CHAPTER: 1

INTRODUCTION

1.1 INTRODUCTION

Over the past few decades, electricity generation techniques across the globe have changed drastically. Solar power is among the most popular forms of renewable energy. The recent rise in the importance of PV implementations is simply because of the way they supply electrical force without hindering the earth by changing the solar irradiance into electrical force [5]. It provides several other benefits, like no cost of fuel, no pollution, lower maintenance requirements and also no noise pollution. Though, there are a few drawbacks to transforming this energy from sunlight into electricity, as we cannot harvest all the energy from the sunlight received by a solar panel [5] [9].

There are two significant issues with solar power generation: one being the varying grid power owing to the significant and abrupt changes in PV power production and another is minimal conversion efficiency. The PV array is an irregular energy source as the maximum power point varies depending on the temperature and the level of irradiation [2] [3]. Monitoring of maximum peak energy points is then required for optimum performance [1] [2]. Thus, resolving these problems is the primary focus region. A detailed research and comprehension of a PV cell and support converter depending on sunlight is conducted.

1.2 LITERATURE SURVEY

Many researchers around the world have worked on the solar power cells. It was recognized that solar cells operate at very poor effectiveness, thus requiring a stronger control system to boost the solar cell's effectiveness. Researchers in this sector have created different algorithms for extracting Maximum Power from the solar PV cell.

In the background of photovoltaic energy management, M. Veerachary provided a comprehensive study on the use of a SEPIC converter. In his study, he used a two-input converter to achieve peak solar cell energy production [14].

M. G. Villalva has presented a comprehensive method to model a solar cell using Simulink or by writing a code. The results obtained are quite similar to the nature of the solar cell output plots [12] [13].

P. S. Revankar even included the change in the tendency of the sun to lay down as much energy as necessary from the incoming solar radiation. The control system changes the panel's stance so that the incoming thermal radiation is always parallel to the panels [16].

M. Berrera contrasted seven distinct models for peak energy point monitoring using two distinct solar irradiations. This features to illustrate the output energy variability in both instances using MPPT models and optimized MPPT models [15].

Ramos Hernanz described the modeling of a solar cell and the variation of the current-voltage curve and the power-voltage curve due to changes in solar irradiation and changes in ambient temperature [17].

1.3 PRINCIPLE OF SOLAR POWER

Usable Electrical & Thermal Energy obtained from sun is called Solar Power. The most common way to harness solar energy is converting sun's rays into electricity using photovoltaic solar panels.

1.3.1 PHOTOVOLTAICS

The photovoltaic (PV) impact was first observed in 1839 however it wasn't until 1954, that researchers could find out precisely how it operates. Solar cells immediately transform sunlight into energy. Solar batteries are frequently used for calculators and watches. Space programs have historically been the biggest advocates of PV technology, as the scheme was the greatest source of electricity for their spacecraft [21]. Solar cells are produced of material comparable to those used in computer chips that are semi conductive [19]. The solar power breaks electrons free from their atoms when sunlight is consumed by these products, enabling the electrons to pass through the material to generate electricity. The method of transferring light (photons) to energy (voltage) is called photovoltaic (PV) impact. Photovoltaics work on the photovoltaic effect concept and transform solar power straight into electricity. Not enough energy is produced by a single photovoltaic cell. A set of photovoltaic batteries are therefore installed on a supporting frame and linked to each other electrically to create a photovoltaic unit or solar panel. In terms of its effectiveness, a solar cell's performance is evaluated in converting sunlight into energy. Only certain energies ' sunlight will operate effectively to generate energy and is mostly reflected or captured by the cell material. A typical industry solar cell has a 15 percent efficiency — about one-sixth of the sunshine that the cell produces energy [20]. Low efficiencies require bigger arrays, which implies greater costs.

Fig 1.1: PV array

1.3.2 PROS AND CONS OF PV CELLS

- PV devices only gather power during hours of sunshine.
- It requires longer to reimburse assembly costs for power savings.
- PV devices have a limited sunlight harnessing ability.

Solar power has many benefits, and a strong type of clean electricity is photovoltaic devices. A correctly mounted PV scheme provides plenty of power, lowers your electric charges, helps with power outages, and even earns utility bill credits when surplus energy is sent to your local power grid.

1.3.3 MATHEMATICAL MODEL

Eq. gives the distinctive V-I characteristic of a solar panel [20].

$$I = I_L - I_D \left\{ exp\left[\frac{q(V + IR_s)}{nkT_k}\right] - 1 \right\} - \left(\frac{V + IR_s}{R_{sh}}\right)$$

where

- V and I respectively depict the PV output voltage and current.
- R_s and R_{sh} are the series and shunt resistance of the cell
- q is the electronic charge.
- I_L is the light-generated current.
- I_D is the reverse saturation current.
- n is a dimensionless factor.
- k is the Boltzmann constant, and T_k is the temperature in ^oK

