T.C.

ISTANBUL AYDIN UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

EFFECT OF DIFFERENT MPPT ALGORITHM FOR LINEAR AND NON-LINEAR LOADS IN PV SYSTEM

MASTER'STHESIS

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ONAY FORMU

DECLARATION

I hereby declare with respect that the study "Effect Of Different Mppt Algorithm For Linear And Non-Linear Loads In Pv System", which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the Project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the Bibliography.

Halmat SAEED

FOREWORD

First of all, I want to thanks Allah for blessing me with the talents necessary to complete this thesis. Professor Murtaza FARASADI spent many hours assisting me with writing this document. And also I would like to thank the institute of applied science of Istanbul Aydin University, the Department of Electrical and Electronic Engineering, every person who gave me any support or advice which help me in my work.

May, 2021   **Halmat SAEED**

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ABBREVIATIONS

AC	: Alternating Current
DC	: Direct Curent
PWM	: Pulse With Modulation
SPWM	: Sinusoidal Pulse With Modulation
kW	: Kilo Watt
MPPT	: Maximum Power Point Tracker
MPP	: Maximum Power Point
PV	: Photo Voltaic Panel
GW	: Gega Watt
P&O	: Perturb And Observe
INC	: Incremental Conductance
HC	: Hill Climbing
D	: Duty Ratio
I-V	: Current-Voltage
I	: Current output.
I_0	: Dark current saturation.
q	: The number of electronic charge constant (1,602.10-19 Coulomb)
k	: Boltzmain constant (1,38. 10-23 J/K)
R_{sh}	: Shunt resistance
Rs	: The series resistance.
T	: Temperature of the cell [Kelvin]
A	: Ideality factor of the diode.
n_p	: Number of solar cells in parallel
n_s	: The number of solar cells in series
FF	: Fill factor
f	: Frequency (Hz)
V_0	: The output voltage
V_{in}	: Input Voltage
t_{on}	: The period time on
t_{off}	: The period time off
Isc	: Short-Circuit Current
Voc	: Open-Circuit Voltage

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EFFECT OF DIFFERENT MPPT ALGORITHM FOR LINEAR AND NON-LINEAR LOADS IN PV SYSTEM

ABSTRACT

The output power of a PV array is dependent on environmental factors such as solar irradiation and temperature, So, it has a non-linear I-V characteristic. Maximum Power Point (MPP) is a point on the I-V, P-V characteristic curve of a PV array where the PV device generates maximum output power. The location of MPP shifts as the climate changes. MPPT's aim is to keep the solar operating voltage as similar to MPP as possible under changing environmental conditions. They must run at their MPPT considering the inhomogeneous shift in environmental conditions in order to continuously gather the full power from the PV array. here the most commonly used MPPT algorithms for PV applications are illustrated because they are easy to implement which are Perturb and Observe (P&O), Hill Climbing (HC) and Incremental Conductance (INC). In this paper, the applications of those three MPPT algorithms in PV systems at linear and nonlinear loads have been investigated. Comparative analysis has been done and the efficient one based on different testing scenarios has been determined based on output results.

Key Words: *MPPT, PV System, linear load, non-linear load.*

PV SİSTEMİNDEKİ DOĞRUSAL VE DOĞRUSAL OLMAYAN YÜKLER İÇİN FARKLI MPPT ALGORİTMASININ ETKİSİ

ÖZET

Bir PV dizisinin çıkış gücü, güneş ışınımı ve sıcaklık gibi çevresel faktörlere bağlıdır, bu nedenle doğrusal olmayan bir I-V karakteristiğine sahiptir. Maksimum Güç Noktası (MPP), PV cihazının maksimum çıkış gücü ürettiği bir PV dizisinin I-V, P-V karakteristik eğrisi üzerinde bulunan bir noktadır. İklim değiştikçe MPP'nin yeri de değişir. MPPT'nin amacı, değişen çevre koşulları altında güneş enerjisi çalışma voltajını mümkün olduğunca MPP'ye benzer tutmaktır. PV dizisinden tam gücü sürekli olarak toplamak için, çevre koşullarındaki homojen olmayan değişimi göz önünde bulundurarak MPPT'lerinde çalışmalıdırlar. burada PV uygulamaları için en sık kullanılan MPPT algoritmaları gösterilmektedir, çünkü bunların uygulanması kolaydır, bunlar Perturb and Observe (P&O), Hill Climbing (HC) ve Incremental Conductance (INC). Bu yazıda, bu üç MPPT algoritmasının PV sistemlerindeki doğrusal ve doğrusal olmayan yüklerdeki uygulamaları incelenmiştir. Karşılaştırmalı analizler yapılmış ve farklı test senaryolarına dayalı verimli olanı çıktı sonuçlarına göre belirlenmiştir.

Anahtar Kelimeler: *MPPT, PV Sistemi, doğrusal yük, doğrusal olmayan yük.*

1. PHOTOVOLTAIC SYSTEM CONFIGURATION

1.1 Introduction

Nowadays the hot topic in the world is climate change. One of the main causes of climate change is using fossil fuels. One of the most widely used effective ways to tackle climate change issues is the installation of renewable energy sources including PV systems. [1]it is clean, free, and renewable. According to the connection to gride or not the photovoltaic systems can arrange as: stand alone and grid connected PV systems. Stand-alone photovoltaic systems are used for locations that are not connected to the electrical grid. The performance of the PV system in these systems is determined by the operating conditions. The maximum power point (MPP) PV source can be affected by three factors: radiation, load characteristics, and temperature. A grid-connected PV system is used in locations with easy access to the connected electrical network.

The earth's climate has fluctuated cycling for 2.4 million years from ice periods to warmer time but from 1900 the global temperature has risen very quickly about 1.2 to 1.4 Fahrenheit. for that reason, the countries wanting to reduce greenhouse gas like carbon dioxide and chlorofluorocarbons emission.

Most countries try to reduce the emissions, the European commission one of the most group the take this seriously, according to the plan of commission they trying to reduce air pollution in 2050 85-95% reducing air pollution compared to 1990. The European Commission policy focused on reducing CO2 emissions by 40%. And 60% in 2030 and 2040, respectively. The current policy corresponds to a 30% reduction in domestic emissions in 2030 and 40% in 2050 as showing in figure 1.1. However, predictions made by Manowska & Korban (2011) show that EU guidelines for reducing CO2 emissions by 20% compared to 1990 emissions are not being developed [2].
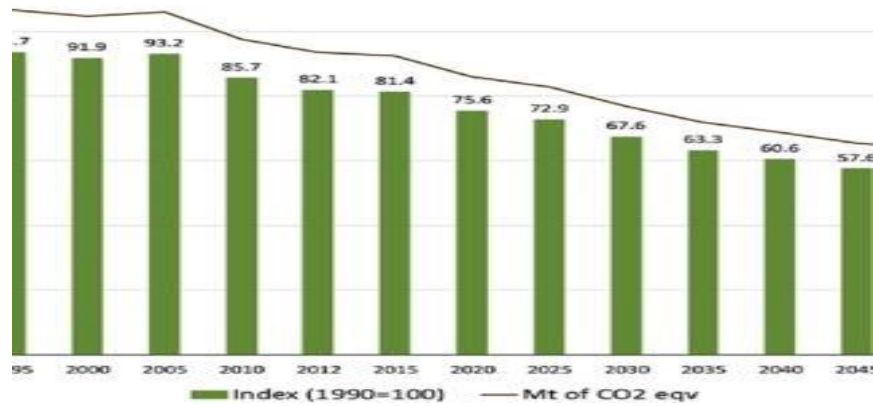
Figure 1.1: Greenhouse gas emissions realized and projected in the European Union for years

As we know that power generation by photovoltaic (PV) play a very big role to reduce greenhouse gas.

The lifetime of (PV) system around 25 years, this is a weak point of solar energy. in the last few years, in the last decade, renewable energy especially solar energy witnessed massive growth globally, because in this last decade the price of installation of PV system is very low. the global installed PV system in 2016 about 310 GW but in 2017 increased approximately 85 GW which mean in 2017 the global capacity is 395 GW generate by solar cell globally. Global capacity may quadruple to 700 GW by the end of this year, the increasing in PV system is continue and in 2050 it could be 4500 GW [3]. This increase in PV system installation is pushing Europe towards responsible end-of-life management of PV modules that have taken shape in the Waste Electrical and Electronic Equipment Directive (WEEE; Directive 2012/19 / UE of the European Parliament and Council) [2] [4].

Photovoltaic system is suitable to installing in a place that no other use, desert, and roof, also we can use PV system as only energy source in remote location if we do not have electricity network which is called off-grid which is hard and very expensive if we connected to grid sometime, we use this place temporary.

However, most photovoltaic power generation comes from grid-connected installations that are supplied from the grid. In fact, China is the fast-growing business developed country which focused on renewable energy especially solar energy, which in 2019 was the world leader in photovoltaic energy, followed by

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the United States and India, with a ratio of (48,12.5,10) per year demand, respectively[4].

in the last decades, the researchers have focused on reducing the cost of photovoltaic system and increasing the efficiency of the system. Current development of research studies could find a method for modular photovoltaic technology. now it can produce the panels which are cheaper and more efficiently in power generation compared to the past decade as shown in figure 1.2 [5]. We can say the price of production for (1 watt) will be reduce everyday by effect of science.
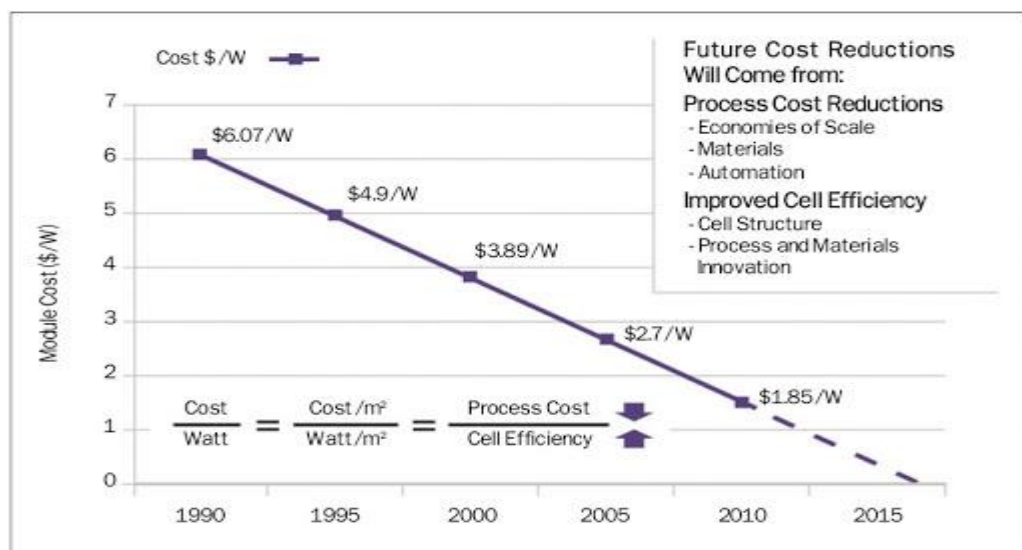
Figure 1.2: shows the history price of solar cell in US dollar.

In developing the efficiency of photovoltaic power plants, the power generated is a key aspect, because it increases revenue as well as reduces the cost of energy produced by approximating the cost of energy produced. From other sources.

The efficiency of photovoltaic system mainly affected by the operator which it is possible to increase or decrease when manufacturing: efficiency of PV panel (8-15%) in commercial depended on technical and used material for manufacturing, efficiency of the inverter which is between (95.5-98%) and the algorithm using to find maximum power point tracking (MPPT) is over (98%) increasing the efficiency. Two of them which are invertor, and the solar panel are not easy to change as they will cost more than expected. we also cannot change the system that already installed. In contrast, control algorithm (MPP)

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maximum power point is best and easy way to work on for increasing efficiency. By apply this technic to the plants that already installed we can get the same result just by update the control algorithm, the effect (MPP)on the PV system is quick and make a power generation is increase and cost will be decrease [6].

MPPT Maximum power point tracking algorithms are needed to get the best power that the solar panel or array can produce because solar energy power-voltage has a non-linear characteristic in a single point in power-voltage carve where the power is maximum algorithm automatically try to find this point [7]. This point (MPP) is changing with changing the irradiance or temperature fall on the panel. Irradiance and temperature situation probably not stable for a long time, this is the main reason to use the MPPT. the irradiance and temperature are different in the different seasons, so the power output changes with changing the season [8].

Moreover, when the atmospheric change such as clouds the irradiance change very quickly and power generation by the panel is change, we should find the new point that the power is maximum the best and easy way is using MPPT technical.

In the previous several MPPT algorithms have been found and published. Which are different in many sides like easy in practice or complex in practice also it is efficiency good or bad. Now it is easier to decide, we choose and use the algorithm that simpler and cheaper in price and we get the same result.

The purpose of this thesis is explained and examine the various MPPT algorithms. The most three popular, P&O perturb and observe, (INC) incremental conductance, and Hill climb (HC), are in-depth analyzed and tested under different condition like standard test condition (STC), changing irradiance, changing temperature when connectet to linear and non-linear load the loacking the result. Subsequently, advance to the P&O, INC, and HC algorithms are proposed for successful MPP tracking under radiation change conditions. At last, we show that MPPT algorithm can find maximum power in all condition like change in irradiance and change temperature.

In the last simple model is made, for each algorithm to show the respond of changing irradiance and temperature on the output power based on using each algorithm.

This thesis may be interested to those readers who are seeking a more in-depth knowledge of MPPT monitoring or those students seeking an introduction to photovoltaic power generation [9].

1.2 Principle Operating of Solar Cell

The main component in the industrial for photovoltaic panel is silicon, However, other materials are sometimes used. but silicon is best because it is cheap, and it is a lot of nature silicon accounts for 26% of the earth's crust.

The semiconductor can convert radiation which is electromagnetic into electric current. Solar cells use this characteristic of the semiconductor to generate an electric current.

Accidental radiation produces charged particles that are quickly separated to generate an electric current that is tailored to the solar cell architecturein. Here explain the detail of semiconductor working [10]

The P-N junction is the essential part of the solar cells. the P and N are the silicon semiconductor that connected which has added some amount of impurity atoms. Free electrons (donor) are the dominant charge carriers in N-type semiconductors, whereas holes (acceptor) are the majority charge carriers in P-type semiconductors [10].

In p-type semiconductors, Because the p-layer has a surplus of holes, holes are the major charge carriers. Because the n-layer in n-type semiconductors has an excess of electrons, electrons are the major charge carriers. When p-type and n-type semiconductors are joined, a junction is formed. The p-n junction creation of the depletion region occurs when p-type semiconductors are appropriately joined to an n-type semiconductor, resulting in a gap between them. The p-n junction, which is prepared by mixing p-type and n-type semiconductors, distinguishes p-type and n-type semiconductors. However, some electrons from the N side enter the P side, and some holes from the P side enter the N side, thus these electrons and holes join at the junction, and the hole and electron

neutralize each other, as observed. As a result, on the p side, only negative ions are left, while on the n side, only positive ions are leftOn each side of the junction, the deplition zone (D) becomes free of mobile charge carriers, with no free electrons on the n-type side and only stationary donor and acceptor ions on the p-type side. Because only immobile donor and acceptor ions exist on each side of the PN junction, the region next to it is known as the depletion region because it is devoid of mobile charge carriers. The potential barrier is the potential gap VD across the junction that prohibits holes and electrons from flowing forward. [11].
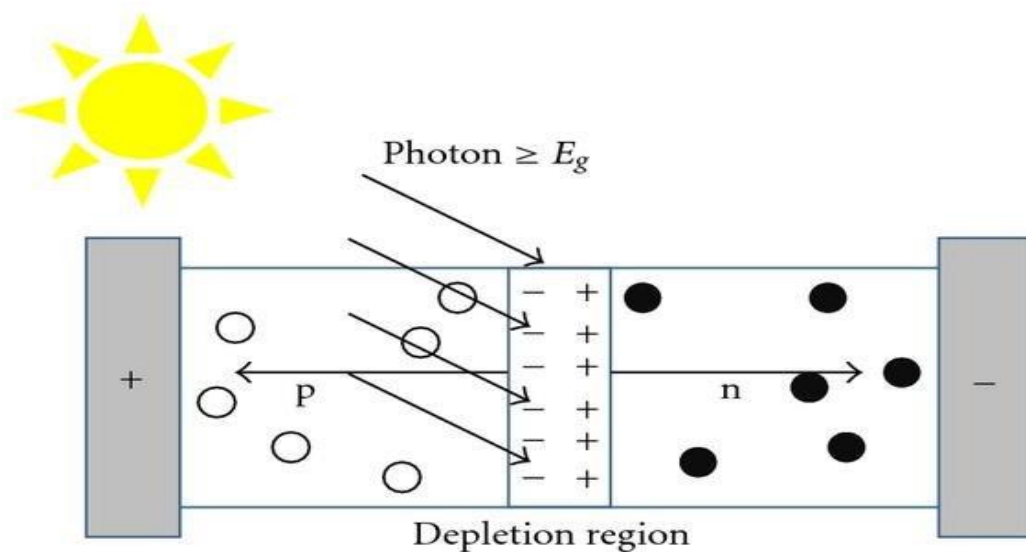
Figure 1.3: Basic Solar Cell.

