow of electrons. When the photons strike a semiconductor material like silicon, they release the electrons from their atoms, leaving behind a vacant space.

The stray electrons move around randomly looking for another “hole” to fill. The silicon layer exposed to sunlight is doped with phosphorus(n-side) which has one extra electron than silicon and the underlying silicon layer is doped with boron(p-side) which has one less electron than silicon.

Now an electric field is created at the junction. Now, these excited electrons are swept to the n-side by an electric field, while the holes drift to the p-side. The electrons and holes are directed to the electrical contacts applied to both sides before flowing to the external circuit in the form of electrical energy. This produces direct current.

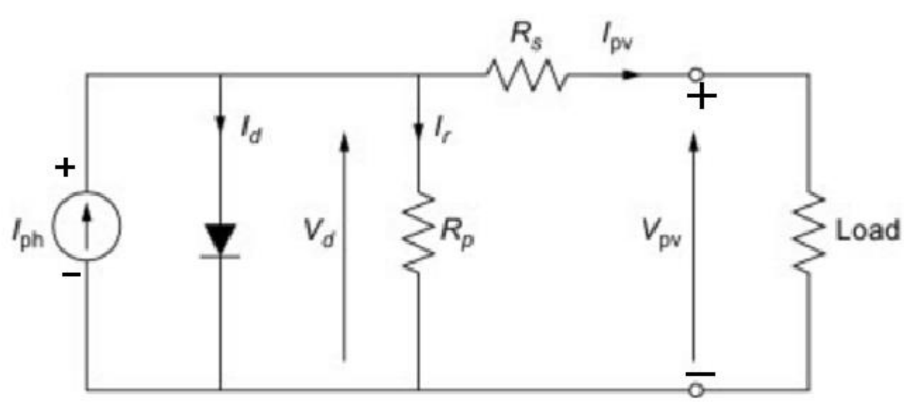

Figure 2.1 Equivalent circuit of a PV cell [5]

2.2 Modules, Panels & Arrays

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents, and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate and are the fundamental building blocks of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.

2.3 Cell relations

Let the cell parameters be

Iph = Photon current at an irradiance and temperature

Id = Diode current

Ir = Leakage current

Ip= Load current

Io = Dark or reverse saturation current

Is = Short circuit current

Rp = Shunt resistance

Rs = Series resistance

Vp = Load voltage

Vo = Open circuit voltage

We have,

$$I_d = I_o\left(e^{\frac{q(V+I_{pv}R_S)}{akT}} - 1\right) \quad (2.1)$$

Applying KCL,

$$I_{ph} = I_d + I_{pv} + I_r$$

$$\Rightarrow I_{pv} = I_{ph} - I_d - I_r \tag{2.2}$$

Using equation (2.2) we get,

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{q(V+I_{pv}R_s)}{akT}} - 1\right) - (V_{ph} + I_{pv}R_s)/R_p \tag{2.3}$$

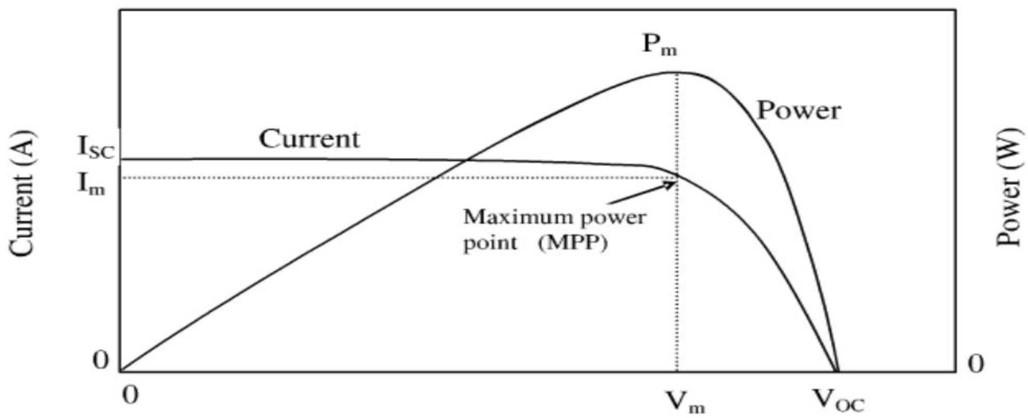

Figure 2.2 PV Characteristics

As we can see from Figure 2.2, to get maximum power from a solar cell we should operate it around maximum power voltage $V\mathrm{mpp}$ as shown in the diagram above. Therefore, the maximum power is: -

$$Pm = VmIm \tag{2.4}$$

2.4 Effect of irradiance & temperature

Irradiance is defined as the measure of the power density of sunlight received and is measured in watt per metre square. With the increasing solar irradiance both the open-circuit voltage and the short circuit current increase and hence the maximum power point varies. Temperature plays another major factor. As the temperature increases, the rate of photon generation increases thus reverse saturation current increases rapidly and this reduces the band gap. Hence this leads to marginal changes in current but major changes in voltage. The cell voltage reduces by 2.2Mv per degree rise of temperature. Temperature acts like a negative factor affecting solar cell performance. Therefore, solar cells give their full performance on cold and sunny days rather than on hot and sunny weather.