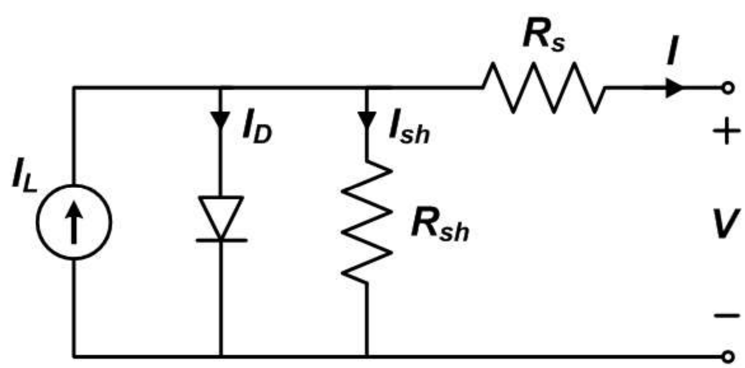
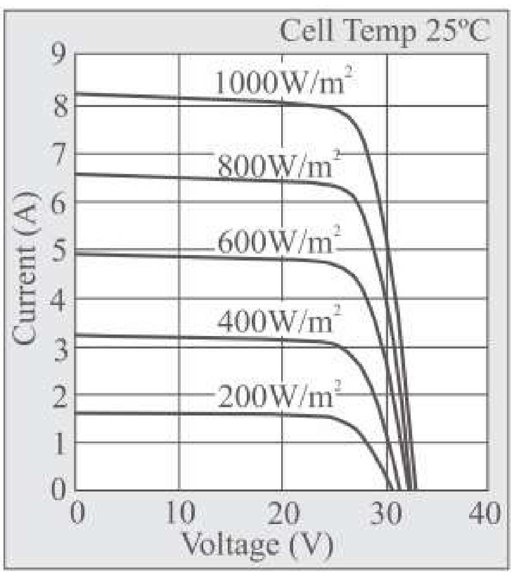


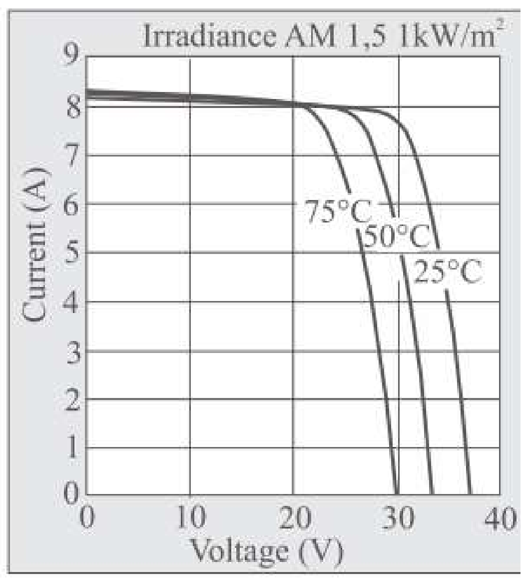
Fig 1.2: One-diode model of a solar cell [23]

By analysing the one-diode model we can show that the solar cell is the current source linked to a diode and shunt resistance in anti-parallel. In the circuit, the current source shows the current I_{PV} taken by the motion of atoms when sunlight falls on the top of the cell. The current I_{PV} relies on the quantity of free-flowing electrons inside a solar cell, which implies that the output power of a solar cell is directly related to the strength of the surface light incident.

1.3.4 DYNAMIC BEHAVIOUR WITH LIGHT & TEMPERATURE

As shown in figure 1.3 (a), the non-linear terminal voltage vs current shows that the efficiency of a solar PV relies primarily on the criterion of solar irradiance, the temperature of the environment as well as the load circumstances [23]. A solar module's output current (I_{PV}) relies on the thermal radiance and the terminal voltage, as illustrated in the figure 1.3 (b). Each curve has an MPP with the most efficient operation of the solar panel.





(a) **(b)**

Fig 1.3: IV-curve showing the dynamic behaviour under a) constant temp., b) constant irradiance and standard air mass index conditions [24]

Therefore, the current and voltage parameters are also quite vibrant appropriately in real lives as the temperature and irradiance circumstances keep changing all the time as well as MPP of solar cell also depends on the load linked to the solar panels [23].

For this research, keeping in view availability and requirements, the solar panel used is Vikram Eldora 40-P [31]. Electrical Data of Eldora 40-P at STC are shown in table 1.1.

Maximum Power (Pmax)	40Wp
Voltage at Maximum Power (Vmpp)	17.84V
Current at Maximum Power (Vmpp)	2.25A
Open Circuit Voltage (Voc)	21.95V
Short Circuit Current (Isc)	2.44A

Table 1.1: Electrical Data of Eldora 40-P at STC

The I-V and P-V characteristics of the solar panel at different irradiances and Temp = 25°C are shown in figure 1.4.