In above we describe the structure of the solar cell now we talk about principal operation of solar cell.

when the solar energy falls on the solar cell as the photon's radiation. all the photon does not have enough energy to break the p-n junction and generate the solar energy. it can be classified the photon into three types: some of the photons are reflected off the upper surface of the panel without any effect. The rest make their way underneath the stratum. Those with lower energy levels than required to get the p-n junction also pass through the cell unaffected. which means the photon could not break the p-n junction. A photon with enough energy can break the gap in silicon, causing an electron-hole pair to form on both sides of the p-n junction.

The charges are split over the junction (on the p side, electrons, on the n side, holes), and the electric field moves them in opposite directions (electrons towards the n-side, holes towards the p-side), producing a current in the cell. Metal contacts on both sides are used to bring it together.

Figure 1.3 above shows the effect of irradiation directly proportional to the amount current produce. If irradiation is high, there are more photons that have enough energy to generate more pairs of electronic holes, and the solar cell can generate more current.

1.3 Solar Cell Equivalent Circuit.

The performance of the PV module we can described by a single standard diode model Shown in Figure 1.4 [12]. A group of identical branching cells that are arranged in a series or parallel, generalized to the PV module.
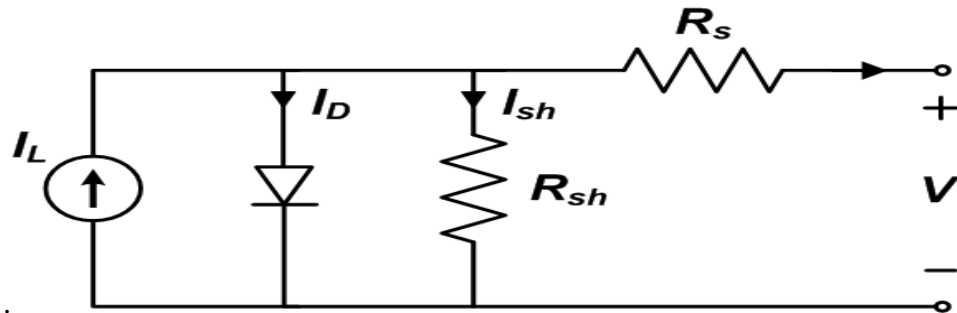
Figure 1.4: Solar Cell Equivalent Circuit

The equation (1.1) calculates ideal solar cell current output:

$$I = I_L - I_0 \left(e^{\frac{q(V - IR_s)}{AKT}} \right) - \frac{V - IR_s}{R_{sh}} \qquad (1.1)$$

Where:

I	: Current output.
I_0	: Dark current saturation.
q	: The number of electronic charge constant (1,602.10-19 Coulomb)
k	: Boltzmain constant (1,38. 10-23 J/K)
R_{sh}	: Shunt resistance.
A	: Ideality factor of the diode.
Rs	: Solar cell series resistance.

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T : Temperature of the cell [Kelvin].

Here it is difficult to understand how the shunt resistance (R_{sh}) works. This is due to the p - n junction's imperfect existence and the presence of inclusions near the cell's edges, which provide a short junction path around the junction. (N. Femia, 2004). In an ideal cell, R_{SH} would be infinite, and R_S would be zero. However, in fact, this is not possible; however, in the product, we will try to mitigate the impact of both resistances.

To simplify the solar cell in calculation(model) (N. Femia, 2004) in we assume that the R_{SH} is infinite, and we can neglect the effect of this resistor. equation (1.1) could be simplified to equation (1.2).

$$I \approx n_p I_L - n_p I_0 \left(e^{\frac{q(V - IR_s)}{AKTn_s}} - 1 \right) \qquad \textbf{(1.2)}$$

Where:

n_p → The number of solar cells that are joined in a parallel.

n_s → The number of solar cells that are joined in a series.

Several solar cells are connected in series and parallel in a single photovoltaic panel, this is mean voltage output and current output are large enough to connect to the grid or be used by the equpoment directly.by considering the simplification talked above, we can show the characteristic of output voltage and current by equation (1.2) (G. M. S. Azevedo, 2008).

1.4 Short Circuit Current, Open Circuit Voltage,, and Maximum PowerPoint:

Short circuit current it could be:

$$I_{SC} \approx I_L \qquad \textbf{(1.3)}$$

To generate the maximum power in the solar cell, the current and voltage at the P-V characteristic should be the maximum. the current is maximum at the short circuit, and voltage is maximum in the open circuit, in the P-V carve this point is called MPP and power is unique which ios ideal MPP. Figure 1.5 shows MPP. it is clear in MPP voltage and current are maximum.
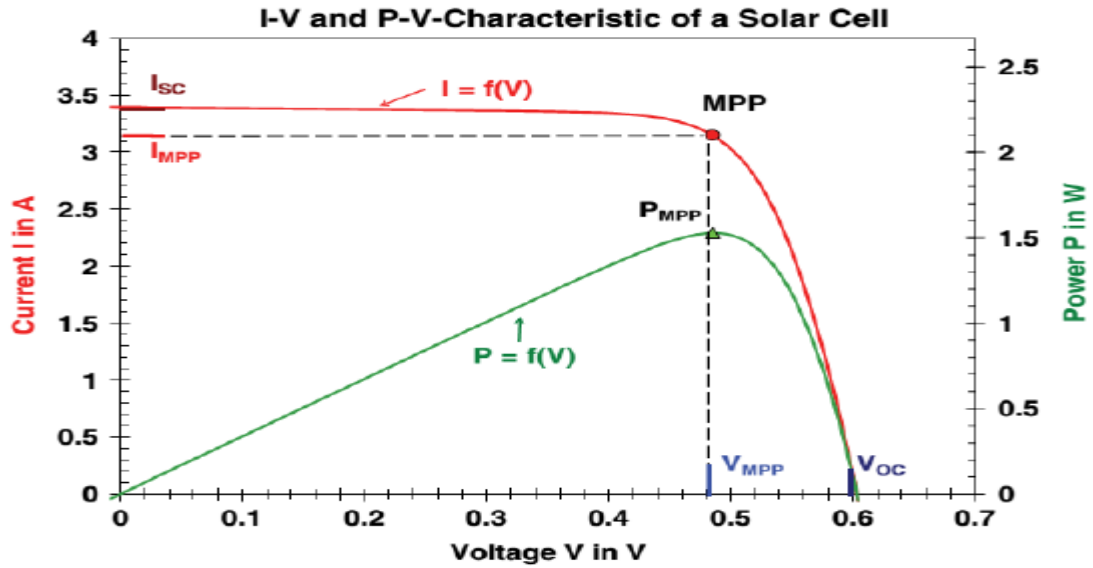
Figure 1.5: Current-Voltage and Power-Voltage solar cell characteristic.

1.5 Fill Fuctor

The fill factor is a percentage value that represents the ratio of real maximum power rated to theoretical maximum power. In figure 1.6 the blue area represents the maximum possible voltage (V_{OC}) and maximum possible current (I_{SC}) that is critically possible from the PV cell this is theoretically we never be reached it is ideal. The green area shows the actual maximum power (I_{MPP}, V_{MPP}). So, the fill factor is the ratio of green area over the blue area shows in equation (1.4).
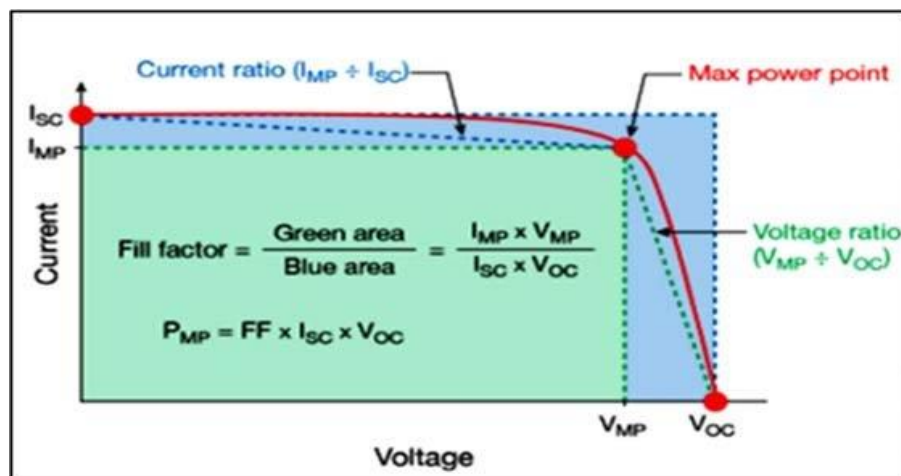
Figure 1.6: fill factor.

$$FF = \frac{I_{MPP}V_{MPP}}{I_{SC}I_{OC}}$$

1.6 Irradiance & Temperature Effects

In the solar module two factor irradiation and the temperature that directly effecting on the working of the panel. these two main reasons that directly affecting on the working of the solar panel which is irradiation and the tempreature. As a result of changes in irradiance and temperature affecting the panel's output power, the MPPT is working to find the panel's maximum usable power in the event of a change in radiation or temperature. The fill factor is a commonly used measure of a solar panel's overall efficiency. (P. A. Lynn, 2010) the value of fill factor in the commercial is above 0.70 this is because the value of MPP current and voltage normally smaller than the short circuit current and open circuit voltage because in the realistic we cannot neglect series and shunt resistance shown in figure 1.7 & 1.8 respectivly.

As previously noted, Irradiance has a direct relationship with the current generated by the solar cell. this means higher irradiance generates a higher current. so, as we see in the results, the change in irradiance has more affected the current compared to the voltage affected by the temperature.

In normal operation of PV cell, the power generated an affected by irradiance of the cell as it is illustrated in equation (1.1), equation (1.2).

as its mentioned before the effect of temperature on the open voltage is small with changing in irradiance on the PV panel but changing irradiance on the short circuit characteristic carve is logarithmic, equation (1.4) shows this relation the characteristic carve bellow shows that in any change in irradiance directly affecting on the current generation by the panel. any increase current generation mean increase in power generated by the panel proportionally.
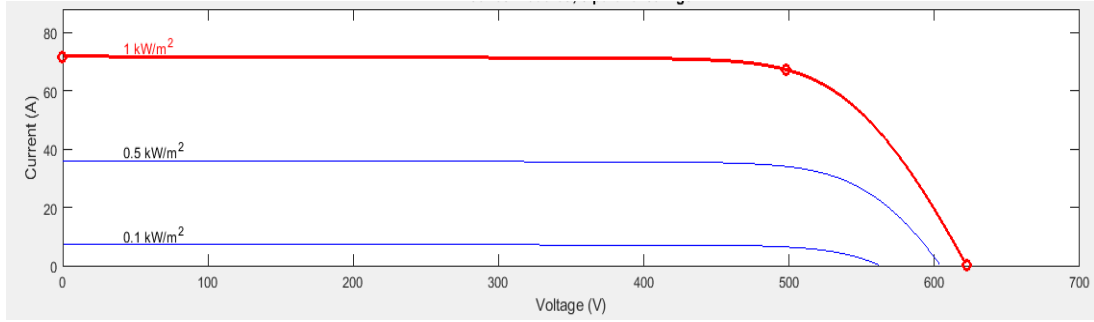
Figure 1.7: MPP changes with changing Irradiance at constant temperature (25), (I-V Curves).
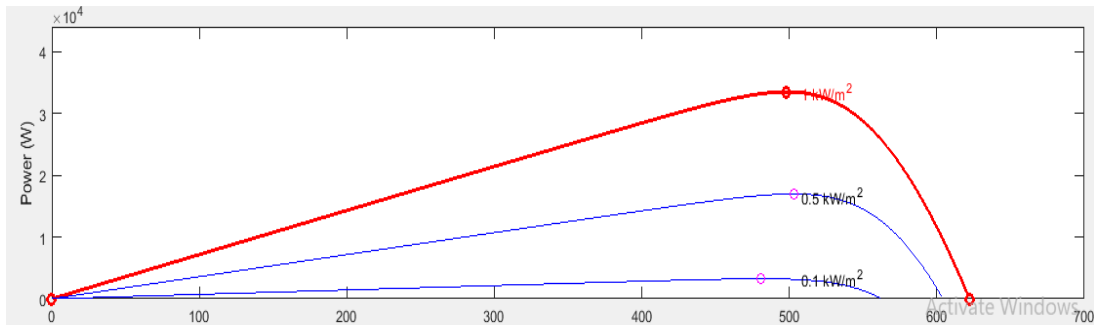
Figure 1.8: MPP changes with changing Irradiance at constant temperature (250) (P-V Curves).

The effect of irradiance on the current is very bigger than its effect on the voltage, for that reason the change in voltage by irradiance is neglected (Markvart, 2000), when the irradiance is increasing the power generated is increase because voltage and current generated in this change is positive.

However, the voltage shift is proportional to the temperature. As the temperature rises, the voltage produced falls. the equation (1.5) is illustrating effect temperature on the $V_{OC.}$

$$V_{OC}(T) \approx V_{OC}^{STC} + \frac{K_{V\%}}{100}(T - 273.15) \qquad \textbf{(1.5)}$$

As mentioned above the effect temperature on both voltage and current is different increase in temperature means decrease voltage much more than increasing in current so the power generated when the temperature is increase is smaller, the figure 1.9 and figure 1.10 shows the effect temperature on the generation of power and current.

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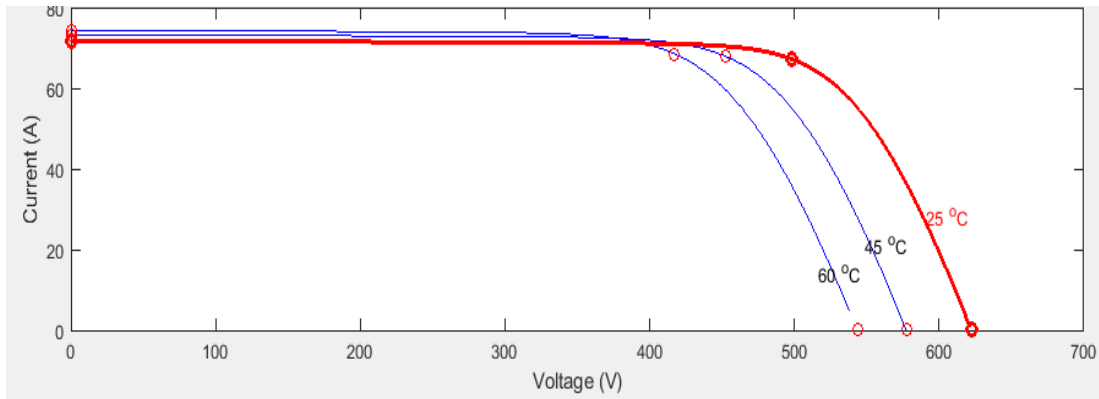
Figure 1.9: MPP changes with changing Temperature at constant irradiation (1 kW/m2), (I-V Curves).
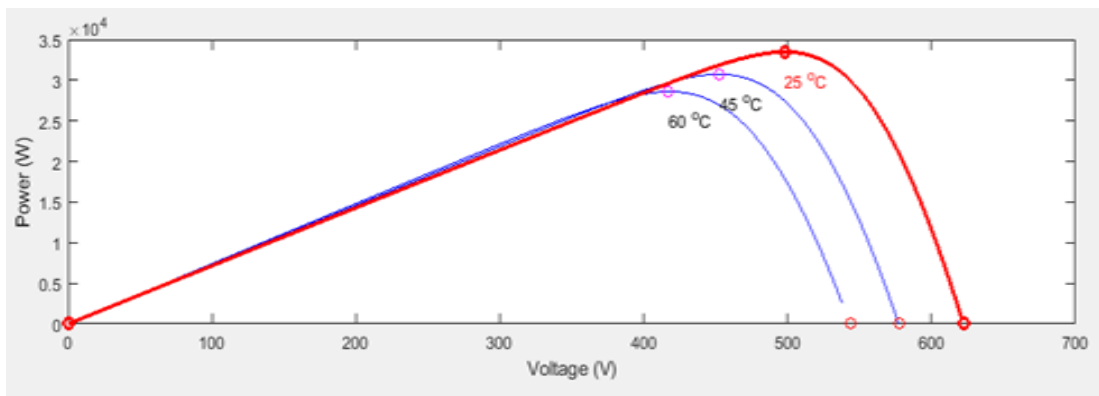
Figure 1.10: MPP changes with changing Temperature at constant irradiation (1 kW/m2), (P-V Curves).

it is clear any change in the weather it means the irradiance and temperature is change decrease or increase and changing in weather is possible in any time in the day may be fast or slow. This change made the power generation is also change, so use MPP to track the new peak power generated in this changing if the MPPT is slow in finding the peak power the losses of power is large and vis versa.