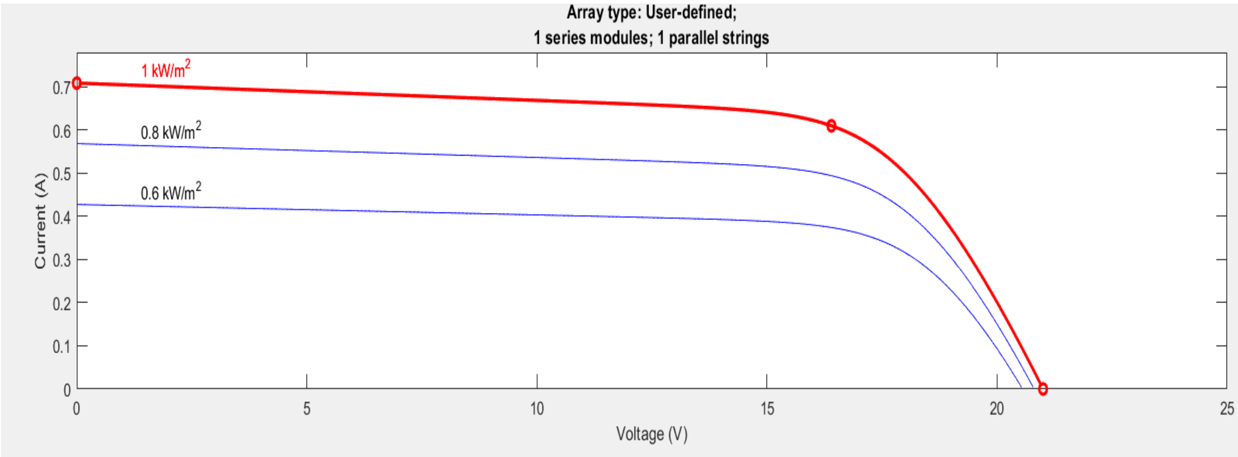

Figure 2.3 Effect of irradiance

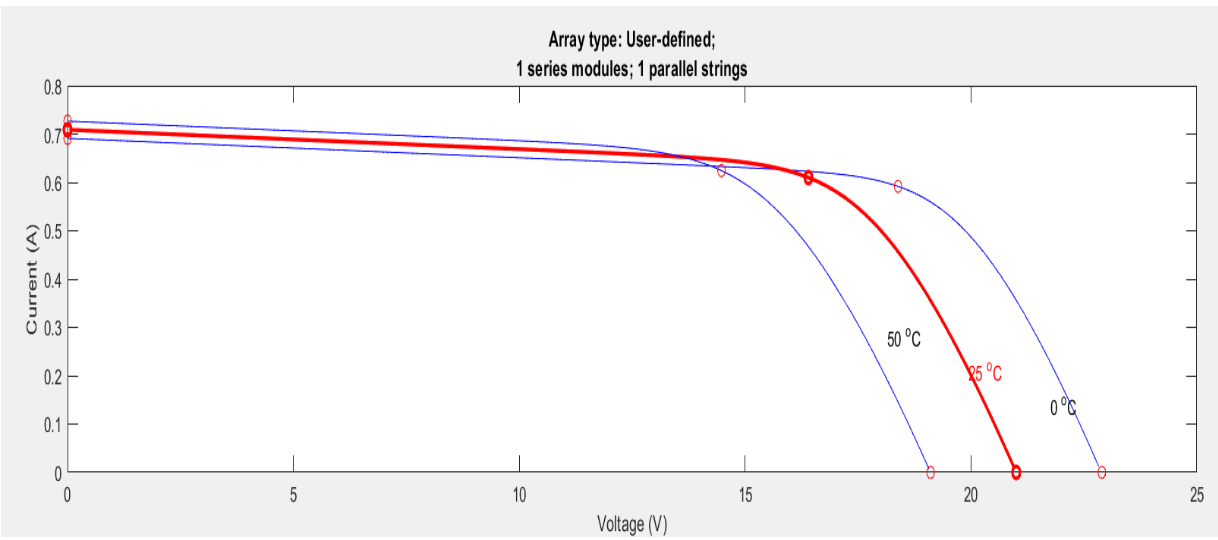

Figure 2.4 Effect of Temperature

CHAPTER 3: - Boost convertor

3.1 Introduction

Boost Converter or StepUp Chopper is a type of DCDC converter which increases the input DC voltage to a specified DC output voltage.

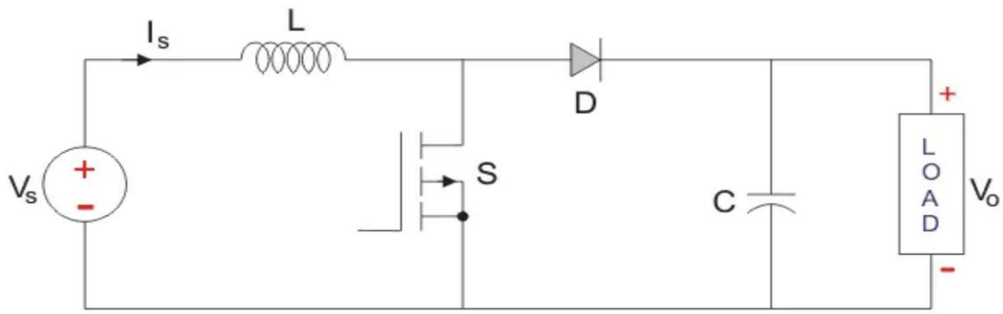

Figure 3.1 Circuit Diagram of Boost Converter

As shown in the Figure 3.1, the input voltage source is connected to MOSFET which act as a switch. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel.

3.2 Steady state analysis

In this we have assumed that the inductor current is continuous which rises and falls linearly and have used same terms and notions.

<u>Mode I: Switch is ON, Diode is OFF</u>

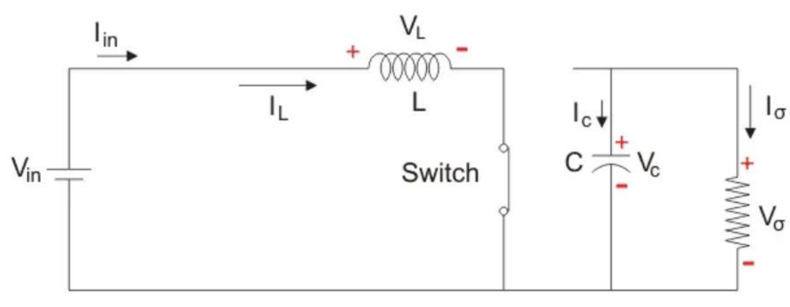

Figure 3.2 Equivalent circuit in Mode 1

In figure 3.2, the switch is on and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is on all the current will flow through the switch and back to the DC input source.