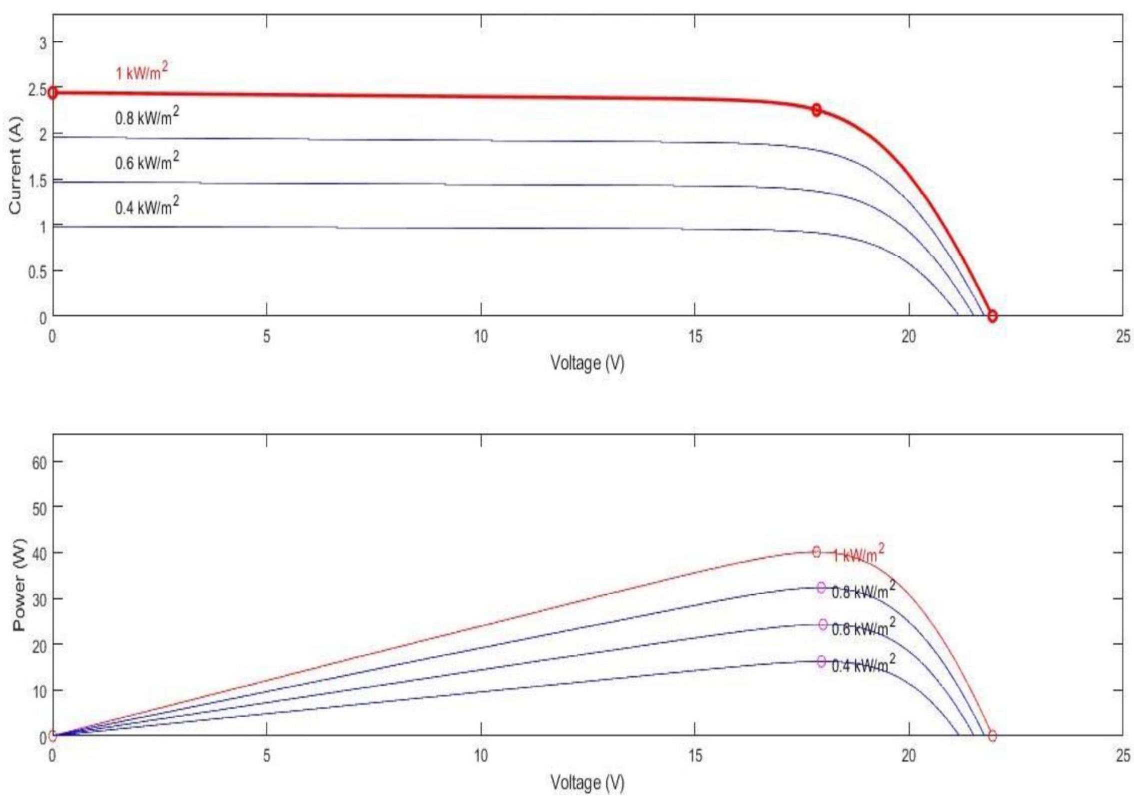


Fig 1.4: P-V and I-V Characteristic curve of Eldora 40-P

1.4 MOTIVATION

One of the burning study areas these days is photovoltaic energy management. Researchers are working round the clock to create better products for solar cells and effective systems of command. The challenges in achieving MPPT is the main motivations behind the project.

1.5 SCOPE AND STRUCTURE OF THE THESIS

The dissertation focuses on researching and developing the effective design and control of the DC-DC boost converter for achieving MPPT in PV panel. Furthermore, Arduino Uno Rev3 microcontroller is used to control the Boost converter for achieving the Maximum Power Point Tracking (MPPT) methods such as Perturb and Observe (P&O), Incremental Conductance and Adaptive Perturb and Observe.

Chapter 2 explains the fundamental knowledge of the DC-DC boost converters and the MPPT. Chapter 3 discusses the MATLAB implementation and the simulation results. Hardware implementation and results are presented in chapter 4.

CHAPTER: 2

BOOST CONVERTER AND MPPT TECHNIQUES

2.1 INTRODUCTION

This chapter focuses on the fundamentals of DC-DC boost converter, its working, modelling and design. In addition, the methods for Maximum power point tracking are discussed.

2.2 DC-DC CONVERTER FOR SOLAR PV SYSTEM

The DC-DC converter is used to output a regulated DC voltage with the designated DC input voltage. These are widely used as an interface between the photovoltaic panel and the load in photovoltaic production devices. The load must be adjusted to match the current and voltage of the solar panel in order to generate maximum power [15] [23]. DC - DC converters are recognized as energy electronic switching systems as they convert one sort of voltage into another. These can be used to transform different ranges of voltage. In general, three basic types of converters are used. They either ascend by boosting output voltage recognized as the Boost converter or stepping down by decreasing voltage recognized as the Buck converters. For both stepping up or down the voltage curve defined as Buck-Boost converters, there is another category of converters. In this thesis, we have adapted Boost Converter due to its simplicity.

2.3 BOOST CONVERTER

A boost converter is a DC-to-DC energy converter which increases voltage from input to output. It is a switched-mode power supply category that usually contains one semiconductor and one energy storage component: a capacitor, inductor, or both in conjunction as shown in fig 2.1. Filters which consists of of capacitors are usually used at the output decrease the voltage ripple in the output [28].

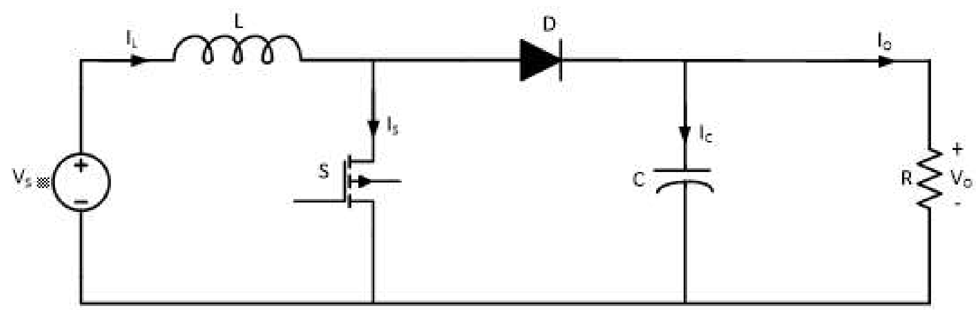


Fig 2.1: Boost Converter Circuit Diagram

A boost converter's output voltage is higher than the origin voltage. Boost converter is called step-up converter because the source voltage is "stepped up" [29]. The output current is smaller than the supply current as the power must be constant.

2.3.1 WORKING OF BOOST CONVERTER

Mode 1

Figure 2.2 depicts the boost converter when the switch is ON. When the switch is closed, the inductor is charged through battery and stores the energy. In this mode, inductor current rises but for simplicity, we assume that the charging and the discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor [30].