1.7 Types of Solar Cells

In general, the solar cell is classified by the type of semiconductor used in manufacturing. The semiconductor has a special characteristic that is absorbing the sunlight.

The solar cell in the practice may has one layer or using complex multi physical technique to take advantage more absorption.

In solar cell manufacturing mostly use silicon semiconductor, Silicon having some advantages in using solar cell:

- Silicon is not toxic material.

- It is easy to obtain because silicon is the most of earth's crust consist of silicon.

from the silicon two substantial of solar cell is made there are polycrystalline and monocrystalline.

Many effort to develop and manufacturing a new material that having a better efficiency of solar cell by the researcher in the last decade. In this section some of different types are illustrated:

When the discussing about the solar cell the efficiency of a solar cell is a far more significant factor to consider.

The standard test condition is used to compare the different types of solar cell's efficiency. The test is this situation should the irradiance 1000 W/m^2, the temperature in 25^0, to reduce the cost and more power output it is better to the solar panel have high efficiency because high efficiency small area is need this is cause the cost to reduce (Onur Ozcan, 5 April 2019).

1.7.1 Crystalline Cells.

Silicon cells are found in this group, Figure 1.12 Since silicon is the second most abundant element on the earth, it is used as the cheapest semiconductor to produce solar cells. In comparison to other materials, this type of cell is thought to be the most effective. which have a structure similar to silicon cells, can also be included in this group (Anna Kijewska, 2016).
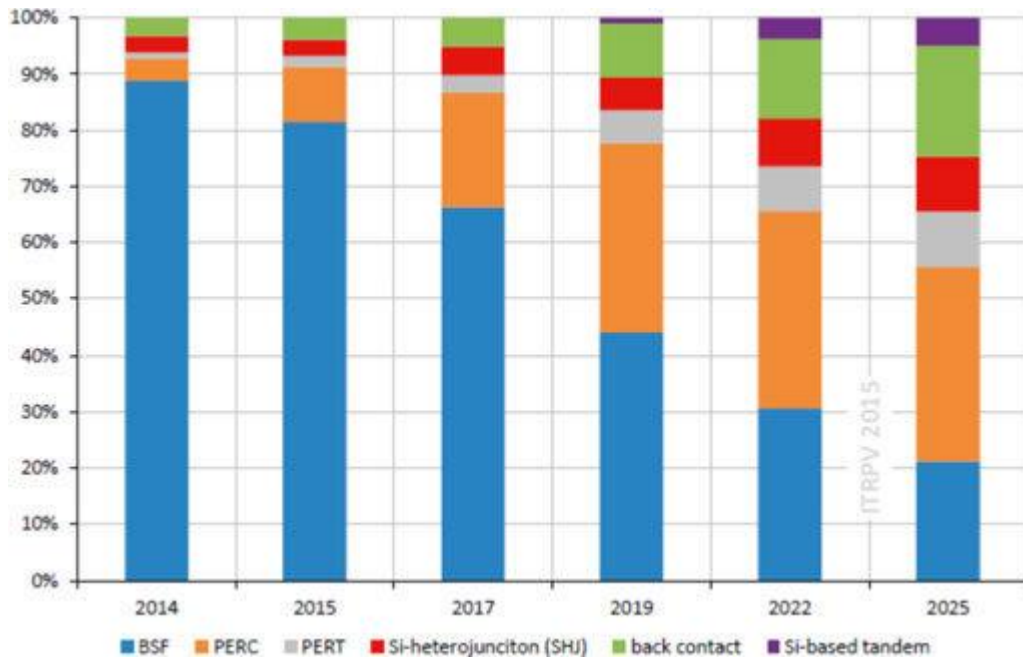
Figure 1.11: Market Share Cell Technologies.

Crystal cells, on the other hand, are more expensive, partially due to the increased in number of materials used to manufacture them. As a result, although other alternatives to silicon were being pursued, they were developing at the same time. Figure 1.12 depicts how its thickness has decreased in recent years while remaining efficient and even rising slightly.
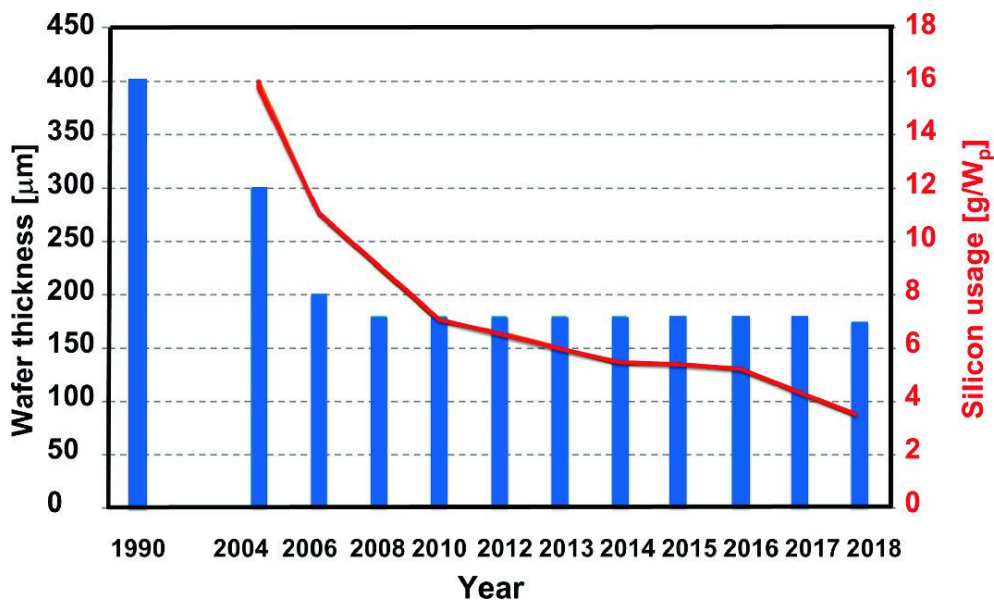
Figure 1.12: Affect of Silicon on reducing thickness solar cell per/years

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1.7.2 Monocrystalline Silicon (mono c-Si)

A few key materials have emerged as the frontrunners in photovoltage cell production monocrystalline silicon was one of the materials used in the solar cells remain the most common it a typical efficiency of 15-20 percent and can last up to 50 years making it the longest-lasting material used in solar cells. This good efficiency in the monocrystalline compared to the other type of solar silicon cell is because it used since 1950 its durability has been proven in both residential and commercial applications.

1.7.3 Polycrystalline Silicon (Poly-Si)

Polycrystalline cell was made by load the silicon about 1300 pound of silicon. It is made up of multiple pieces of silicon pressed together.it has lower silicon purity this is caused lower efficiency it about 11-15 percent, the lower the efficiency mean to same amount of power we need more solar panel, so the area needed to installation is bigger than mono crystalline.

1.7.4 Gallium Arsenide Cells (GaAs)

These cells are manufactured from gallium (Ga) and arsenic compound semiconductor (As), and they are a good alternative to silicon cells in terms of efficiency and weight. However, they are more expensive. They do, however, have a higher heat tolerance than other first-generation cells, making them ideal for CPV systems. These cells have achieved their full efficiency of 26.2 percent.

Furthermore, these Gallium Arsenide Cells (GaAs) material are used in multi-junction cells with an efficiency of 28 percent, and extremely concentrated multi-junction solar cells now have efficiencies of up to 46.0 percent in the lab.

1.7.5 Thin-Film solsr cell

The second generation of solar cells in the world is the thin film solar cell with lower efficiency. These cells are a less expensive alternative to first-generation technology. Since they are made up of thinner layers ranging from a few nanometers to tens of micrometers, they need less material to manufacture due to their direct bandgap energy. It is also very heat resistant. However, in comparison to silicon cells, both performance and environmental effect are

lower, and they have issues with low irradiance. Amorphous silicon, cadmium telluride cells, copper, indium, and selenium cells are among the options in this second generation.

1.7.6 Amorphous Silicon (A-Si).

Another type of manufacturing solar cell is Amorphous which is non - crystalline silicon the major substrates of Amorphous is thin-films which is used in different purpose.

The best benefit of using of this type is:

- Process manufacturing is easy and simple.

- The cost of manufacturing is lower than the other type.

- It can work in partial shading on the panel.

- Reacting to the temperature is low.

- Light absorption is higher than other type.

But the efficiency Amorphous is lower than other type which is (6 to 8) percent in the STC (P. A. Lynn, 2010) this is a big disadvantage.

Amorphous and thin-film silicon in the previous mostly used in small electronic application like calculator but in the last decade it is used in power generation because this advantage mentioned above.

1.7.7 Cadmium Telluride (CdTe) and Copper Indium Di-Selenide (CIS) Cells / Copper Indium Gallium Di-Selenide (CIGS) Cells

In these cells, new materials have begun to be utilized. These systems are inexpensive because they use direct bandgap materials. Furthermore, since their performance is relatively high and continues to improve, they'll start competing with crystalline silicon cells on the market.

CdTe cells remain the industry leader in thin-film technologies, with laboratory efficiency of up to 21% and modules with an efficiency of about 13% and a thickness of (3-5) μm. Cadmium, on the other hand, is toxic to both the maker and the user in CdTe cells. The CIGS cells are still growing, achieving a 20.5

percent efficiency. The performance of these technologies in commercial goods varies between 14-18% and 12-16%, respectively.
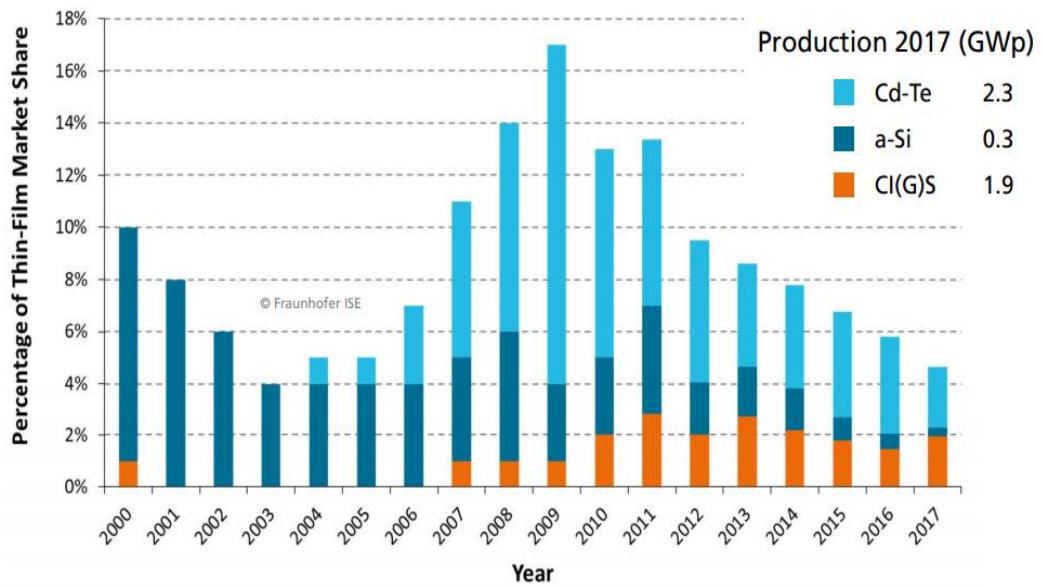
Figure 1.13: Market Share of thin-film technologies

2. DC-DC CONVERTERS

2.1 Introduction to basic DC-DC converters

The DC-DC converter is a type of power transformer that is an electrical circuit, this convertor's basic operation can be illustrated by momentarily storing input voltage and then releasing that voltage to the output at various voltages with the help of the duty cycle, it can arrange different voltage levels in the output voltage, which may be less or greater than the input voltage, depending on the type of dc-dc converter. in the (back-boost converter) in the same circuit, the output can be greater or less than input voltage as desired. with the help of the magnetic field characteristics in the transformer and inductor, the capacitor in a dc-dc converter is used to store electric field energy.

The majority of dc-dc converters are designed to transmit power from input to output in one way. on the other hand, could be made bi-directional power transfer, in this type of Power can be transferred in both directions with a bi-directional converter, which is useful in regenerative braking applications.

The duty cycle (D) between input and output can be managed to control output and input power. Duty cycle has the advantage of being able to regulate the output voltage and current, also, current and voltage input. briefly, the duty cycle can arrange power output or make the power constant. it is possible to Isolation input and output using transformer-based converters. also, the dc-dc convertor has some disadvantages, Complexity, electronic noise, and high cost are all factors to consider. in this paper, several different types of DC/DC power converters have been proposed. (Huang-Jen Chiu, JULY 2006).

2.2 Operation principles

In various computer equipment, computer machines, communication units, industrial control, mobile devices, DC / DC power converters are commonly used.

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The basic operation of DC-DC convertor depending on the input voltage, DC / DC converters are used to increase or decrease the output voltage.

Here are the main types of DC-DC converters:

- Buck converter.

- Boost converter.

- Buck-Boost converter.

2.3 Duty cycle

Duty cycle is the ratio of the pulse width Tw to the period t (Sunnie George Baroi[1], April 2017).
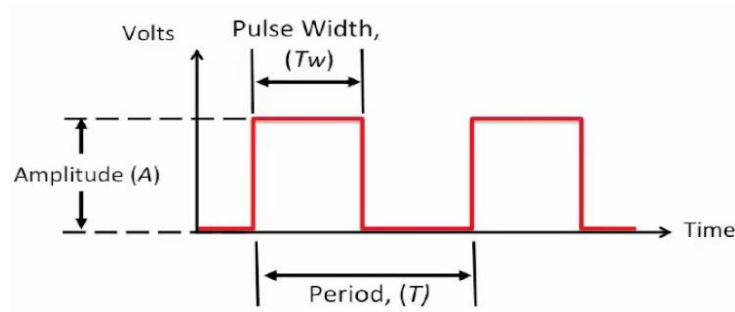
Figure 2.1: %50 duty cycle.

$$Duty\ Cycle = \frac{Tw}{T} \times 100\ \% \qquad \textbf{(2.1)}$$

Tw: is a time on (Pulse width).

T: is a period.