Analyzing the circuit at steady state using KVL,

$Vi = V_{L,ON}$

$I_{C,ON} = I\text{o}$

Also: $T_{ON} = D\text{T}$

Mode II: Switch is OFF, Diode is ON

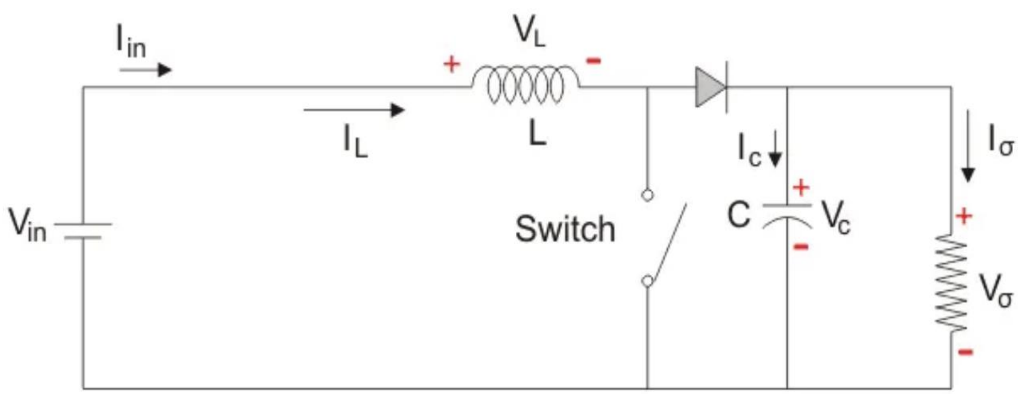

Figure 3.3 Equivalent circuit in Mode 2

In figure 3.3, the polarity of the inductor is reversed. The energy stored in the inductor is released and is ultimately dissipated in the load resistance, and this helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in conjunction with the input source.

Using KVL for analyzing the circuit in this mode,

$V_{L,OFF}$ = Vin -Vo

$I_{C,OFF}$= IL-Io

$T_{OFF} = (1\text{-}D)T$

Applying volt-sec balance

$V_{L,ON}\, T_{ON} + V_{L,OFF}\, T_{OFF} = 0$

$$v_0 = \frac{v_i}{1-D} \tag{3.1}$$

Applying ampere sec balance

$I_{C,ON}T_{ON} + \; I_{C,OFF}T_{OFF} = 0$

$$I_L = \frac{I_O}{1-D} \tag{3.2}$$

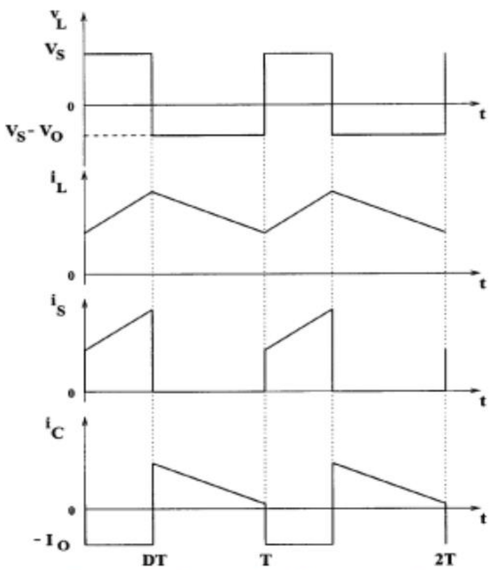

Figure 3.4 Current and voltage waveforms

3.3 DESIGN AND CALCULATION: -

Before going ahead let's define some terms and electronic devices used here:

1. *Time-Period (T)*: The time is taken by the switch to complete one cycle of ON and OFF.

2. *Duty Ratio (D):* It is defined as the fraction of the time period during which the switch is ON i.e. D=Ton/T, where "Ton" is the time during which the switch was closed.

3. *Switching Frequency (fs):* The multiplicative inverse of the Time-period i.e.

$$fs=1/T \tag{3.3}$$

MOSFET(Switch): It is the most widely used electronic switch which is due to its very small size, very low power consumption, and high switching frequency (up to nearly 20kHz). It is considered the best achievement in electronics history.

A. Conventional Design While designing the conventional boost converter, as per the required output voltage the duty cycle is calculated by equation (3.4)

$$D = 1 - \frac{Vo}{Vi} \tag{3.4}$$

B. *Selection of inductor:* The value of the inductor is selected on the basis of the estimated inductor ripple current at maximum input voltage, given by equation (3.5)

$$L = \frac{DVs}{f\Delta Il} \tag{3.5}$$

and for Continuous Conduction Mode (CCM),

$$L \geq \frac{D(1-D)^2 Ro}{2fs} \tag{3.6}$$

C. *Selection of capacitor:*-The capacitor value is calculated by the variation in output voltage or ripple given in equation (3.7)

$$L = \frac{DI_0}{fVo} \tag{3.7}$$

For Continuous Conduction Mode (DCM),

$$C \geq \frac{DVo}{VrRofs} \qquad \text{, Where Vr is Ripple factor} \tag{3.8}$$

Table 3.1 Parameters used for Boost converter design

Parameters	**Values**	**Unit**
Input voltage	16.4	volt
Output voltage	54.78	volt
Switching frequency	15000	Hz
Inductor	62.928	mH
Capacitor	23.35	uF
Duty ratio	0.70	
Output resistance	300	Ohm