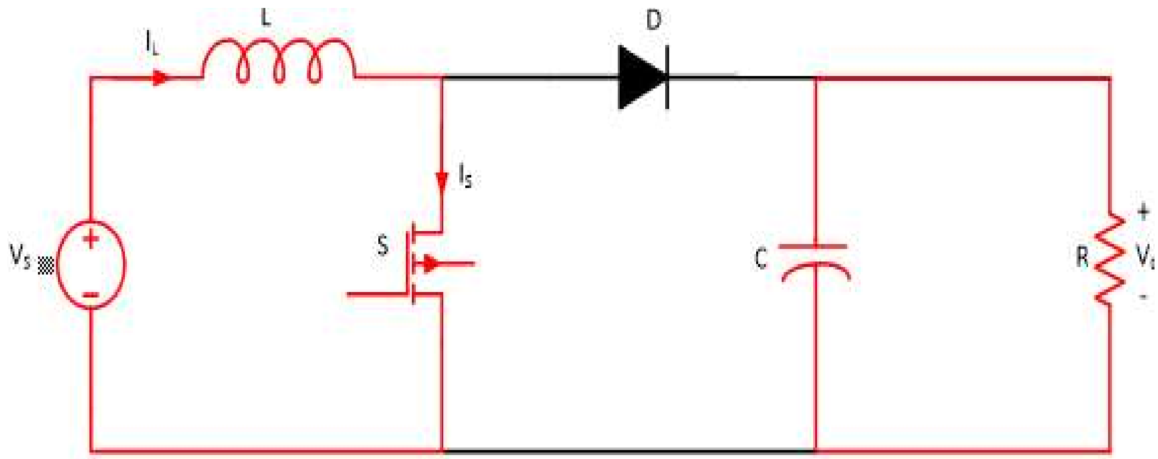


Fig 2.2: Switch ON Mode

During Turn ON

$$V_L = V_S$$

$$I_C = \frac{-V_O}{R}$$

Mode 2

Figure 2.3 depicts the boost converter when the switch is OFF. In this mode the switch is open and so the diode becomes short circuited. The energy stored in the inductor gets discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation [30].

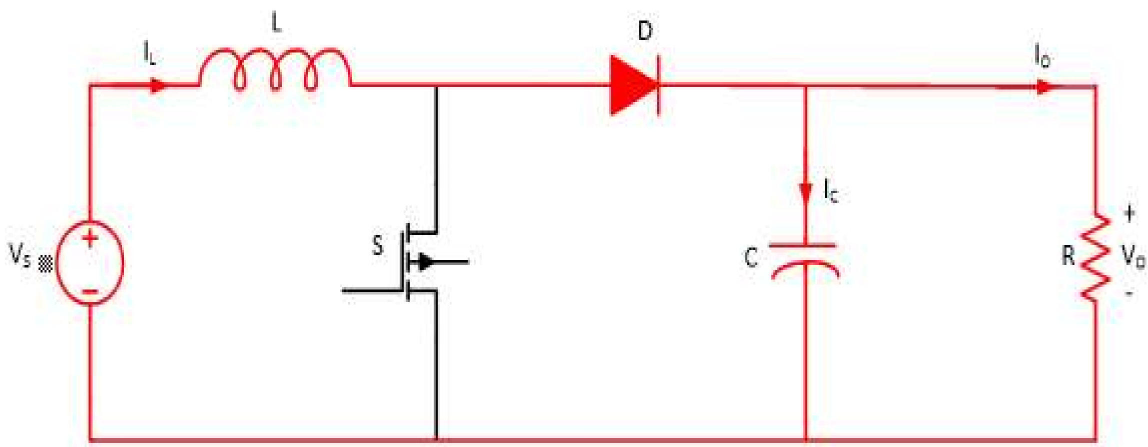


Fig 2.3: Switch OFF Mode

During Turn OFF

$$V_L = V_S - V_O$$

$$I_C = I_L - \frac{V_O}{R}$$

2.3.2 IDEAL WAVE FORMS

The distinct features of boost converters are shown in Figure 2.4. It indicates the source voltage, source current, inductor current, capacitor current for a full cycle of operation.

It is assumed that at a fixed frequency the switch is made ON and OFF and that the period corresponding to the frequency of switching is T. If the duty cycle is D then the switch is ON for a period equal to DT and OFF for the remaining time.