For Example:
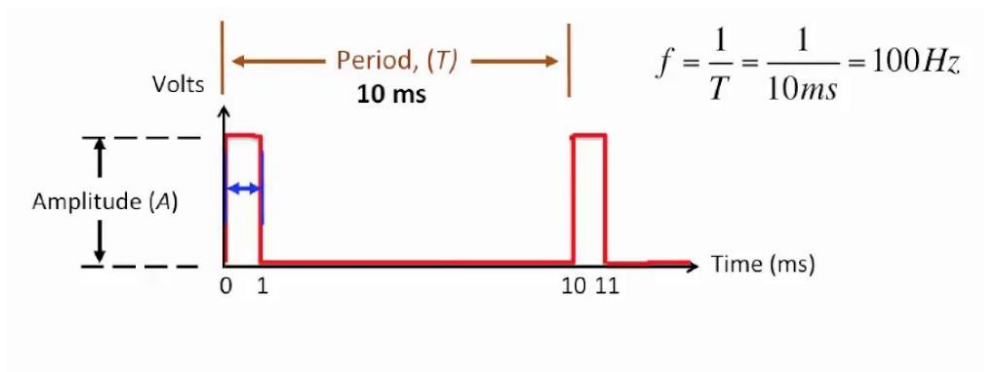
Figure 2.2: %25 duty cycle.

$$f = \frac{1}{T} = \frac{1}{10 \; ms} = 100 \; Hz \qquad\qquad \textbf{(2.2)}$$

f =Frequency (Hz)

$$Duty \; Cycle = \frac{Tw}{T} \times 100 \; \% = Duty \; Cycle = \frac{1}{10} \times 100 \; \% = 10\%$$

$$Duty \; Cycle = 10 \; \%$$

2.4 Pulse width modulation

to control the output power in the dc-dc converter by the easy way the (PWM) pulse width modulation is used, It is a method for efficiently grinding an electrical signal into separate components to reduce the average power supplied by it. the basic operation of (PWM) By rapidly switching the switch between the power source and the load on and off, the average voltage (and current) delivered by the load can be adjusted.

In comparison to off times, the brighter the turn, the greater the overall energy supplied to the load. One of the key strategies is to reduce the performance of the solar panels through the consumption of the battery with maximum power point tracking (MPPT)

For inertial loads, like motors, which are not easily influenced by this discrete switching, PWM is especially suitable as their inertia causes them to respond slowly. The frequency of the PWM switching should be high enough not to impact the load, ensuring that the resulting waveform should be as smooth as possible [13].

2.5 Types of DC-DC convertors.

2.5.1 Buck converter

The buck dc-dc converter is using as a step-down voltage (step-up current) because power is constant it reduces the output voltage. In this type of convertor the output voltage is lower than the input voltage because we supply the voltage to the electronic system, for example charging the battery by solar panels, using

a buck converter when the voltage of the solar panel is compressed, from the battery voltage, increasing the voltage can reduce the amount of battery charge (Fathy M. Mustafa, 2016).

Only, battery life plus other electronic devices that use a buck converter, the Buck converter in implementation usually use these components, namely fast MOSFET for electronic switching, capacitor, inductor, and diode. to get the desired result, it should note that the component selection is suitable.

2.5.2 Boost converter

The boost convertor is using as step-up voltage (step-down current) the princeple working is opposite to the buck converter, Because the voltage generated by the PV is lower than the voltage utilized directly, the boost dc-dc converter is commonly used in PV systems to increase the voltage to the desired value. the figre showes the ciruite diagram of boost dc-dc converter.

The circuit's boost dc-dc convertor components are as follows: Diode (D), Inductor (L), Capacetor filter (C), control Switch (MOSFFET,IGBT) (S), to control the output voltage using the switch with high frequency with certain duty cycle, the output voltage is equale to input voltage ($V_{in} = V_{out}$) when the switch is **ON** in periode t_{on} , during the periode t_{off} the inductor current pathing through the diode the made the output voltage V_0 equal to the V_{sw} , when the system reach the steady state avarage voltage pathing throuth the inductor must be equal to zero.

$$V_{in}.t_{on} + (V_{in} - V_0).t_{off} = 0 \qquad (2.3)$$

V_0 = the output voltage

V_{in} = input Voltage

t_{on} = the peride time on

t_{off} = the peride time off

So, it can write the eq in the term of time.

$$\frac{Vin}{V_0} = \frac{t_{on} + t_{off}}{t_{on}} \qquad (2.4)$$

Witch $T = t_{on} + t_{off}$, T is the periode of the switch, the duty cycle is calculated by the the ratio of T and t$_{on}$.

It is clear from equation (2.4) that the duty cycle can be used to regulate the boost converter's output voltage. boost converter is one of the methode to increase the output voltage to a desier value. The boost converter's output voltage is DC, but most applications need AC power, here the dc voltage must convert to ac voltage in this case it should use the inverter.

2.5.3 DC-DC Buck-Boost converter

Another type of converter is the Buck-Boost dc-dc converter, which is used when the desired output voltage is larger or lower than the input voltage. depending on the changing in duty cycle. Because of the polarization of high-voltage transformers' output energy with the reverse input power, inverters known as inverter controllers are often used in high-voltage transformers.

In the step-up model, the output voltage is greater than the input voltage (Vin < Vout). As can be seen, the input current is greater than the output current. As a result, the buck-boost converter operation like a boost convertor.

$$Vin < Vout \text{ and Iin} > Iout$$

In step-down mode, the output voltage is smaller than the input voltage (Vin > Vout). The output current thus exceeds the input current. As a result, the buck boost converter operation like back convertor.

$$Vin > Vout \text{ and Iin} < Iout$$

The use of pressure transducers has many benefits, including improved performance and the ease with which short circuit current safety can be implemented. However, its major weaknesses include erratic input current, increased peak current through the control switch, plus increased complexity compared to other transformers. The figure below shows the primary electrical path of a transducer. It has a capacitor (C), inductor (L), diode (D) and a switch it may be a transistor or Mosfets (J.M. Enrique a, (2007)).
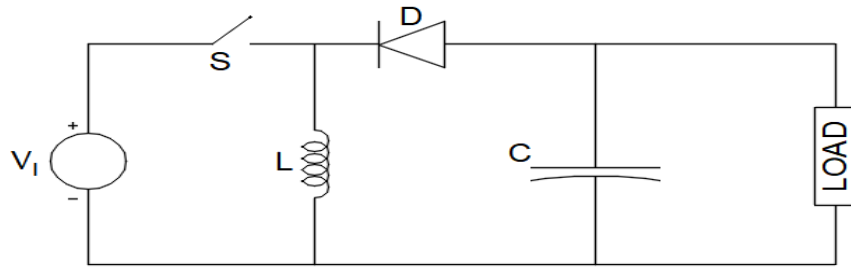
Figure 2.3: circuit diagram of dc-dc back-boost converter

buck boost converter consists of connected two type of DC-DC convertor a buck converter and a boost converter. These converters have a wider output voltage range than their input voltage range. In the diagram below, a basic buck boost converter is shown.
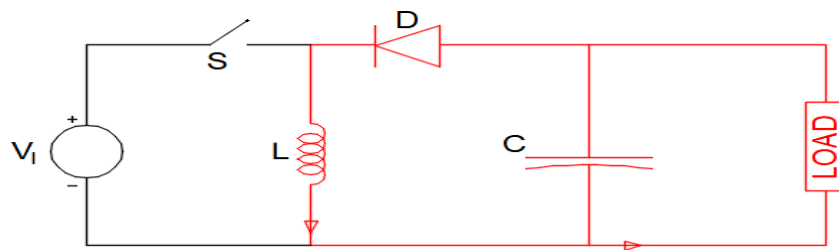
Figure 2.4:the operation of back-boost convertor (Off-state)
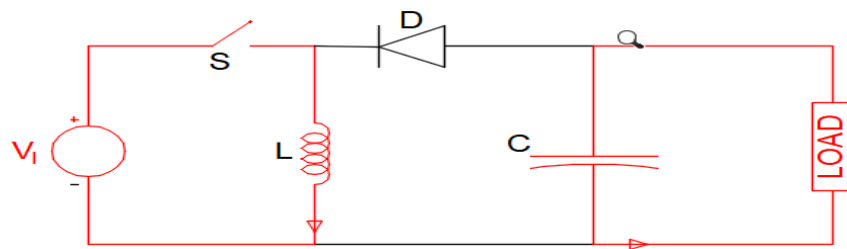
Figure 2.5:the operation of back-boost convertor (On-state)

2.6 Buck-Boost convertor methods:

There are two different modes of pressure transducer. There are two different types of back-boost convertor.

2.6.1 Continuous conduction mode.

In the continuous conduction mode, the current from the terminal to the inductor terminal never reaches zero. as a consequence, the inductor is discharged before the switching cycle.

2.6.2 Discontinuous conduction mode.

in this mode the current through the inductor reaches zero. as a consequence, it is fully discharged at the end of the inductor switching cycles.

2.6.3 Linear and non-Linear load

Load classification is a term that refers to the classification of different types of loads. The sorts of loads both non-linear and linear loads can be identified by how they take current from the main power supply waveform.

2.6.3.1 Linear load

in the linear load, voltage is always proportional to the current mean when the voltage increases the current is decreased and vis versa according to (Ohm's law). However, in a DC system, a linear load is a totally resistive load, and the current-voltage relationship is (Ohm's law). Also, most of the conventional lighting systems are accounting for linear loads (Daniele Gallo, OCTOBER 2007).

2.6.3.2 Non-linear load

In non-linear loads, the current is not proportional to the voltage and fluctuates based on the alternating load impedance. Non-linear loads are usually connected to the electrical source via electronic devicesin the non-linear it can not represent relationship between voltage and current by (Ohm's law). All capacitive, inductive, and motors are accounting for non-linear loads.

3. MAXİMUM POWER POİNT TRACKİNG ALGORİTHMS

3.1 Introduction

Maximum Power Point Tracking (MPPT) is a photovoltaic (PV) transducer algorithm that continuously modifies the impedance seen by the solar array to preserve the variable efficiency of the PV device at the peak power of the PV panel. Conditions, such as sunshine, temperature, and battery alterations.

MPPT algorithms are implemented by engineers designing solar inverters to optimize the power produced from photovoltaic systems. Algorithms regulate voltage to ensure that the device runs on the voltage power curve at the "maximum power point"(MPP) (or maximum voltage), figure 3.1 shows the different MPP when irradiance are changes.
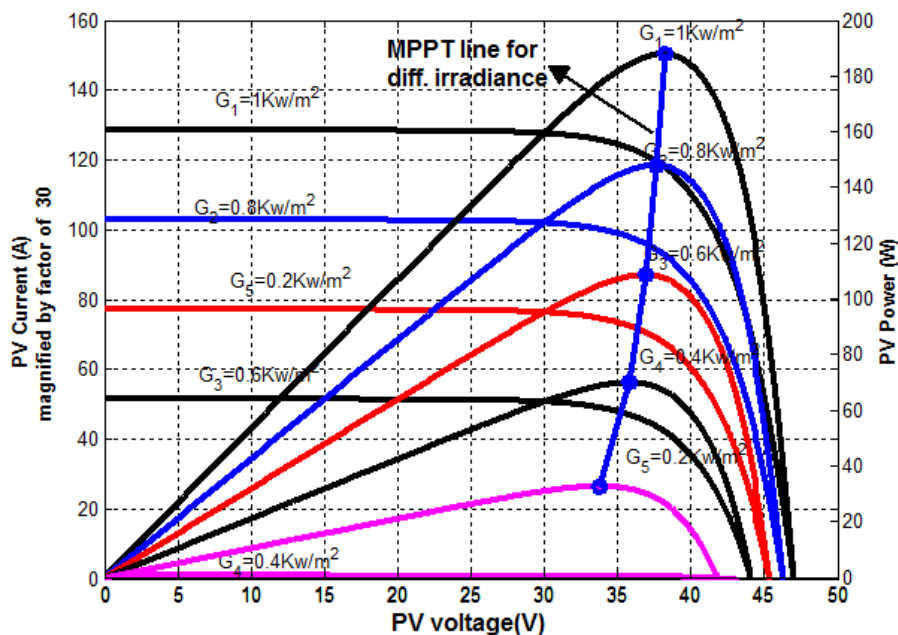
Figure 3.1: different MPP in different irradiance.

For PV systems, MPPT algorithms are widely used in controller design. In order to ensure optimum photovoltaic device power generation at all times, these algorithms consider variables such as variable radiation and temperature.

The three MPPT algorithms which are most popular which are:

3.2 Perturbation and Observation P&O Algorithm

One of the conventional methods to find MPPT is P&O in this method the voltage V_{MPP} and current I_{MPP} automatically is found under change in weather condition (irradiance and temperature) for the PV panel or array (Jacob James Nedumgatt, December 2011). The basic operation of the P&O MPPT algorithm continuously makes incremental changes to the voltage and monitors changes in power. In the figure 3.2 showes if the change in voltage increase the power output of the solar panel the next perturbation will be continue the same directionIf a change in voltage reduces the panel's power output, the next perturbation would be in the opposite direction. untill the different between the previous power and new power equal to zero means ΔP is equal to zero, which is MPP.the table 3.1 showes all possibility in algorithm P&O (Jacob James Nedumgatt, December 2011).

Table 3.1: shows all possibility in P&O algorithm.

Prior perturbation	Change in power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive
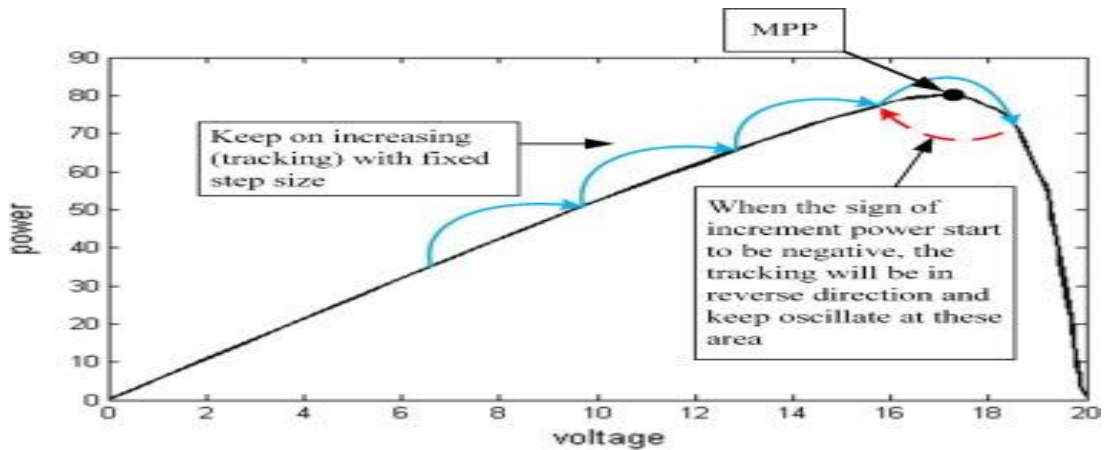
Figure 3.2: Operation of P&O algorithm.