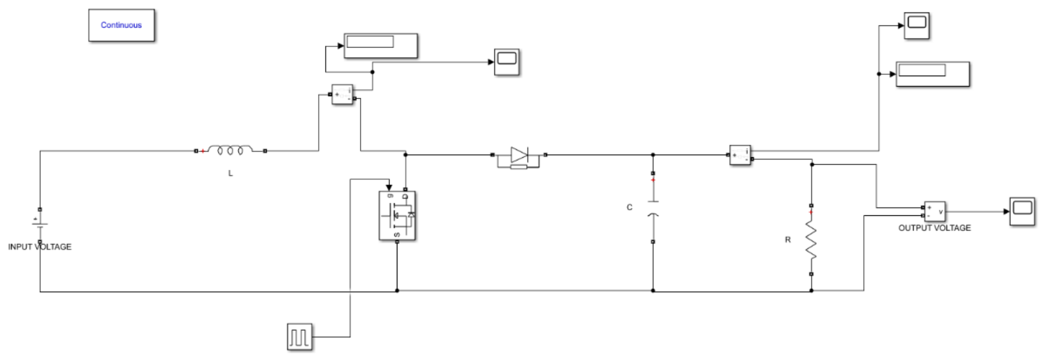

Figure 3.5 Simulink circuit for Boost- Convertor

3.4 MPP Tracking

Using the fact that input power is equal to output power we can get,

$\because Pi = Po$

$$\Rightarrow \frac{v_0}{v_{in}} = \frac{I_{in}}{I_o} = \frac{1}{1-D} \quad \rightarrow I_{in} = \frac{Io}{1-D} \quad \rightarrow R_{in} = \frac{v_{in}}{Iin} = \frac{v_0(1-D)^2}{I_0} \qquad (3.9)$$

Now as D varies from 0 to 1, hence $R\text{in}$ would vary from 0 to R. The MPPT system will modify the value of $R\text{in}$, trying to get $R\text{in}$ = R_{MPP}. However, from the graph in figure 3.6, we can see that the system will not reach MPP if $R_{\text{in}} < R_{\text{MPP}}$.

This behavior is opposite to that shown by the buck converter and therefore we can observe the inversion of zones with respect to the buck converter. Thus for this converter, the MPP capture will only be possible for $R \geq R_{\text{MPP}}$ values.

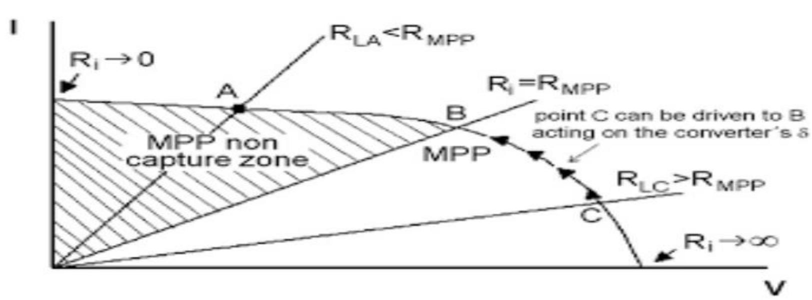

Figure 3.6 Capture zone for Boost convertor

3.5 Perturb and Observe

To understand the working principle of the Perturb and Observe method, we first need to understand the PV array's output characteristics curve of Power v/s Voltage

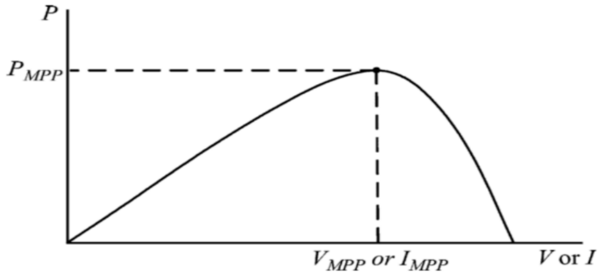

Figure 3.7 P-V curve for solar cell

In the given curve in figure 3.7, D = 1.0 at the origin, and D = 0.0 at Vmpp thus, the value of D decreases as we move from left to right in the curve. Now, we can divide the power curve into 2 parts for analysis. The part to the left of the maximum power point, and the part to the right of it. In the left part, the power output increases as we increase the voltage, or in other words, the power output increases with a decrease in the value of D. Contrast to this, in the right part of the curve, the increasing voltage (or the decreasing D) leads to a decrease in the power output.

PERTURB & OBSERVE ALGORITHM For Maximum Power Point Tracking in a PV Array: -

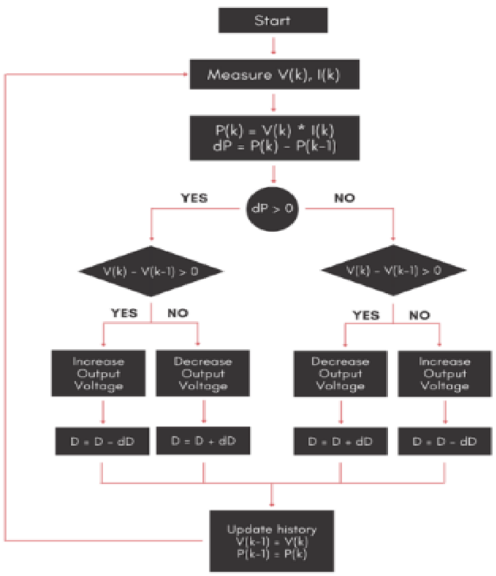

Figure3.8 *P&O flowchart*

As shown in the above figure 3.8 , the flowchart, the Perturb & Observe algorithm runs continuously in a loop. The steps of the algorithm are as follows:

• The current power output is measured using the formula $P = VI$ and the difference between current power and the power in the previous step is calculated. We also calculate the difference between the current output voltage and the voltage output in the previous step.