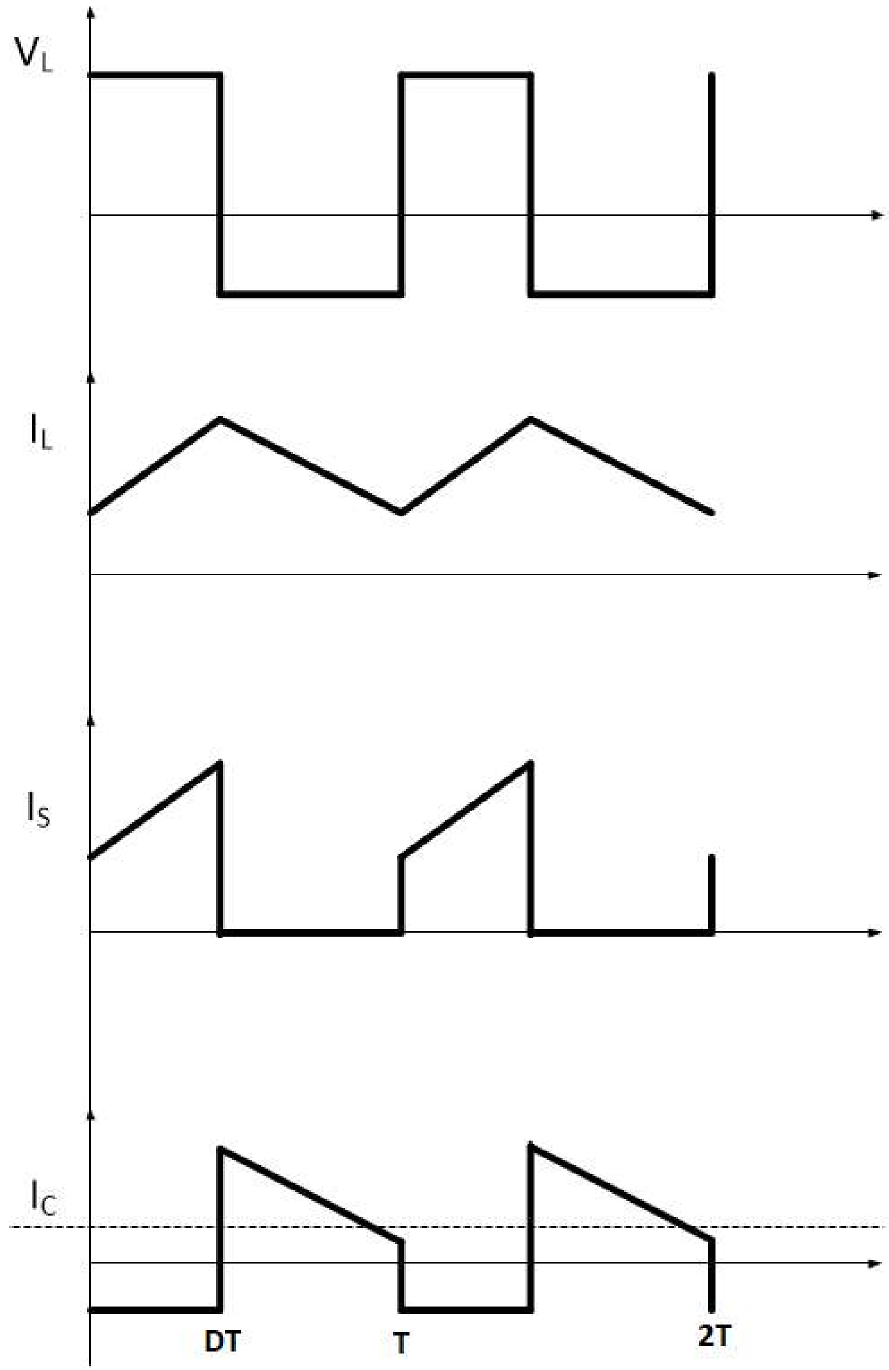


Fig 2.4: Typical voltage & current waveforms of a boost converter [23]

2.3.3 MODELLING OF BOOST CONVERTER

The DC-DC boost converter circuit consists of Inductor (L), Diode (D), Capacitor (C), load resistor (R_L) and the control switch(S). These components are connected in such a way with the input voltage source (Vin) steps up the output voltage (Vout). The duty cycle of the control switch controls the output voltage of the boost converter [29]. Hence by varying the ON time of the switch, the output voltage can be varied. Thus, for the duty cycle "D" the average output voltage can be calculated using

$$V_o/V_{in}=1/(1-D)$$

where V_{IN}, V_O are the input and output voltage of the converter respectively and D is the duty cycle of the control switch. In an ideal circuit, the output power of the converter is equal to input power which yields.

$$P_o = P_{in}$$

$$\text{i.e. } V_oI_o = V_{in}I_{in}$$

Applying Voltage-second balance

$$\int_0^{Ts} V_L(t)dt = (V_S)DT_S + (V_S - V_O)\, D'TS$$

$$\int_0^{Ts} V_L(t)dt = 0$$

$$V_S\,(D + D') - V_OD' = 0$$

$$D + D' = 1$$

$$\therefore \boxed{V_O = \frac{V_S}{(1-D)}}$$

Applying Charge-second balance

$$\int_0^{Ts} I_C(t)dt = (\frac{-V_O}{R})DT_S + (I_L - \frac{V_O}{R})D'T_S$$

$$\int_0^{Ts} I_C(t)dt = 0$$

$$\frac{-V_O}{R}(D + D') - I_L D' = 0$$

$$D + D' = 1$$

$$\therefore \boxed{I_L = \frac{V_O}{(1-D)R}}$$

2.3.3.1 Selection of Inductor:

Value of inductance must be chosen appropriately such that it can handle peak and RMS current over complete range of output and input Voltage.

During Turn ON

$$V_{in} - L\frac{dI_L}{dt} = 0$$

$$V_{in} = L\frac{dI_L}{dt}$$

$$\int_0^{DT_S} V_{in}(t)dt = \int L dI_L$$

$$V_{in}(DT_S) = L\Delta I_L$$

The inductor value of the Boost converter is calculated using

$$\boxed{L = \frac{V_{in}D}{f_s \Delta I_L}}$$

Where f_s is the switching frequency and ΔI_L is the input current ripple. Current ripple factor (CRF) is the ratio between input current ripple and output current. For good estimation of inductor value CRF should bound within 30% [29] [30].

$$\Delta I_L/I_o = 0.3.$$

The current rating of inductor should be always higher than that of the maximum output.

The DC-DC boost converter in this thesis is designed for V_{in}= 17V, V_{out} = 24 V, I_{out} =1.8A, f_s = 30kHz.

$$L = \frac{17 * 0.29}{30000 * 0.714} H$$

$$L=230\mu H$$

2.3.3.2 Selection of Capacitor:

Based on the maximum ripple in input voltage, capacitor value is calculated.

During Turn ON

$$V_C - V_O = 0$$

$$V_C = \frac{1}{C}\int I_{out} dt$$

$$\frac{1}{C}\int_0^{DT_S} I_{out} dt = V_O$$

Differentiating both sides

$$\frac{1}{C} I_{out} DT_S = \Delta V_O$$

The capacitor value can be obtained from

$$\boxed{C = \frac{I_{out} D}{f_s \Delta V_O}}$$

Where ΔV_o is the output voltage ripple which is usually considered as 5% of output voltage which yields, $\Delta V_o/V_o$= 5%.

$$C = \frac{1.8 * 0.29}{30000 * 0.05 * 24} F$$

$$C=15\mu F$$

2.4 MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking (MPPT) is an efficient method for PV systems to enhance the solar energy to solar power conversion efficiency. The peak value of PV output current Ipv and voltage Vpv is located in the IV curve MPP [6]. Since this stage is non-linear and continues to change based on the climatic circumstances, it must be continually monitored and the PV module must be operated on this MPP. MPPT is recognized as this whole method of monitoring the point and running the PV system at the full energy level [10]. Figure presented the P-V curve of a solar module where the generated power is plotted vertically and output voltage is plotted horizontally.