The P&O method's most significant problem is oscillation around the MPP. Since the algorithm is unsure if MPP exists or not, it will continue to move. As a result, there will be a reduction in power production. The perturbation step size can be reduced to minimize the oscillation and power losses. but with a small step perturbation cause operation of MPPT is slow. in any change in temperature and irradiance, the current and voltage is changing so the voltage power carves have a new MPPT for each change. It is at this point that the converter is provided with the corresponding maximum voltage. The flowchart of P&O is illustrated in the figure 3.3. In the flow chat randomly choose initial value for (D), then calculating power from (I(n) and V(n)) of the PV this power is the instantaneous power (P(n)). After that calculate the dP and dV if the dP greater than 0 (dP>0) then see the dV. if the (dV<0) then increase the duty ratio. or if (dV>0) decrease the duty ratio. Also, if the dP smaller than 0 (dP<0) then see the dV if the (dV<0) then decrease the duty ratio(D). if (dV>0) increase the duty ratio(D).
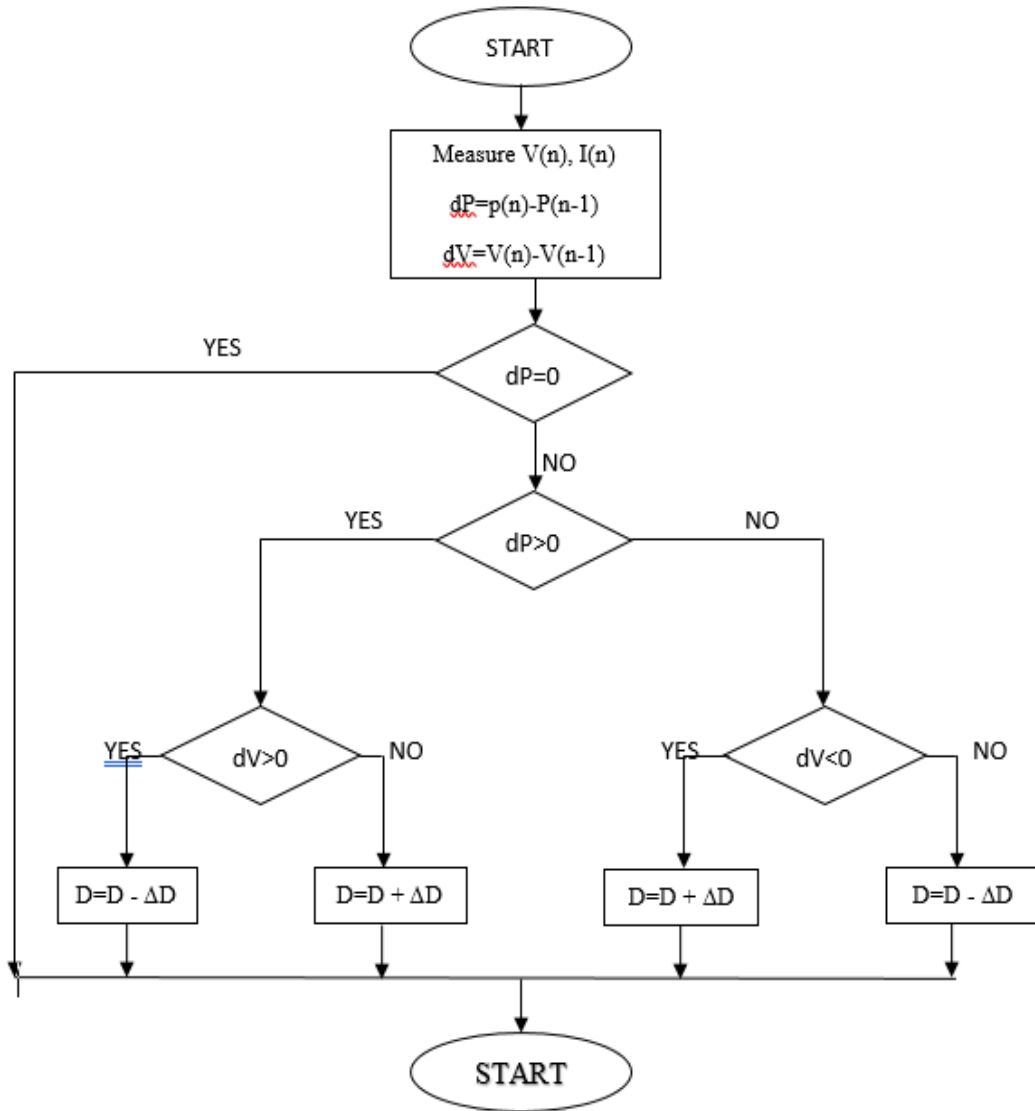
Figure 3.3: The flowchart of P&O Algorithm

In the past decade, several authors have attempted to overcome this problem to improve the P&O method as the weather changes (Nowak-Ocło, 2020). Thus, the effect of changing atmospheric conditions and the effect of disturbance on voltage (current) can be measured in this way for all three subsequent samples. As a consequence, the increase in the algorithm's power only includes the effect generated by the MPPT algorithm. The correct decision can then be made for the next perturbation path, improving tracking efficiency. The method was tested using irradiation slopes.

3.3 Incremental Conductance (INC) Algorithm

The method incremental conductance (INC) is known as a direct technique which is a a one methode of hill claim, some of the drawbacks in P&O can be solving by using (INC) conductance like rapid change environmentalto understand how the INC algorithm operate, the power voltage carve can help to illustrate, in the P-V carve only in the MPP (maximum power point) the slope of the carve will be zero. in the right side of P-V carve the power and voltage is deacrese and in the left side the voltage and power is increase this is shown in figure 3.4.

The maximum power output is at $\frac{dP}{dV} = 0$ and

$\frac{dP}{dV} > 0$ then $V_P < V_{mpp}$ at left of MPP.

$\frac{dP}{dV} = 0$ then $V_P = V_{mpp}$ at the MPP

$\frac{dP}{dV} < 0$ then $V_P > V_{mpp}$ at right of MPP

From the discribtion above we can written that:

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I\frac{dV}{dP} + V\frac{dI}{dV} \qquad\qquad \textbf{(3.1)}$$

$$= I + V\frac{dI}{dV} \qquad\qquad \textbf{(3.2)}$$

Also, the MPP can be find by the ratio of changing current and voltage.

If $\frac{\Delta I}{\Delta V} > -\frac{I}{V}$ then, at left of MPP.

If $\frac{\Delta I}{\Delta V} = -\frac{I}{V}$ is the MPP

If $\frac{\Delta I}{\Delta V} < -\frac{I}{V}$ then, at right of MPP
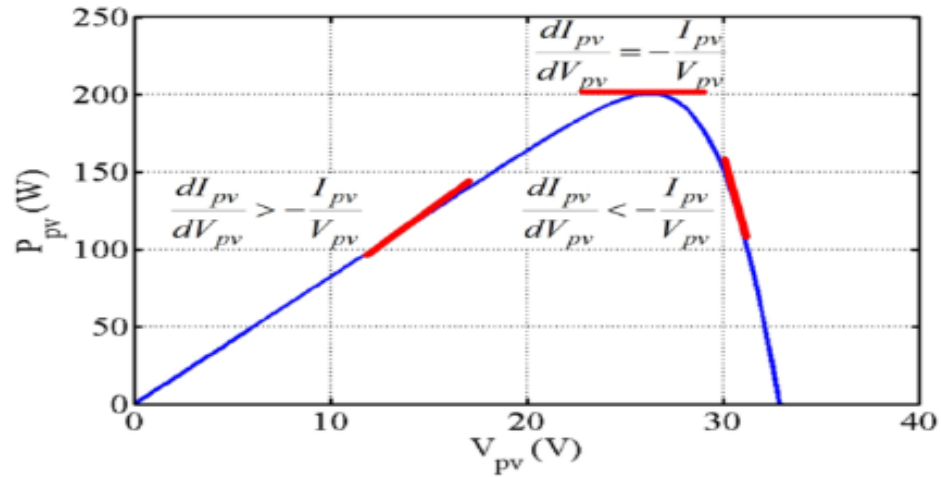
Figure 3.4: The operation of INC algorithm.

In general, this method uses fixed step size with a duty cycle increase or decrease dictated by the necessary follow-up accuracy and speed. The time it takes to complete MPP is determined by the scale of the workflow. The most advantage of INC is ease to implementation, high tracking speed, and better efficiency. However, if the irradiation changes rapidly it is to easy lose the MPP these is the biggest disadvantage of this techniques. Furthermore, as the irradiation varies on a slope. As a result, variations in voltage and current are caused by more than just voltage fluctuations. As a consequence, the algorithms are unable to decide if the transition is due to a rise in power or a change in voltage.

In figure 3.5. the incremental conductance can be illustrated by the following flowchart, starting by calculate the current and voltage.
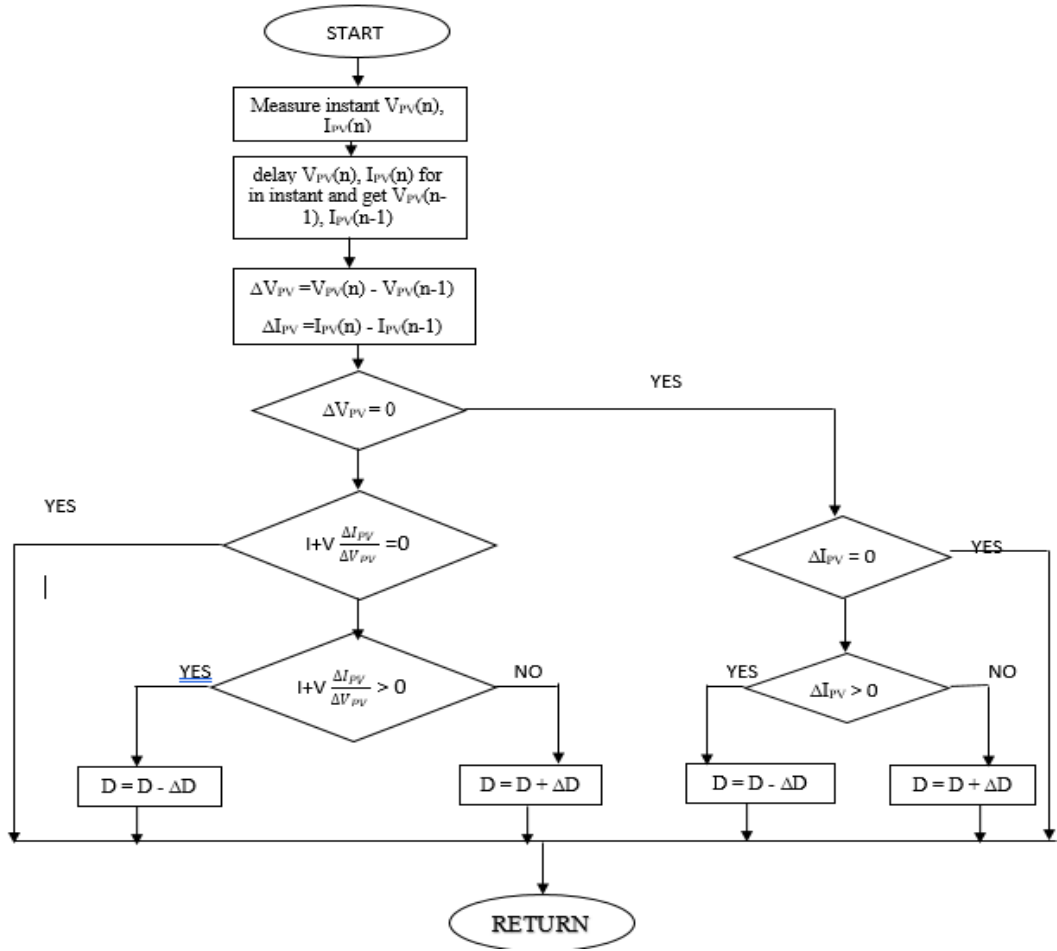
Figure 3.5: The flowchart of INC algorithm

First of all, measure the voltage and current of PV array $V_{PV}(n)$, $I_{PV}(n)$, the next step memorizes the previouse value for voltage and current $V_{PV}(n-1)$, $I_{PV}(n-1)$. The net step subtracts the prviose valuse of the voltage and current to find the differences.

$$\Delta V_{PV} = V_{PV}(n) - V_{PV}(n-1)$$

$$\Delta I_{PV} = I_{PV}(n) - I_{PV}(n-1)$$

If the diffrence of the voltage is equal to zero($\Delta V_{PV} = 0$) this mean both previous value and instant value not changing this mean the PV in this duration of time, in this time cheak the diffrent of current, if there is not changing in current value($\Delta I_{PV} = 0$) in this case when not changing in current and voltage mean the irradiance and tempreature of the PV array is not constant and not needed to change the duty cycle, this procese is reapeated until one or both irradiance and tempreatur is changing.if $(\Delta V_{PV} \neq 0)$ then cheak ($I + V \frac{\Delta I_{PV}}{\Delta V_{PV}} = 0$) when equal to

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zero this mean no change in weather. If not check (I+V $\frac{\Delta I_V}{\Delta V_{PV}}$ > 0) if greater than zero, the duty ratio should decrease if smaller than zero increase the duty ration. If ($\Delta I_{PV} \neq 0$) it may be lease than zero in this case incearse the duty cycle if greater than zero deacrease the duty ratio.

3.4 Hill Climb (HC) Algorithm.

The method Hill Climb (HC) is known as a direct technique which is a a one methode of hill claim. the principle of working is the same as the P&O algorithm as described before with some diffrence. They are tests compare the P(n) with the P(n-1) if P(n) is greater than or not if the new power is less than the previous power the algorithm decides this is th maximum power point. But in P&O method to get the MPP dP/dV shows if it is maximum point or not (Nacer K. M'Sirdi a, 42 (2013)).

normally the duty cycle ratio controll DC-DC converter, it is often referred to as the direct duty cycle technique when used without a PI controller.

After that, depending on P(n)-P(n-1) with change in the duty ratio (D) of the DC / DC converter, which causes the operating point to reach the MPP. A change in the work duty cycle has an immediate effect on the value of I_{PV} and V_{PV}. The figure 3.6 shows the principal operation of HC algorithm.
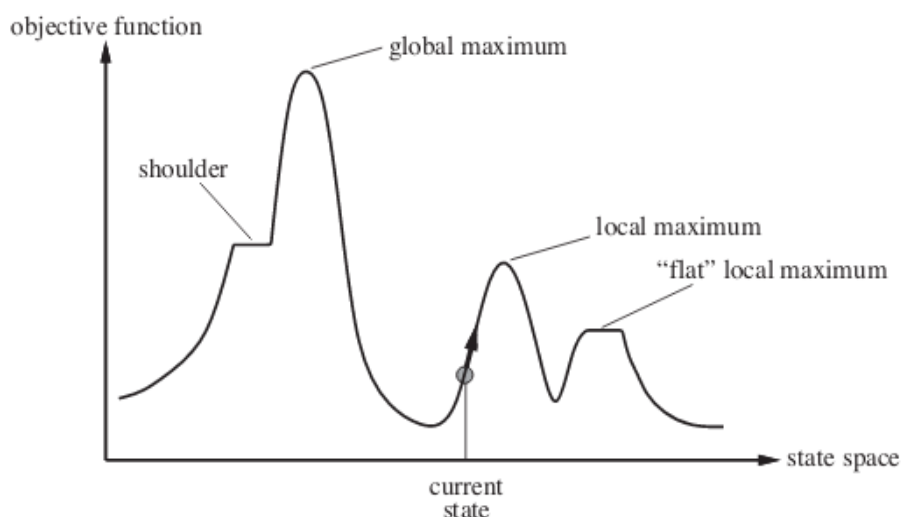
Figure 3.6: State Space diagram for Hill Climbing
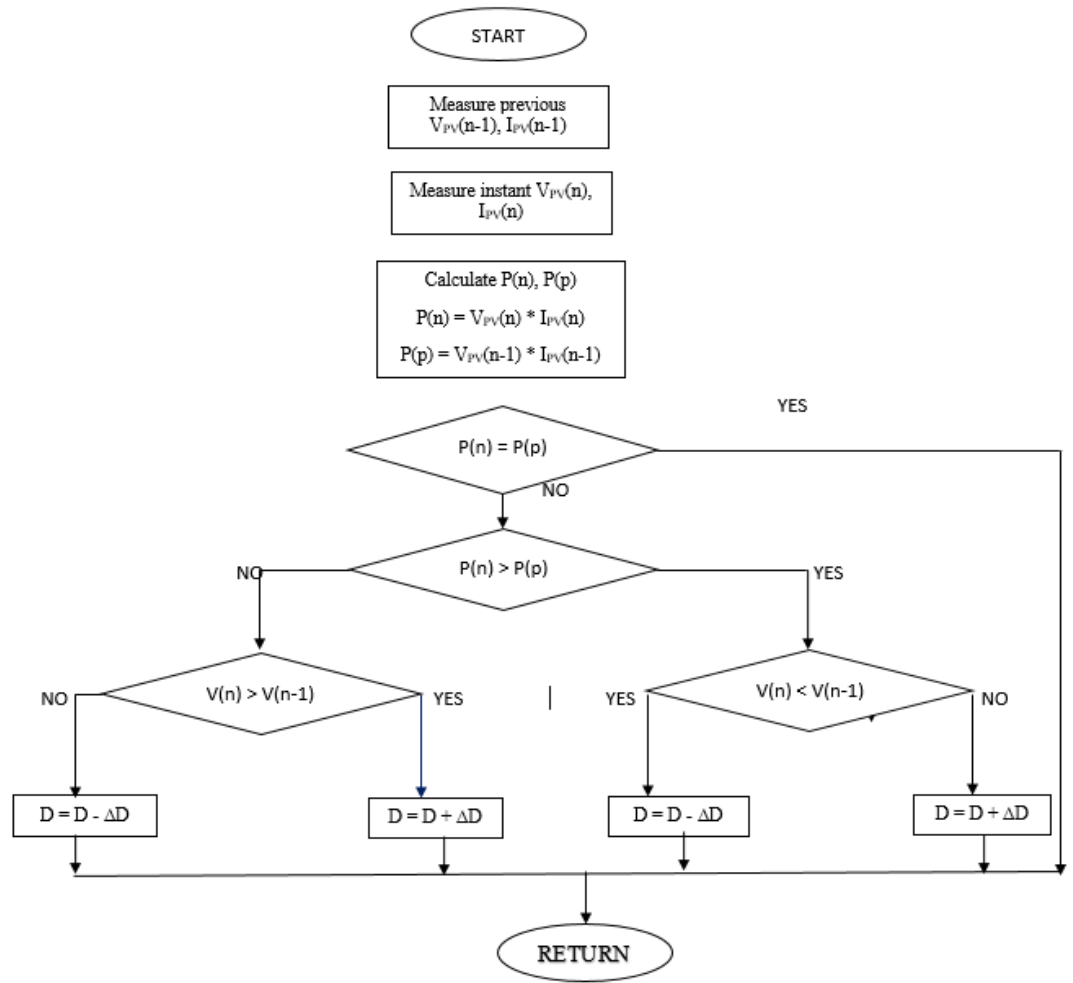
Figure 3.7: Flowchart of the hill-climbing algorithm

A flowchart diagram of the hill climbing algorithm is shown in Figure 3.7. The operation of the HC flowchart can be illustrated as:

Step 1: Detecting and calculating the PV array's voltage and current.