• If this difference is greater than zero, it means that the power is increasing, i.e., we are climbing the hill. In such a case:

i. If the voltage is increasing, it means that we are in the left part of the power curve. Thus, we need to decrease the value of D to move towards the maximum power point

ii. If the voltage is decreasing, it means that we are in the right part of the power curve. Hence, to move towards the maximum power point, we need to increase the value of D.

• If this difference is less than zero, it means that the power is decreasing, i.e., we are climbing down the hill. In such a case:

i. If the voltage is increasing, it means that we are in the right part of the power curve and hence we need to increase the value of D to approach the maximum power point.

ii. If the voltage is decreasing, it means that we are in the left part of the power curve. This, decreasing the value of D will move us towards the maximum power point

• After incrementing or decrementing the value of D accordingly, we update the values of P(k-1) and V(k-1) to the current values and then start again from step 1.

Hence, it is evident that using the Perturb and Observe method, we ensure that the circuit adjusts itself in such a way that the output power approaches the maximum power point, hence fulfilling our purpose.

After some time, we start MPPT, the power output of the PV array adjusts itself to the maximum power. Now, whenever the irradiance or temperature of solar energy changes due to some factor like clouds, rain, fog, etc. the P&O algorithm sets into motion and achieves a steady-state wherein the power output becomes equal to the maximum power output possible under the given conditions of irradiance and temperature.

```
function D = PO(time, Vpv, Ipv)
 persistent Dprev Vprev Pprev prevTime
 if isempty(prevTime)
    prevTime = 0;
    Dprev = 0.7;
    Vprev = Vpv;
    Pprev = Vpv * Ipv;
  end

  dT = time - prevTime;
 delD = 0.01;
 timeStep = 0.01;
 if dT >= timeStep && time >= 0.1
    Ppv = Vpv * Ipv;
    dP = Ppv - Pprev;
    dV = Vpv - Vprev;
    if dP ~= 0
        if dP > 0
            if dV > 0
                % left side of MPP
                D = Dprev - delD;
            else
                % right side of MPP
                D = Dprev + delD;
            end
        else
            if dV > 0
                % right side of MPP
                D = Dprev + delD;
            else
                % left side of MPP
                D = Dprev - delD;
            end
        end
    else
        % MPP reached
        D = Dprev;
    end
    % Store current values in the previous variables
    Dprev = D;
    prevTime = time;
    Pprev = Ppv;
    Vprev = Vpv;
else
    % MPPT is not engaged
    D = Dprev;
end

end
```

Figure 3.9 Implementation in MATLAB

3.6 Conclusion: -

In this chapter we understood the MPPT or Maximum PowerPoint Tracking algorithm that involves the controllers used under some conditions to draw optimal power out of the PV module. The voltage at which the PV module will generate maximal power (or peak power voltage) is called the maximum power point. Maximum power depends on solar energy, atmospheric temperature and the temperature of the solar cell. Figure 3.8 shows the flowchart of the MPPT control method. MPPT is primarily based on the extraction of full power from the PV module by letting it run at the most powerful voltage. MPPT tests the performance of the PV module and matches it with the battery voltage and fixes the best power PV module can generate in order to charge the battery. It can also provide power to a DC charge that is directly attached to the battery.

CHAPTER 4: MPPT USING BOOST CONVERTOR

4.1 INTRODUCTION

Modified Design for MPPT Operation

In MPPT the role of DC-DC converter is to shift the Vi corresponding to the VMPP although the load voltage is less (buck) or more (boost) than the input voltage or terminal voltage of solar PV system. Design becomes more difficult as the output voltage is not known corresponding to maximum power point. The modified design is in terms of impedance seen from solar PV (Zsource) presented in [4] which eliminates the term output voltage and presents the equation of

duty cycle as: $z_{source} = \frac{V_i}{I_i}$ (4.1)

For boost converter, Vi= (1-D) V0 and $I_L = \frac{I_O}{1-D}$

Substituting these values in equation (6)

$$z_{source} = \frac{v_o}{Io}(1-D)^2 \; = \; Zo(1-D)^2 \qquad (4.2)$$

Modifying above equation,

$$D = 1 - \sqrt{\frac{z_{source}}{z_o}} \qquad (4.3)$$

For transferring maximum power, Zsource = ZMPP, where, ZMPP=$\frac{Vmpp}{Impp}$.Thus, duty ratio is modified to:

$$D = 1 - \sqrt{\frac{z_{MPP}}{z_o}} \qquad (4.4)$$

From equation (4.4) duty cycle corresponding to MPP can be obtained for $0 \le D \le 1$ load impedance must be: $z_0 \ge z_{MPP}$

From equation (3.5) inductor value can be modified as:

$$L = \frac{DV_i}{\Delta I_L f_s} \qquad (4.5)$$

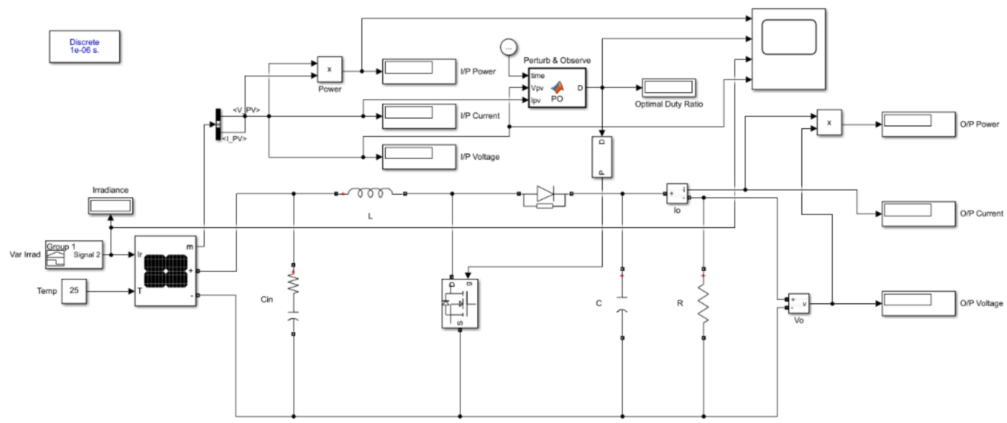

Figure 4.1 MPPT using Boost Convertor

In the above figure 4.1, circuit diagram shows the circuit used for MPPT using the P&O method in a PV system connected to a boost converter. The voltage and current outputs of the PV array are taken as inputs for the MATLAB function, which contains the code shown in Fig 3.9. This function determines the optimal duty cycle to obtain maximum power under the given conditions. This value is then fed into the MOSFET of the boost converter through a PWM generator. A signal generator with time-varying signal is connected to the irradiance input of the PV array.

4.2 Circuit parameters

T = 25℃
R = 300 Ω
C_{in} = 1000 µF
R_{in} = 0.1mH
f = 15
D = 0.7
Using formulas derived in section (3.5) & (3.8),
L = 62.928 mH
C = 23.353 µF