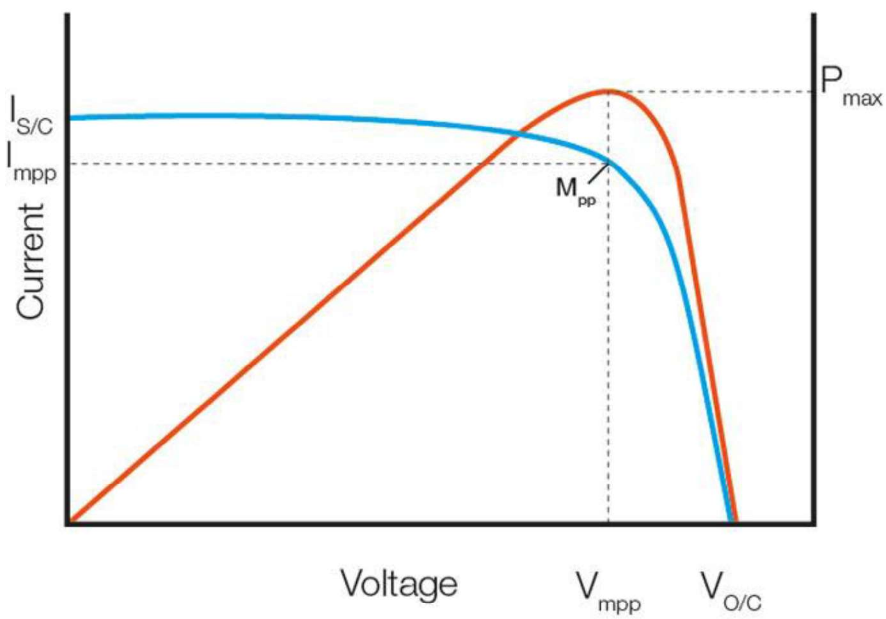


Fig 2.5: I-V and P-V characteristics of solar PV cell

The monitoring of MPP and the operation of the PV module on MPP involves two primary categories. One might be related to the type of DC-DC converter and the type of load connected to the PV source, while the other might be the software or the techniques of MPPT achieving.

2.3.1 METHODS FOR MPPT

There are many methods used for maximum power point tracking a few are listed below:

- Constant Voltage method
- Constant Current method
- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method

CONSTANT VOLTAGE METHOD

In this method, the power supplied to load is interrupted then open circuit voltage is measured at zero current. Then controller operates with voltage controlled at fixed ratio. The ratio of these two voltages is generally constant for a solar cell, roughly around 0.76. Thus, the open circuit voltage is obtained experimentally and the operating voltage is adjusted to 76% of this value. This method which is a not so widely used method because of the losses during operation is dependent on the relation between the open circuit voltage and the maximum power point voltage.

CONSTANT CURRENT METHOD

Similar to the constant voltage method, this method is dependent on the relation between the open circuit current and the maximum power point current. The ratio of these two currents is generally constant for a solar cell, roughly around 0.95. Thus, the short circuit current is obtained experimentally and the operating current is adjusted to 95% of this value. Since the losses depend on the relation between the open circuit current and the maximum power point current, this method is not much used.

PERTURB AND OBSERVE METHOD

This method is the most commonly used algorithm. In this method, very a smaller number of sensors are required. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and calculates dP/dV. If dP/dV is positive, then the algorithm increases the voltage value towards the MPP until dP/dV is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but oscillates around the maximum power point (MPP). Flow chart of the algorithm is shown in fig 2.6.