Step 2: Calculate the instantaneous power in step two (Pin).

Step 3: Setting up the service cycle (D) to a specific value.

Step 4: Examine the discrepancy between instantaneous and predecessor power (Pin) (PP).

3.5 P&O, INC, and HC Algorithms Comparative Test.

The three of the MPPT algorithms that have been built over time have been discussed in previous sections. all of them described in Hill Climbing Techniques, the basic concept of working of P&O and INC is very similar but in

HC is a little different and faster to get steady state. The number of P&O posts, INC, are the most common MPPT algorithms (Jacob James Nedumgatt, December 2011). This is understandable because it is the simplest algorithm for finding the MPP. They do, however, have disadvantages, as previously mentioned.

The incremental conductance (INC) and P&O algorithms are easy and simple to use, but they have some drawbacks in terms of DC-link and output inverter current. In the absence of an external perturbation. The efficiency of each process has been evaluated under a variety of irradiation conditions in particular. With the proposed MPPT, it is demonstrated that the proposed device will always extract the full power available from the solar PV panels.

The last chapter the output of these three algorithms is show the effect of changing solar irradiance panel tempteature on linear load and non-linear load. Laso, the performance of these three algorithms is analyzed when connected with linear and non-linear load. They were chosen due to their success and ease of use. Some improvements to P&O and INC are suggested to resolve the limitations of the original methods in monitoring the MPP under irradiation slopes.

4. SIMULATION MODEL DESIGN, RESULTS AND DISCUSSION.

4.1 Detail of modelling and design of the parameters for the PV system.

Photovoltaic technology, which transforms sunlight into electricity, is increasing among other energy industries. This sector is improving as a result of the oil prices and significant amounts of carbon emissions from various energy utility systems. This study aims to provide readers with the fundamentals of PV systems in all respects, this simulation design for a 33kw system.

Photovoltaic systems are divided into two categories as shown in figure 4.1. There are two types of systems: stand-alone PV system and grid connected PV system. In a stand-alone system, the energy provided by the solar system corresponds to the total energy demand. Due to the fact that photovoltaic energy efficiency is not always proportional to load, when solar energy generated is not in use, it is stored in the storage system.

Systems that are connected to the grid Energy is stored in the public power grid. PV systems will account for the majority of power generation in the coming years, according to the German Solar Energy Society, after countries establish feed-in tariffs to encourage investment in PV generation. Figure (4.1) shows PV systems are used in a variety of ways.
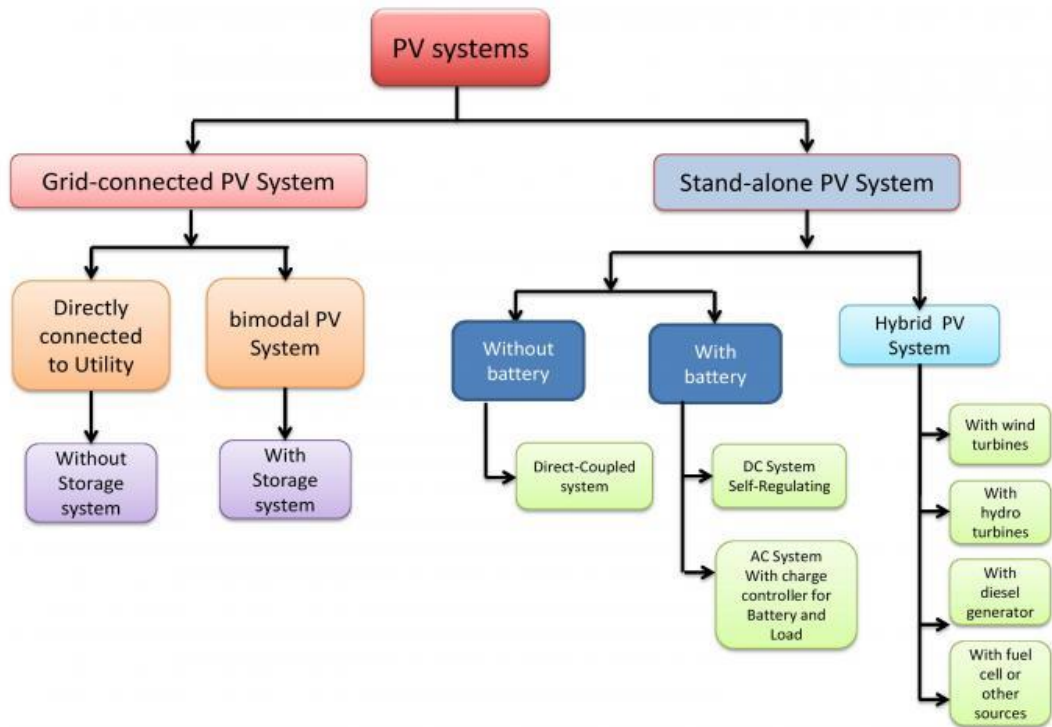
Figure 4.1: Application of PV systems

4.2 Design Considerations and 33kw System Simulation

4.2.1 Simulation model of the tested system.

A stand-alone PV system with a capacity of 33 Kw is designed for this paper. As explained in the table 4.1 (A, B) 1Soltech 1STH-220-P Solar panel is proposed. For this purpose, 153 panels were used. The panels connection is arranged such as connecting 17th panels in series to form an array with connecting 9th strings in parallel. As a part of the model MPPT was used to track maximum power in all situations. the DC-DC Boost converter was included to boost the input voltage. The model was tested under two different loads (Linear Load and Non-Linear Load) to compare the efficiency of each MPPT. The figure 4.2 shows the simple diagram for the entire PV system connected to the load.

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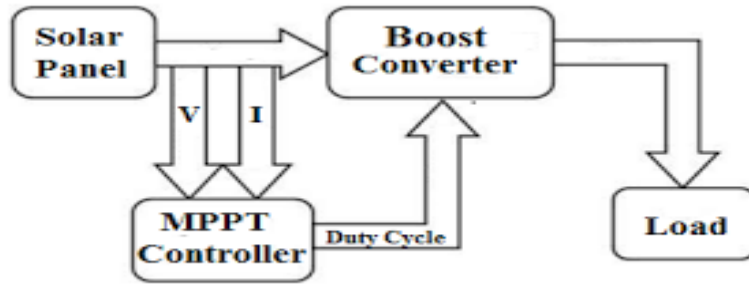
Figure 4.2: The simple diagram of PV system

The design and discussion of the simulation model are discussed in this chapter.

The figure 4.3 shows the MATAB/Simulink of the system.
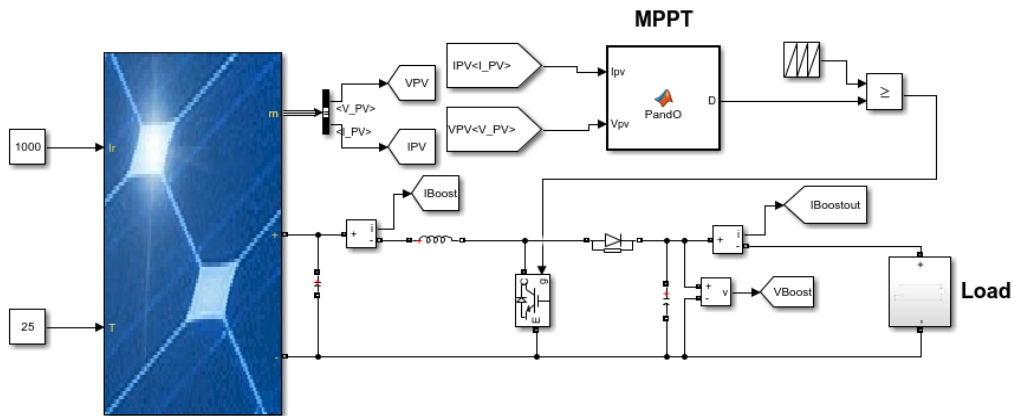
Figure 4.3: MATLAB Simulink Model PV System

4.2.2 Modşule Selection

PV module selection requirements include:

- A performance warranty in the event of a problem.

- Ease of module replacement.

- Adherence to natural electrical and building codes.

- Manuals for inspecting the module's performance and characteristics should be available.

For instance, consider 1Soltech 1STH-220-P (220W Polycrystalline Module) and First Solar. Schott has a power of 220W in standard test conditions (STD).

The electrical data is for the panel (1Soltech 1STH-220-P) under standard test condition (STC): in STC irradiance 1000 W/m2, cell temperature 25°C the performance of the panel is:

Table 4.1: (A, B) standard Data sheet for 1Soltech 1STH-220-P

Power (max)	218.871 W
Voltage @ Max. Power Point	29.3 V
Current at MPP	7.47 A
Voc (Open Circuit Voltage)	36.6 V
Isc (Short Circuit Current)	7.97 A
Number of cells in series Ns	60

(A)

Cell Temperature Coefficient		
Power	$T_K(P_P)$	-0.47 %/deg.C
Open-Circuit Voltage (Voc)	$T_K(V_{oc})$	-0.36101 %/deg.C
Short-Circuit Current (Isc)	$T_K(I_{sc})$	0.10199 %/deg.C

(B)

4.3 Charge Controllers (MPPT)
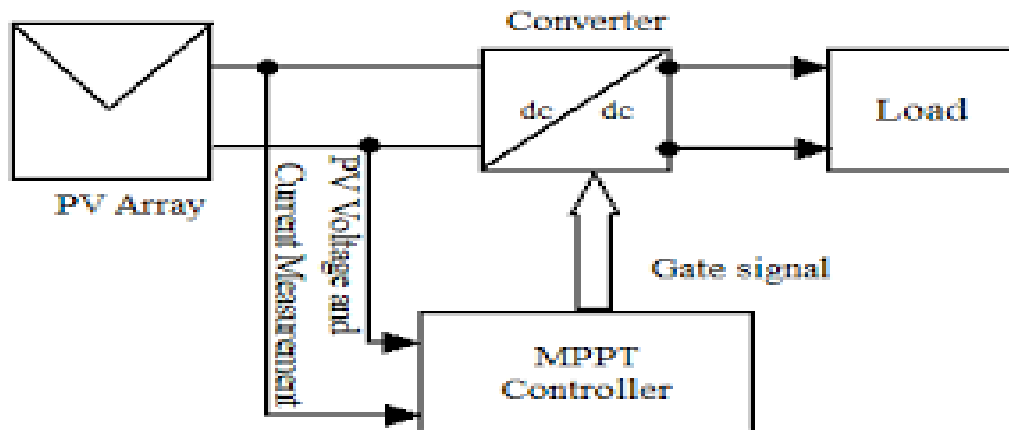
Figure 4.4: MPPT Controller

The temperature and irradiation of the PV array are continuously changing during PV operation, causing the PV array's I-V curve to change as well. To calculate the maximum power at that point at which the voltage and current are maximum, The MPP detector easily checks the voltage and current of an MPPT connected to a DC/DC converter and passed through the PV array's specifications. As a result, the DC/DC converter is operational from the specified point on the curve. The aim of this paper is illustrating the effect of different MPPTs while connecting to either the linear load or non-linear load.

4.4 Mathematical Calculation of DC-DC Boost Converter.

When the output voltage required is greater than the input voltage, a boost converter is used. In a PV system, a boost converter is used to raise the voltage to the desired value. The circuit diagram of a DC-DC boost converter is shown in Figure 4.5.
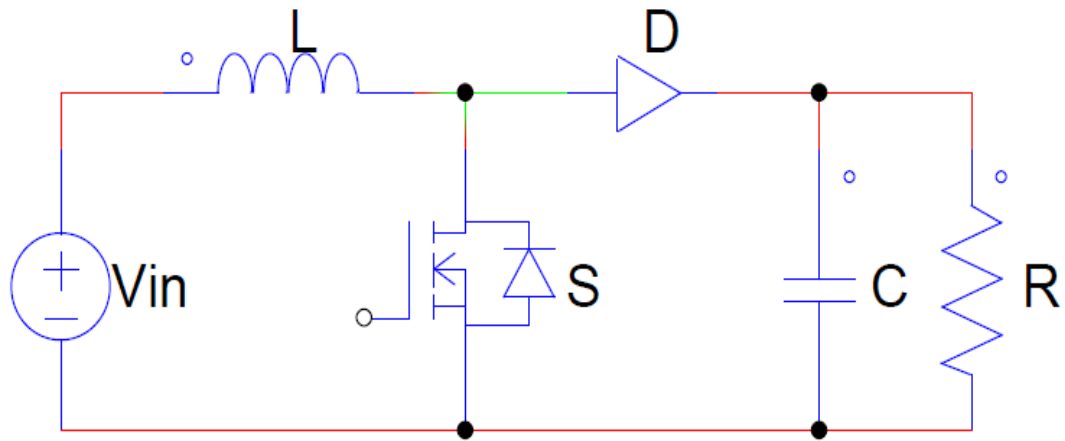
Figure 4.5: circuit diagram of Boost Convertor

The boost converter is made of two power storage elements, an n-channel MOSFET and a diode. During the switching process, the MOSFET and the diode, for example, complement each other. When the MOSFET is on, the diode is turned off, and when the diode is on, the MOSFET is turned off for a specified period of time.

Replacing the mathematical model with the storage elements of a capacitor and an inductor in an amplifier transformer as shown in Figure 30. The inductor voltage and capacitor current are given in Equations (4.1) and (4.2), respectively.

$$V_L = L\frac{di_L}{dt}$$ .... **(4.1)**

$$V_L = L\frac{di_L}{dt}$$ .... **(4.2)**

The amplification switch begins with the initiation of the switching process, resulting in the two circuit shapes, as shown in Figure 31,32.

While the VL inductor for the ON and OFF switching conditions are shown in equation (4.3) and (4.4), respectively.