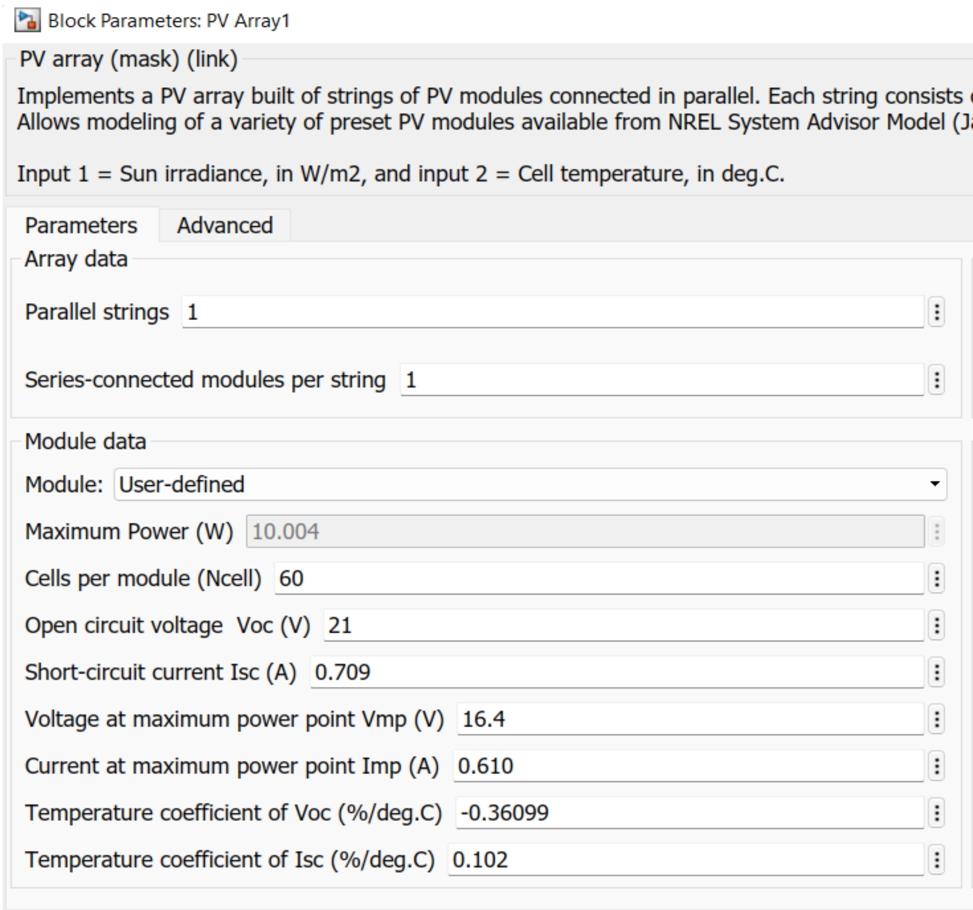

Figure 4.2 PV array & module parameters

4.3 Simulation: -

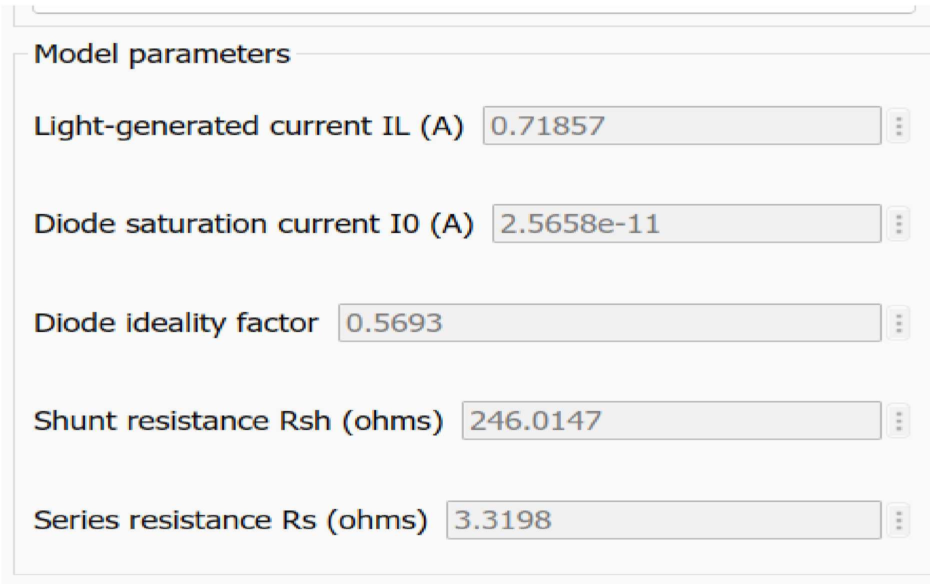

Figure 4.3 PV cell parameters

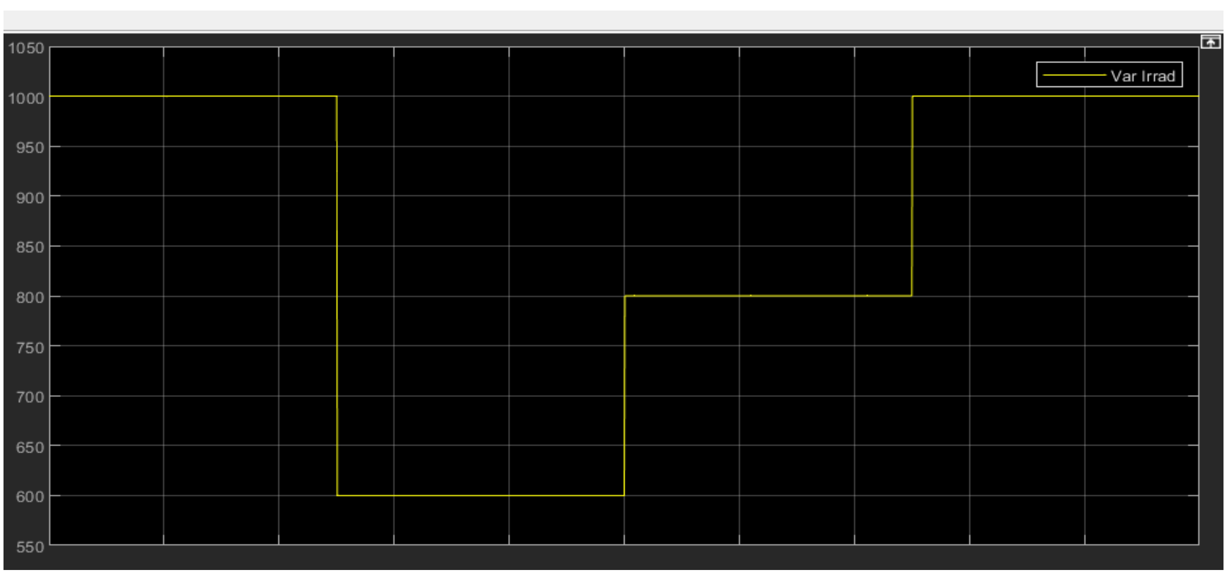

Figure 4.4 Varying irradiance

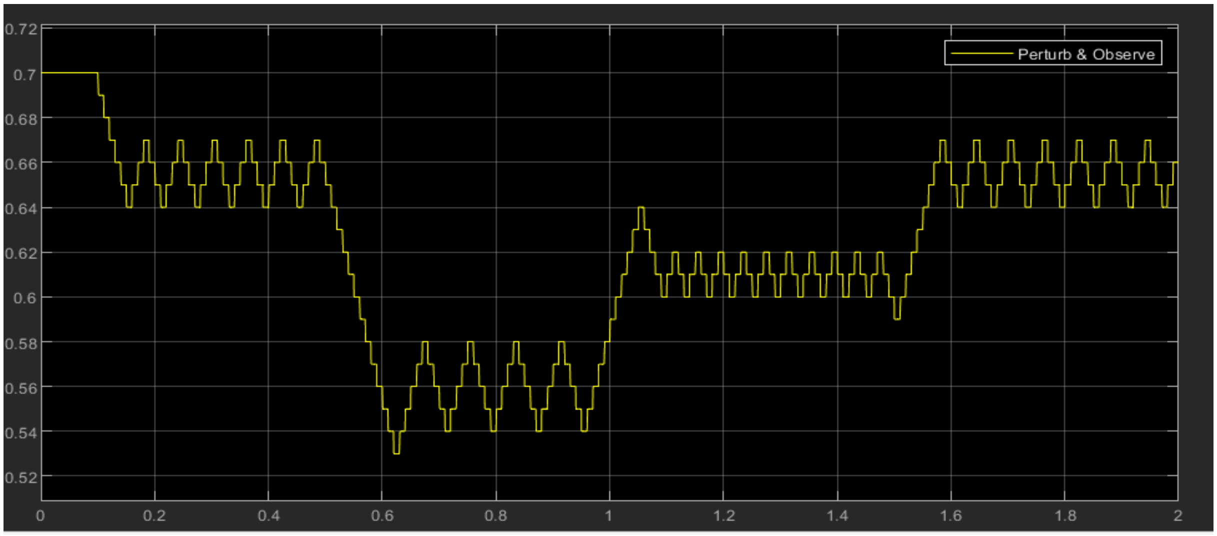

Figure 4.5 Duty ratio via P&O

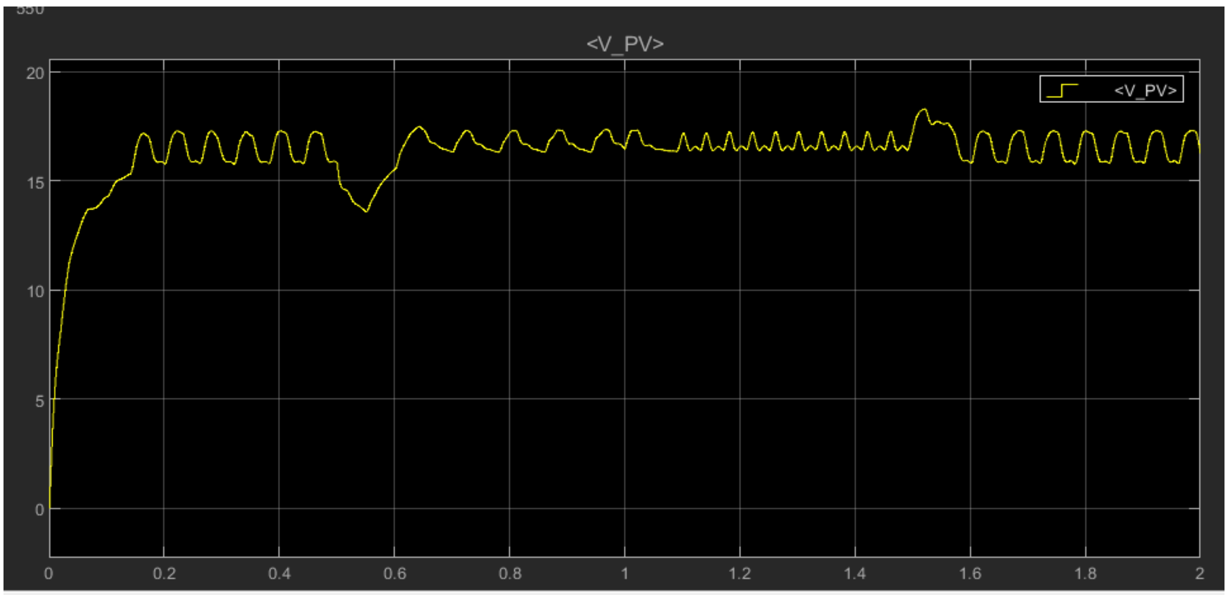

Figure 4.6 PV array voltage

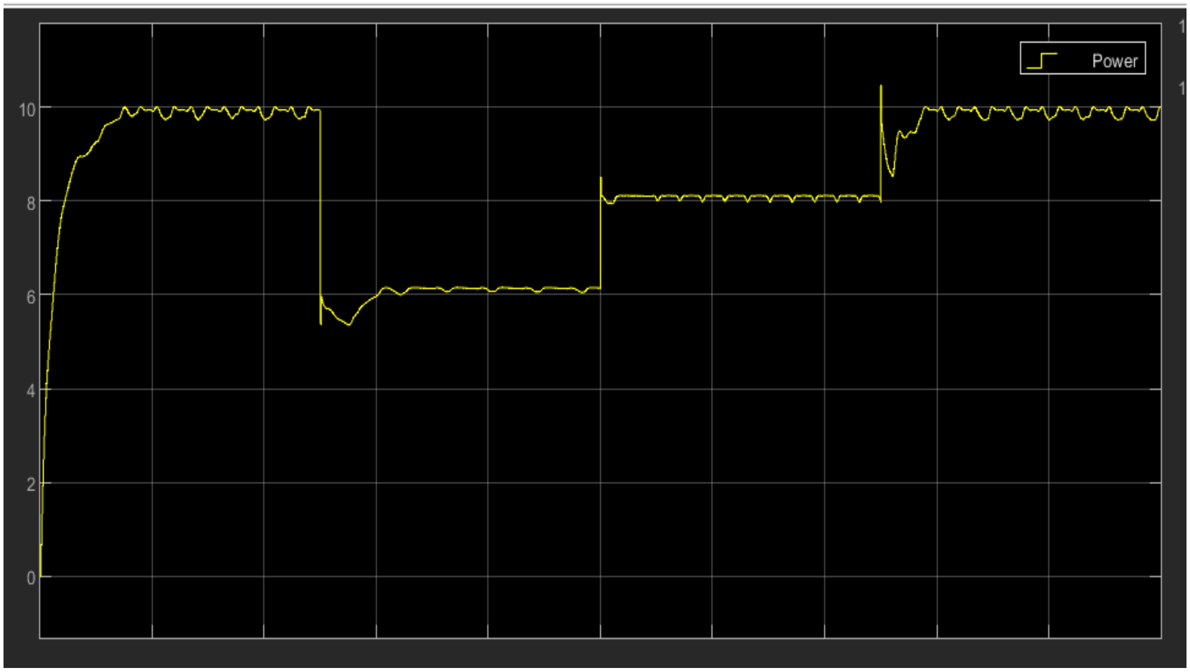

Figure 4.7 output power of PV array

4.4 Conclusion: -

Hence from the simulations, it is evident that MPPT algorithms eventually reach the optimal duty ratio required for extracting maximum power. P&O do so by changing the duty ratio slightly and observing changes. The result of this is a hill-climbing like pattern that can be seen in Fig. 4.3, Fig. 4.4, Fig. 4.5 and Fig. 4.6. Hence, at steady state, the duty ratio oscillates around the optimal value in P&O. The P&O method has been widely used for MPPT because it is straight forward. This approach requires only measurements of V_{pv} and I_{pv}, and it can track the MPPT accurately under varying irradiance and temperature. The advantage of employing boost converters for MPPT is the high efficiency that can be obtained due to absence of resistive components.

CHAPTER 5

CONCLUSION

The correct and fast tracking of MPP under change solar irradiation and change load conditions are challenging tasks for researchers. The proposed MPPT scheme provides a solution to improve the existing methods. The proposed scheme may help in achieving accurate and fast response in standalone and grid-connected solar PV energy conversion systema. It can be applied in fast-changing solar irradiation areas where solar PV is used. The limitation of the proposed method is that it is not evaluated under partial shading conditions.

By seeing the world population and demand of electricity, it is necessary to use solar power and extract more power from it, MPPT is one of the techniques to done efficiently. So as the population is increasing, there is need to use the renewable energy source. Therefore, solar energy is gaining the popularity. To extract maximum power, it is desirable to use MPPT algorithm, therefore to develop different types of algorithms of MPPT, so that maximum power can be extracted from solar energy with good efficiency.

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