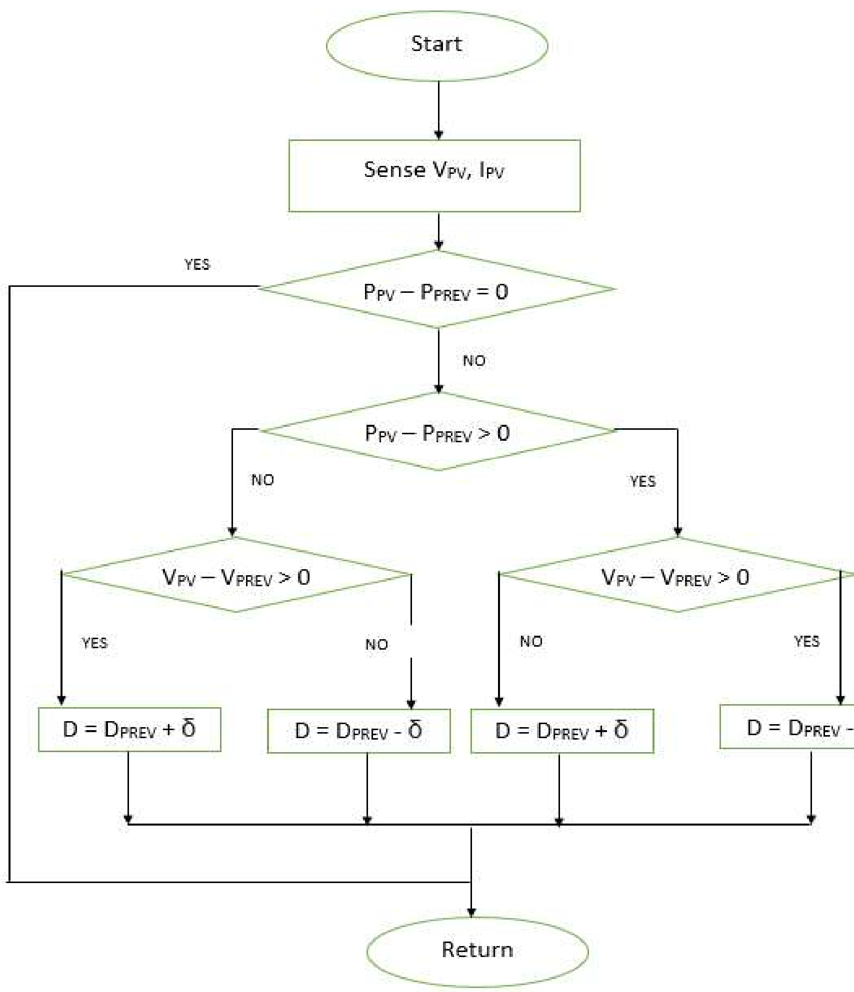


Fig 2.6: Flow chart of Perturb and Observe MPPT algorithm

INCREMENTAL CONDUCTANCE METHOD

This method uses the PV array's incremental conductance dI/dV to compute the sign of dP/dV. When $dI/dV$is equal and opposite to the value of I/V (where dP/dV=0) the algorithm knows that the maximum power point is reached and thus it terminates and returns the corresponding value of operating voltage for MPP. This method tracks rapidly changing irradiation conditions more accurately than P&O method. One complexity in this method is that it requires many sensors to operate and hence is economically less effective.

P=V*I

Differentiating w.r.t voltage yields;

dP/dV=$d(V*I)dV$

$dP/dV = I*(dV/dV) + V*(dI/dV)$

$dP/dV = I + V*(dI/dV)$

When the maximum power point is reached the slope dP/dV=0. Thus the condition would be;

dP/dV=0

$I + V*(dI/dV) = 0$

$dI/dV = -I/V$

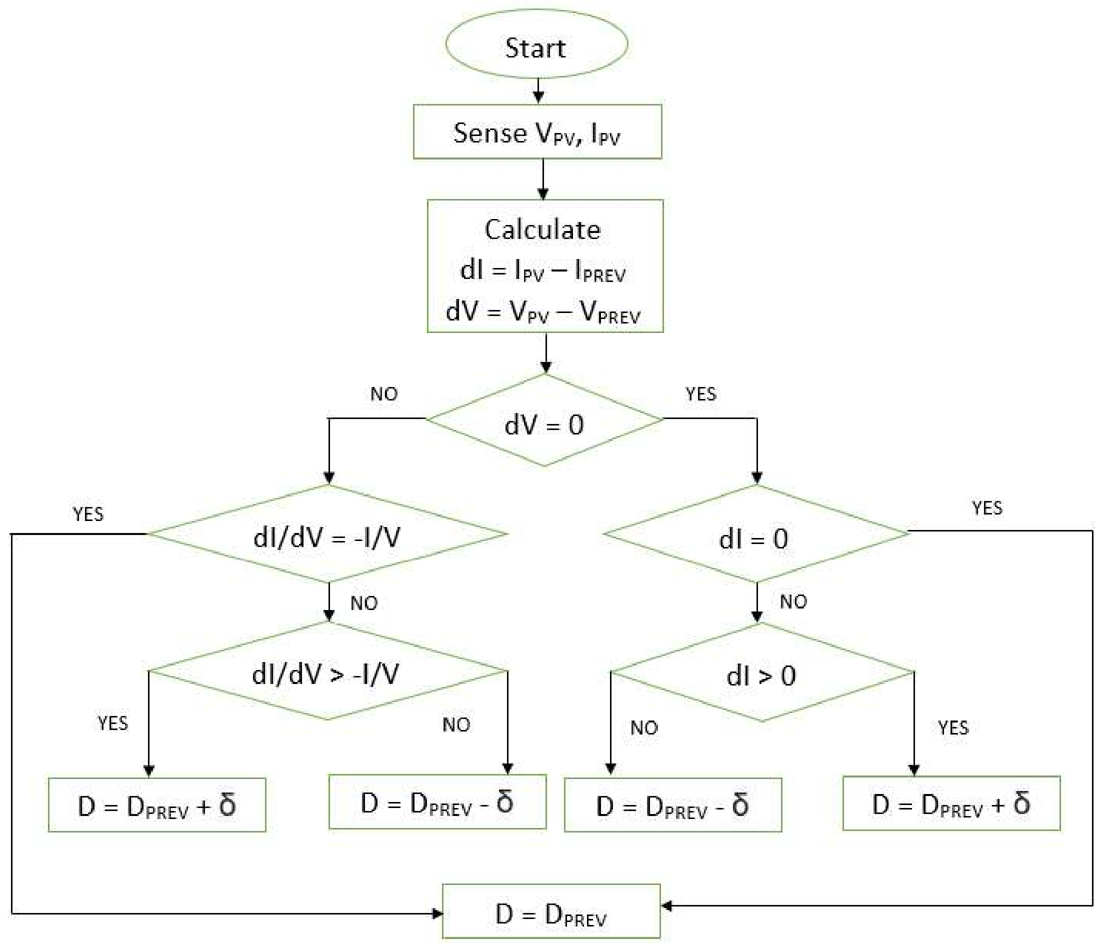


Fig 2.7: Flow chart of Incremental Conductance MPPT algorithm

PARASITIC CAPACITANCE METHOD

This method is an improved version of the incremental conductance method, with the improvement being that the effect of the PV cell's parasitic union capacitance is included into the voltage calculation.

The methods have certain advantages and certain disadvantages. Choice is to be made regarding which algorithm to be utilized looking at the need of the algorithm and the operating conditions. For example, if the required algorithm is to be simple and not much effort is given on the reduction of the voltage ripple then P&O is suitable. But if the algorithm is to give a definite operating point and the voltage fluctuation near the MPP is to be reduced then the IC method is suitable, but this would make the operation complex and more costly. This research proposes a confined search space based improved P&O algorithm.

PROPOSED CONFINED SEARCH SPACE-BASED P&O METHOD

Reduction in the search space reduces the response time to reach the maximum power and the oscillations of the steady-state. Enslin et al. (1997), Huynh and Dunnigan (2016) states that the V_{MPP} is about 76% of the open circuit voltage (V_{MPP} = 76% of V_{OC}) [11]. So, The P-V curve was divided into three areas named Area1, Area 2, and Area 3 as shown in Fig 2.9.