The Boost converter switch begins with the initiation of the switching process, resulting in the two circuit shapes, as shown in Figure 4.6, Figure 4.7.

$$V_L = L\frac{di_L}{dt} \text{...} \quad \textbf{(4.3)}$$
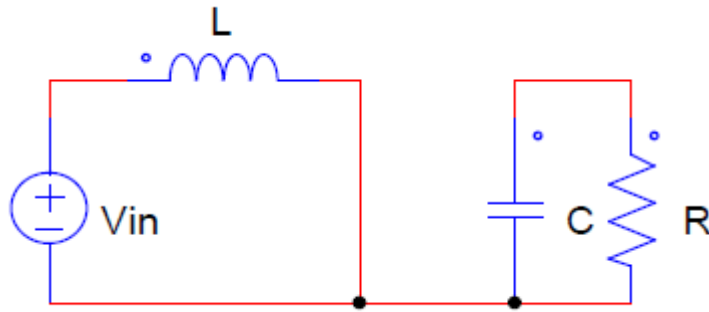
Figure 4.6: ON condition MOSFET boost convertor.
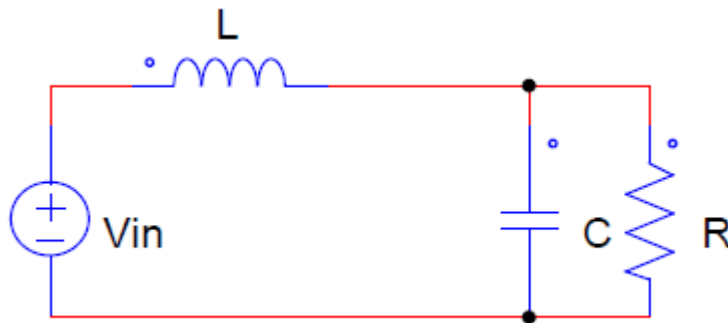
Figure 4.7: OFF condition MOSFET boost convertor.

$$V_L = L\frac{di_L}{dt} \text{...} \quad \textbf{(4.4)}$$

The PWM switching frequency determines the switching time between equations (4.3), (4.4), and its duty cycle is shown in equation (4.5), where the duty cycle is V0 - Vin to V0.

$$V_L = L\frac{di_L}{dt} \text{...} \quad \textbf{(4.5)}$$

Integrating the current flowing through can be used to evaluate the current flowing through in equation (4.6)

$$V_L = L \frac{di_L}{dt} \quad \text{..} \quad \textbf{(4.6)}$$

After receiving, use equation (4.7) to calculate the current through the capacitor, where is the current through the load resistor.

$$V_L = L \frac{di_L}{dt} \text{...} \quad \textbf{(4.7}$$
$$\textbf{)}$$

After receiving i_C, equation (4.8) may be used to measure the capacitor voltage, which, in the case of an ideal model, indicates the boost converter's load voltage.

$$V_L = L \frac{di_L}{dt} \text{...} \quad \textbf{(4.8)}$$

The graphical implementation method in which data flow is drawn in Simulink platform is part of the mathematical modeling approach. It actually uses a graphical representation of the differential equation to model the boost converter system, as shown in Figure (4.8) The KVL and KCL basic laws are applied to the ON and OFF states of the boost converter, as well as the obtained states. On the basis of these two equations, a graphical computational model is created, as shown in Figure (4.8).
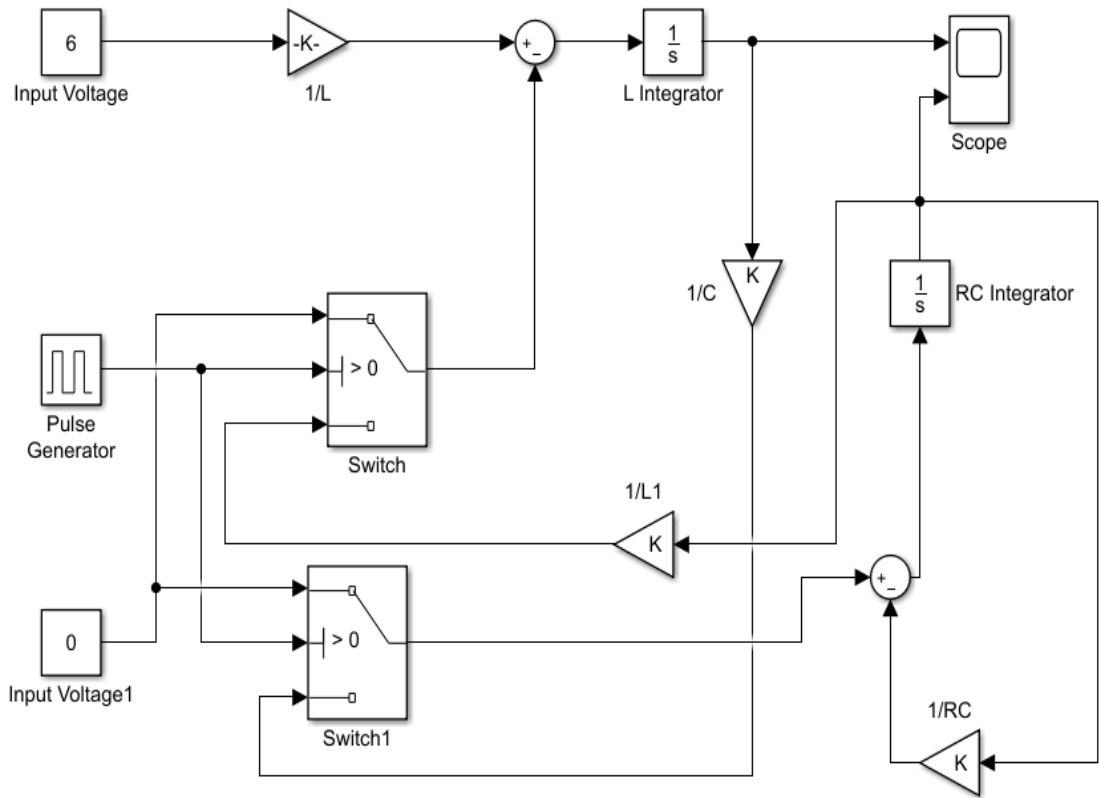
Figure 4.8: simulation modeling of DC-DC Boost Converter

5. RESULTS & CONCLUSION

5.1 Result discussion and comparative analysis.

This part shows the effect of the different algorithms on the linear load and nonlinear load. to more illustrating, three different sicarios are discussed which is:

- MPPT algoritms working under standard test condition (STC).

- MPPT algoritms working under variable irradiance.

- MPPT algoritms working under variable temperature.

5.2 Under Standard Test Condition (STC).

5.2.1 Power at Perturbation and Observation (P&O) Algorithm
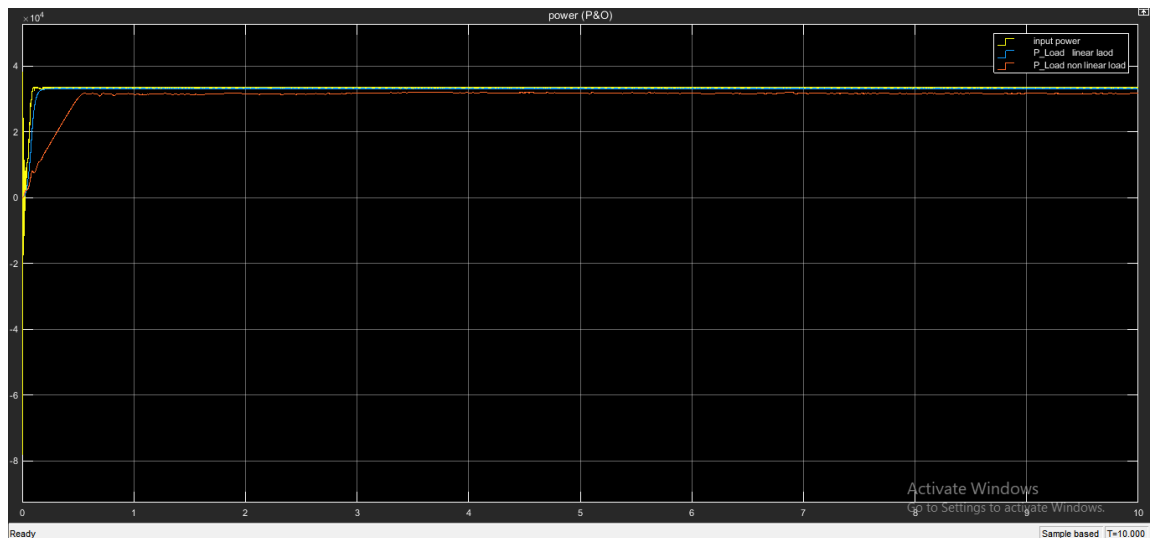
Figure 5.1: The output powers for P&O algorithm under STC.

Figure (5.1) shows the results of the power P&O algorithm under STC, the brown carve shows the power non-linear load (DC Motor) which shows the time need to get a steady state is very high compared to the power linear load. The power generation by PV in both linear and non-linear loads is nearly the same. Because we have different loads the amount of output power is not equal until

can compare the load of linear and non-linear. Also, the non-linear load affected the power generation and made the oscillation was high.

5.2.2 Power at Incremental conductance (INC) Algorithm:
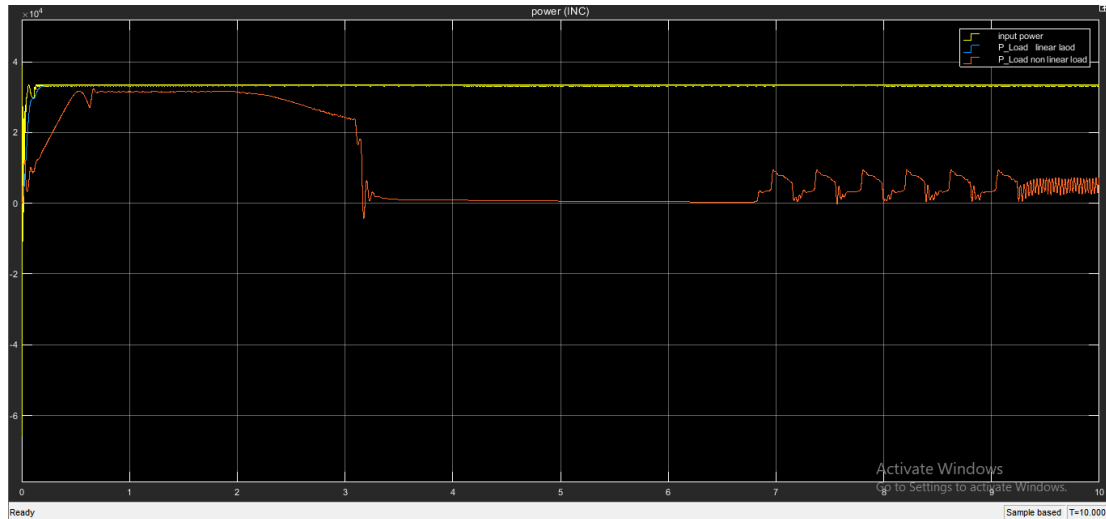
Figure 5.2: The output powers for incremental conductance (INC) algorithm under STC.

In the (INC) Algorithm compare with the (P&O) and (HC) for non-linear load the time need to reach saturation is high, the power line cannot be stable the fluctuation is higher than P&O Algorithm and (HC). So, the INC algorithm could not find the MPPT in 10 sec when connected to non-linear load may be after 10 sec could find it. The performance of INC very poor compared to the P&O, HC algorithms.

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5.2.3 Power at Hill Climb (HC) Algorithm
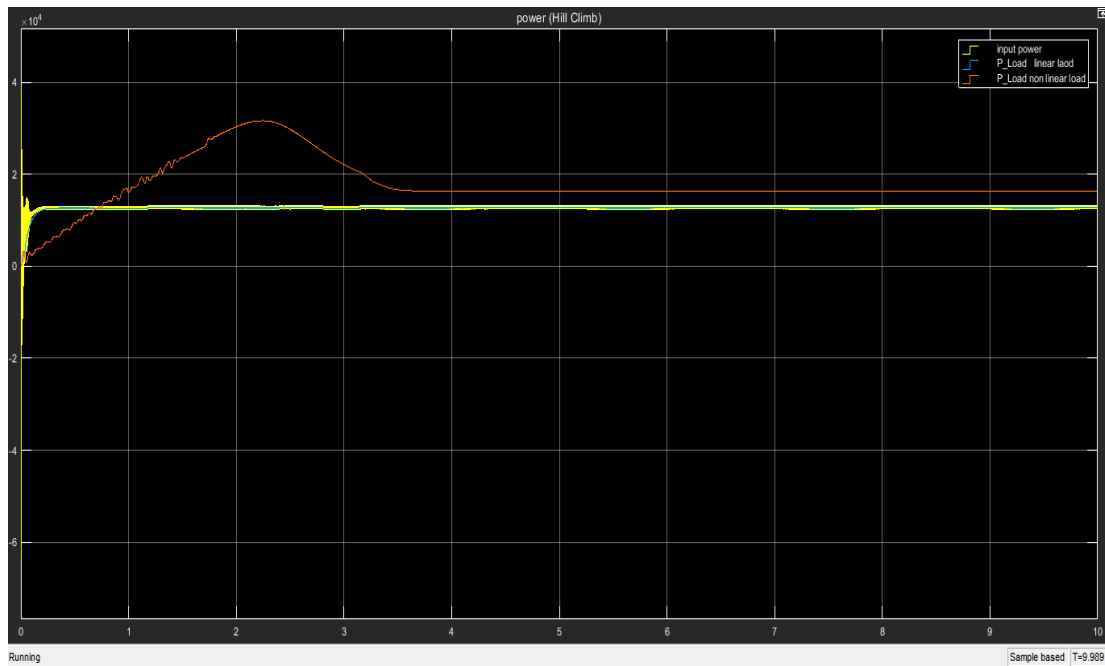
Figure 5.3: The output powers for Hill Climbing (HC) algorithm under STC

Under standard test condition the power of the PV near the power of the linear load. The requested time to get steady state for non-Linear load is very high. note the output power of the nonlinear load is greater than the power of PV because the DC-motor (non-linear load) in the starting operation draws more current, also normally oscillation of non-linear load is higher than the linear load.

5.2.4 Voltages of All Algorithms for linear and nonlinear load.
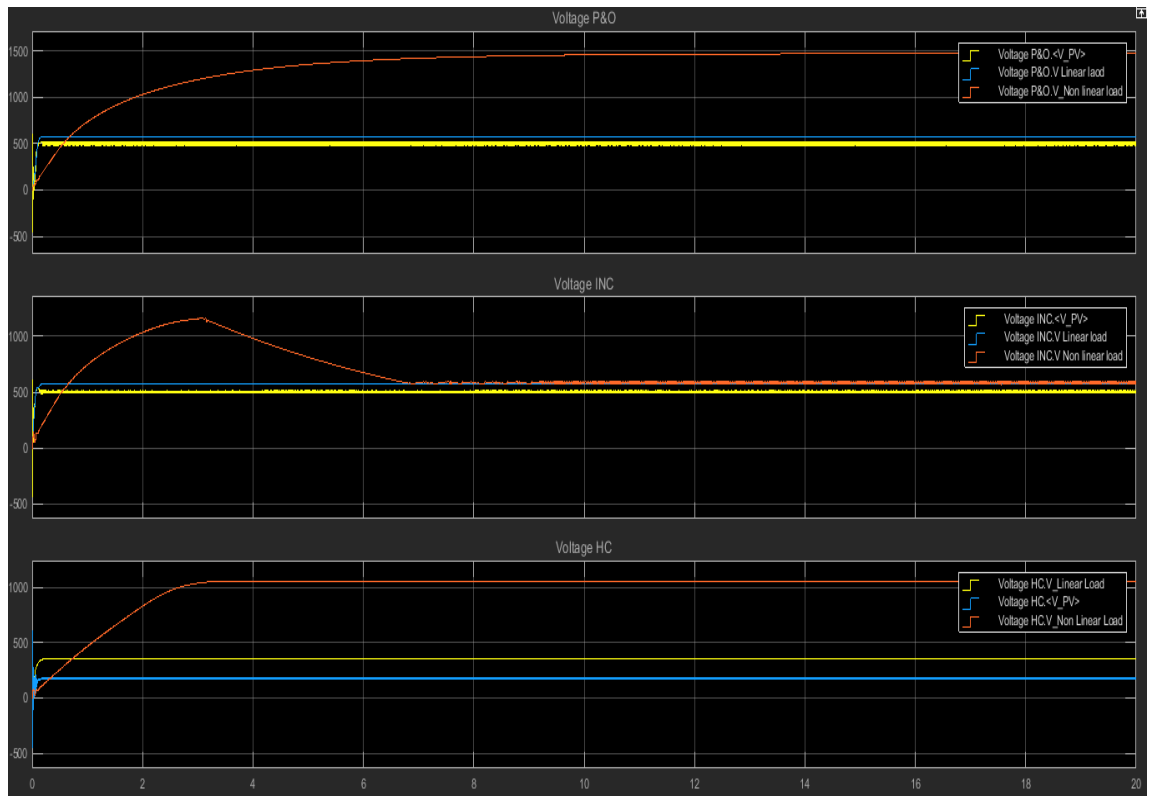
Figure 5.4: voltage under standard test condion (STC).

As it is clear in figure (5.4) the amount of voltage output for linear load in all algorithms near the same but in P&O, INC the output voltage higher than HC voltage output, in all algorithms the time needed to got steady state is very short for the linear load. If the load is nonlinear, the voltage is very high in P&O and HC because the starting rotating the motor needs more voltage, also, the time required to get a steady state is higher compared to linear load. In the HC, the required time to get a steady state is shorter than the two others In STC all the algorithms could find the Vmpp.