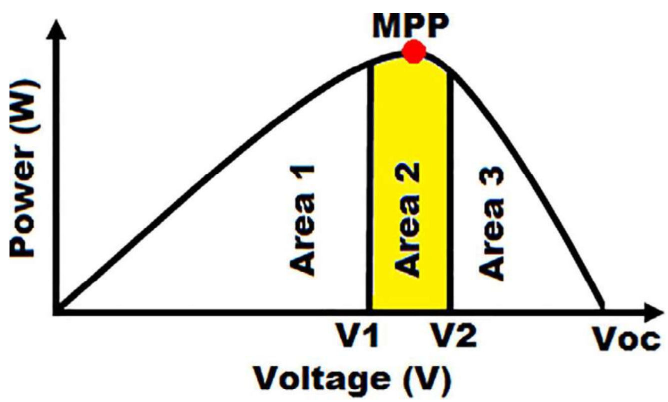


Fig 2.8: Search space limitation of the power curve

Area 1 and Area 3 contain 90% of the region of the power curve removed from the search room. Area 2 is the MPP region comprising only 10 percent of the PV curve and the enhanced algorithm requires to search for the highest energy stage only in area 2 which decreases the algorithm's phase reaction time and eliminates the MPP's steady state oscillations. Specifications of each of these areas are given in Table 2.1.

	Starting (% of V_{OC})	Ending (% of V_{OC})	Total Area (% of V_{OC})
Area 1	0	70	70
Area 2	70	80	10
Area 3	80	100	20

Table 2.1: Area distribution of power curve

It first estimates the voltages V1 and V2 to locate the region comprising MPP to limit the solar panel's working point to area 2 which is only 10 percent of the energy curve and then begins disturbance and inspection. MPP is accomplished and retained in a few disturbances. It sticks to the highest energy level under standardized climate circumstances while it discovers fresh local maxima as defined for the steady irradiance as the irradiance modifications and then retains it.

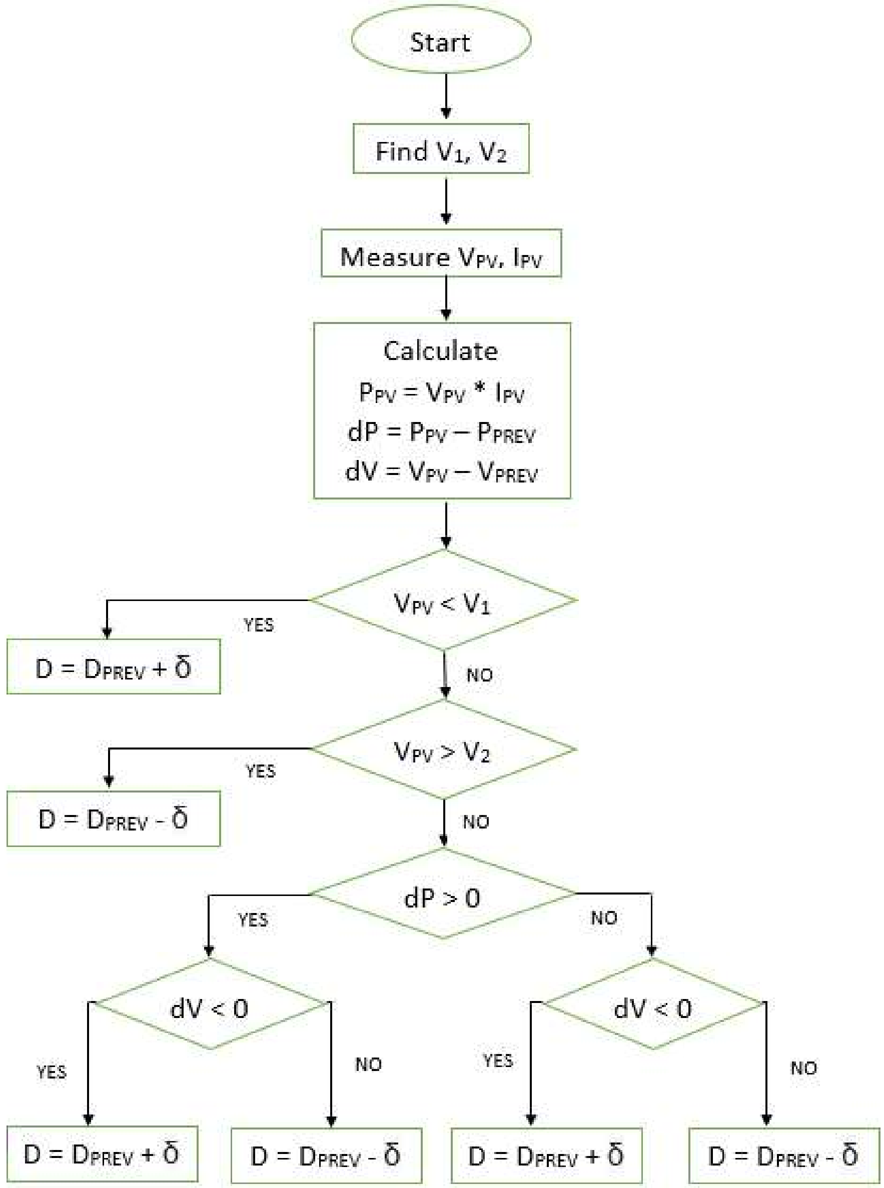


Fig 2.9: Flow chart of Modified Perturb and Observe MPPT algorithm

These 3 algorithms are implemented using the Embedded MATLAB function of Simulink, where the codes written inside the function block are utilized to vary certain signals with respect to the input signals.