5.2.5 Current of All Algorithms for linear and nonlinear load.
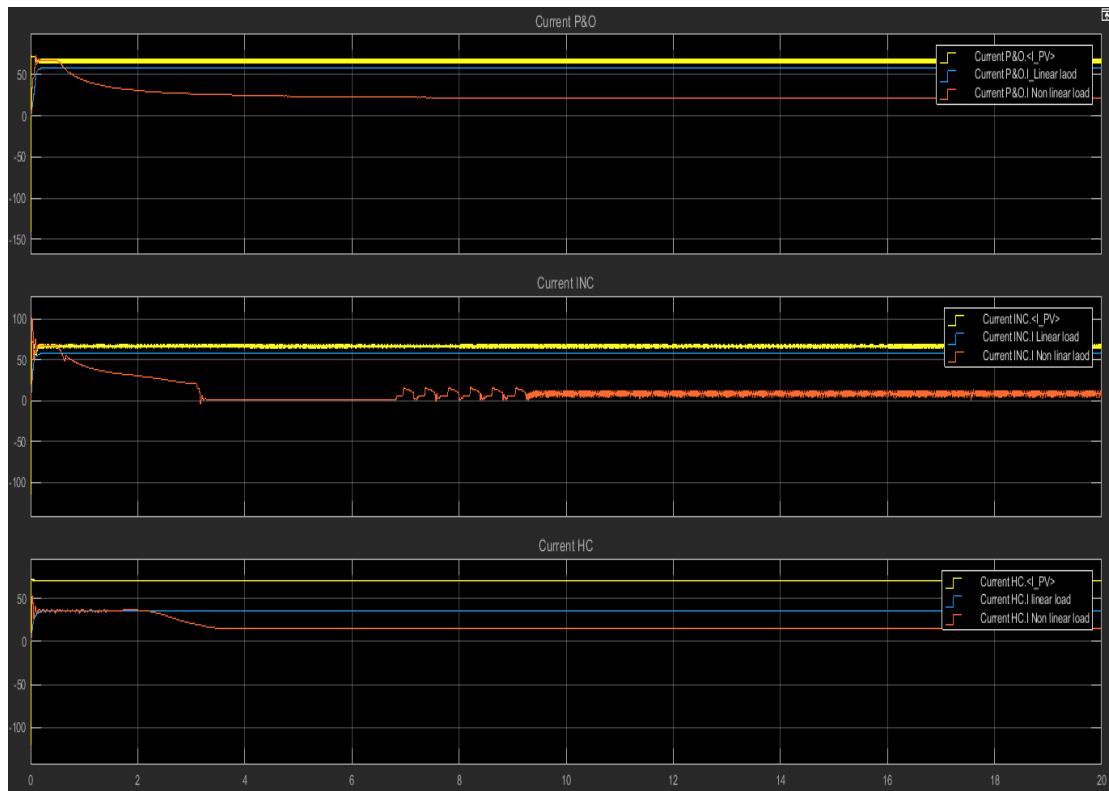
Figure 5.5: Current Under Standard Test Condition (STC).

it could be noticed in figure (5.5) the amount of current output for linear load in the P&O, INC near the same and higher than HC current output, in linear load the time needed to get a steady state is very short. If the load is nonlinear, the current is low in P&O and HC because the starting rotating the motor does not need high current, also, the time required to get a steady state is high. In STC all the algorithms could find the Impp. in the INC Algorithm the current is not stable, and the fluctuation is very high it means that the INC algorithm is not a good choice when the load is nonlinear load.

5.3 Under Variable Solar Irradiance temperature is fixed.

5.3.1 Power P&O Algorithm

Figure 5.6: The output powers for perturb & Observation (P&O) under changing irradiance (1000, 800, 500, 1000)
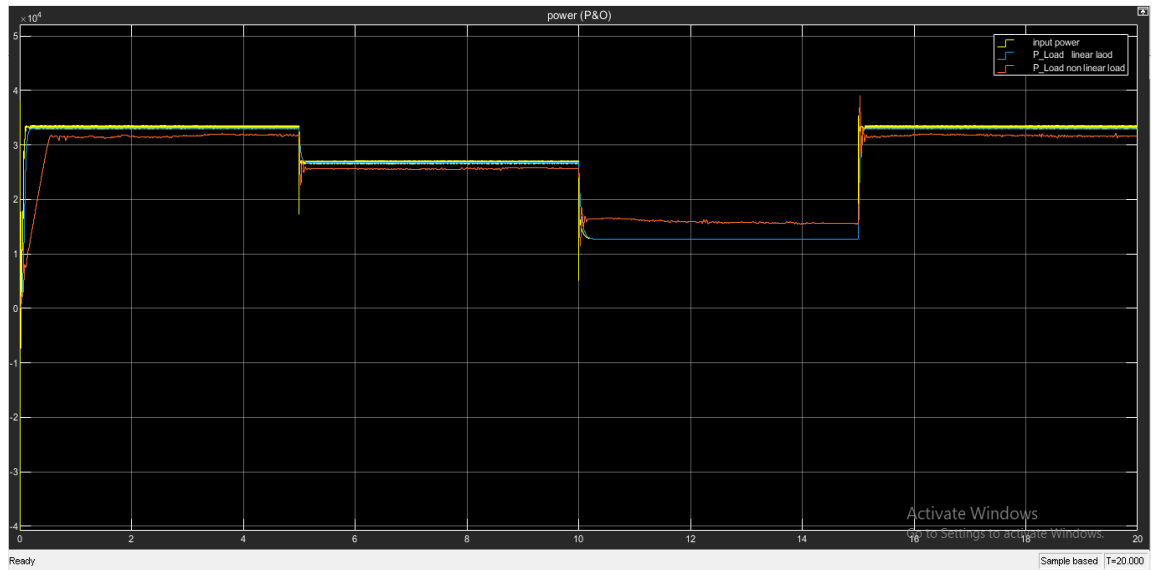
Figure (5.6) shows the results of the power P&O algorithm under changing temperature from (1000,800,500,1000) W/m2, the yellow line shows the power input with more oscillation compare to the blue line which is the power of linear load, but in non-linear load (DC Motor) the output power is lower with more oscillation. for the non-linear load (DC Motor) witch shows the time need to get a steady-state is very high compare to the power linear load. The power generation by PV in both linear and non-linear loads is nearly the same. Because we have different loads the output power level is very different. Also, the non-linear load affected the power generation and made the oscillation was high. For each irradiance changing the P&O could find MPPT that is mean the algorithm working properly.

The rising time of the P&O Algorithm needed to reach the steady-state is smaller than INC Algorithm, but the oscillation of P&O is greater than INC Algorithm.

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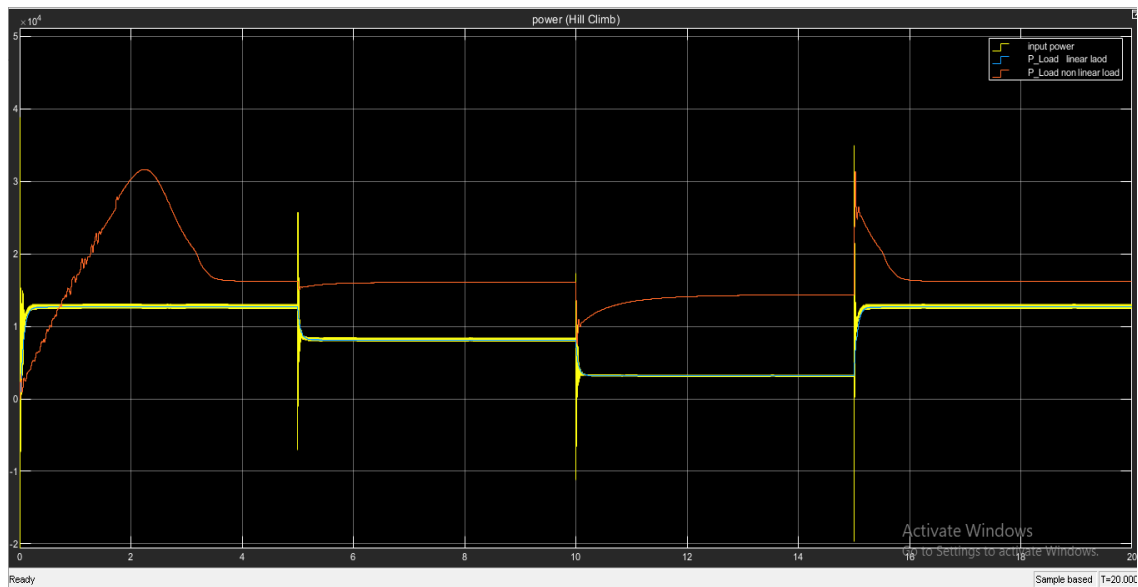### 5.3.2 Power Hill Climbing (HC) Algorithm

Figure 5.7: The output powers for Hill Climbing (HC) under changing irradiance (1000, 800, 500, 1000)

in Hill Climb (HC) algorithm opposite to P&O, INC algorithm the output power of the PV is very low as mentioned before for HC algorithm it is normal because it cannot find the best power that the panel can generate. Also, we note that the time needed to rich steady state for non-linear load is more than the linear load. In all case of changing irradiance, the HC can find MPPT and reach to steady state.

5.3.3 Power INC Algorithm

In the case of a sudden shift in solar irradiance, the INC algorithm takes longer to hit the new MPP in non-linear load , as shown in Figure (5.8). As a result, the system's performance under variable solar irradiance is poor.
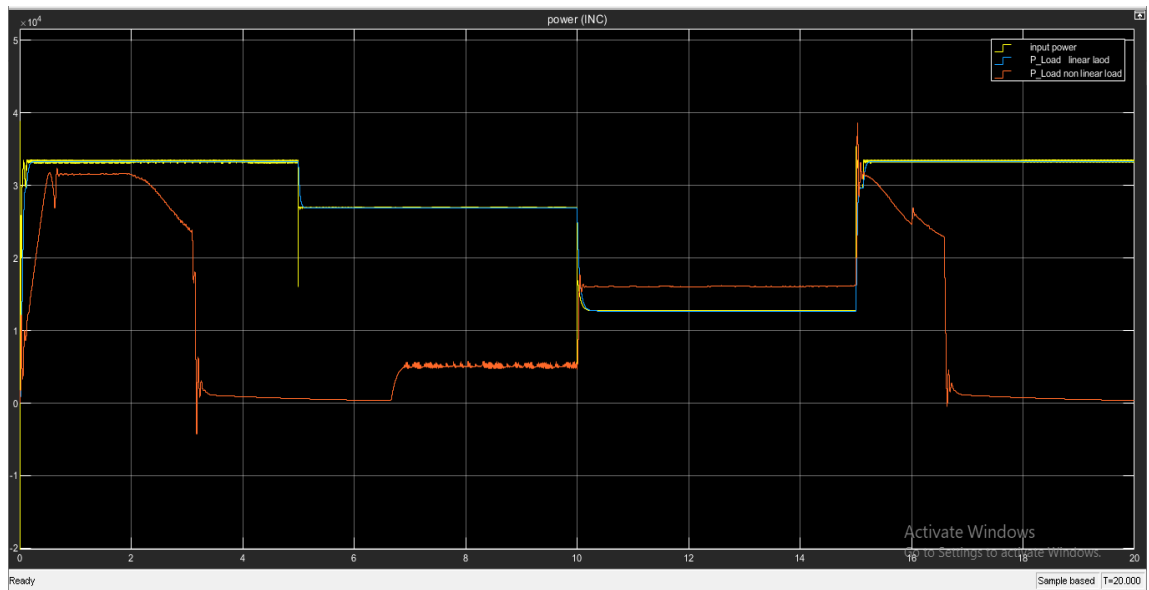
Figure 5.8: The output powers for Incremental Conductance (INC) under changing irradiance (1000, 800, 500, 1000)

The three figures (5.6,5.7,5.8) show the effect of changing irradiance on power generation and output power for a linear and non-linear load like all the case the oscillation in non-linear load is high and affect of change irradiance is very clear in non-linear load the rising time needed to saturation is higher than non-linear.

In general, when irradiance change directly affected output power, P&O is better than the two other algorithms in order to reach steady-state, oscillation, and output power for the linear and non-linear load.

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5.3.4 Voltage of All Algorithms for linear and nonlinear load.
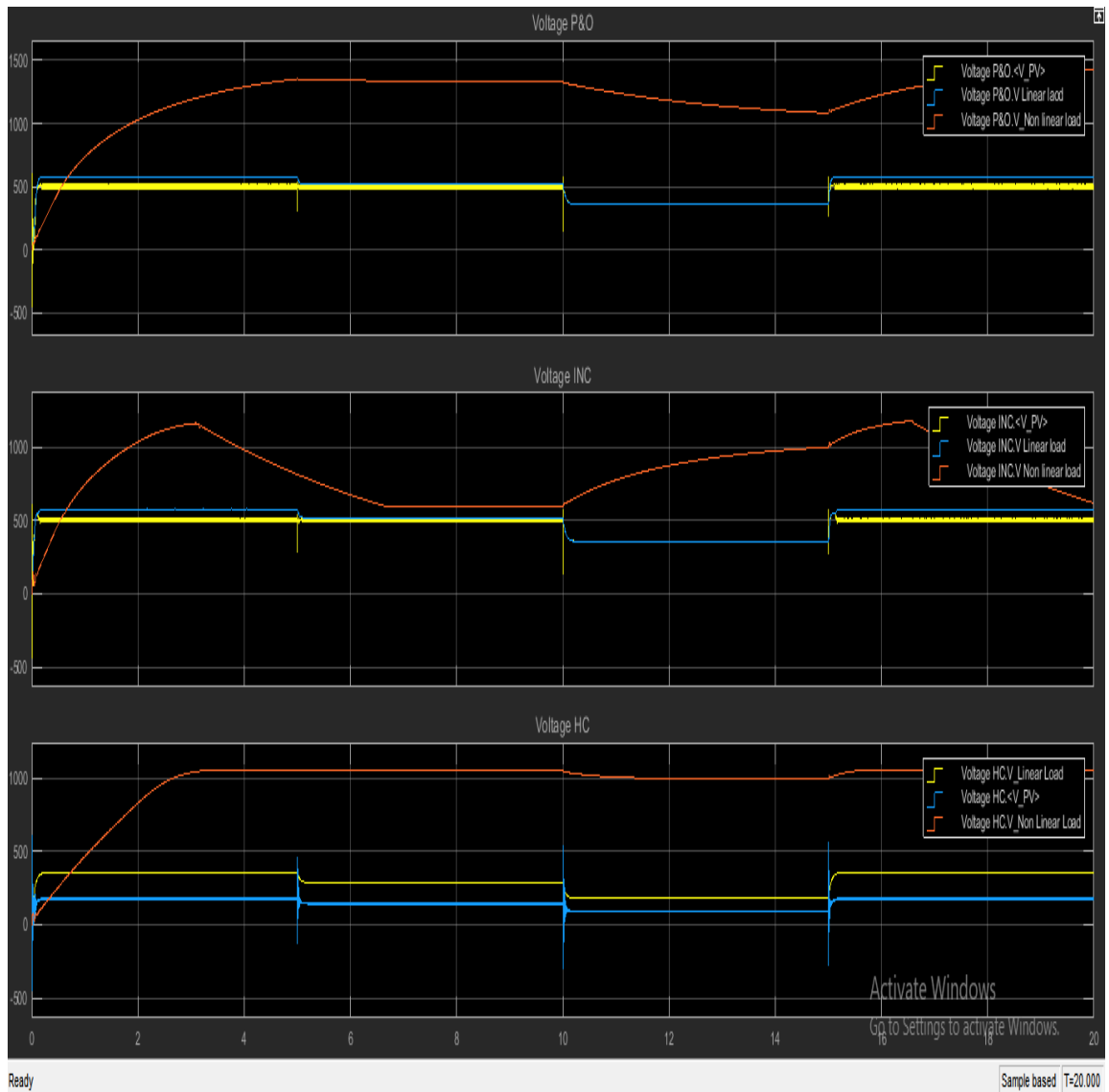
Figure 5.9: Voltage Under Variable Solar Irradiance temperature is fixed
(1000,800,600,1000).

Since photo-generated current is proportional to irradiance, an increase in irradiance results in a higher photo-generated current. When the irradiance changing the output, voltage is changing too. In figure 5.9 the P&O, HC, has a good response to find the new Vmpp in a very short time. But INC algorithm in nonlinear load could not find Vmpp well. When irradiance changes the output voltage will be low when irradiance is lower than 1000 w/m^2. voltage proportional change with irradiance. The HC has a good characteristic to respond to irradiance change but with lower voltage.

5.3.5 Current of All Algorithms for linear and nonlinear load.
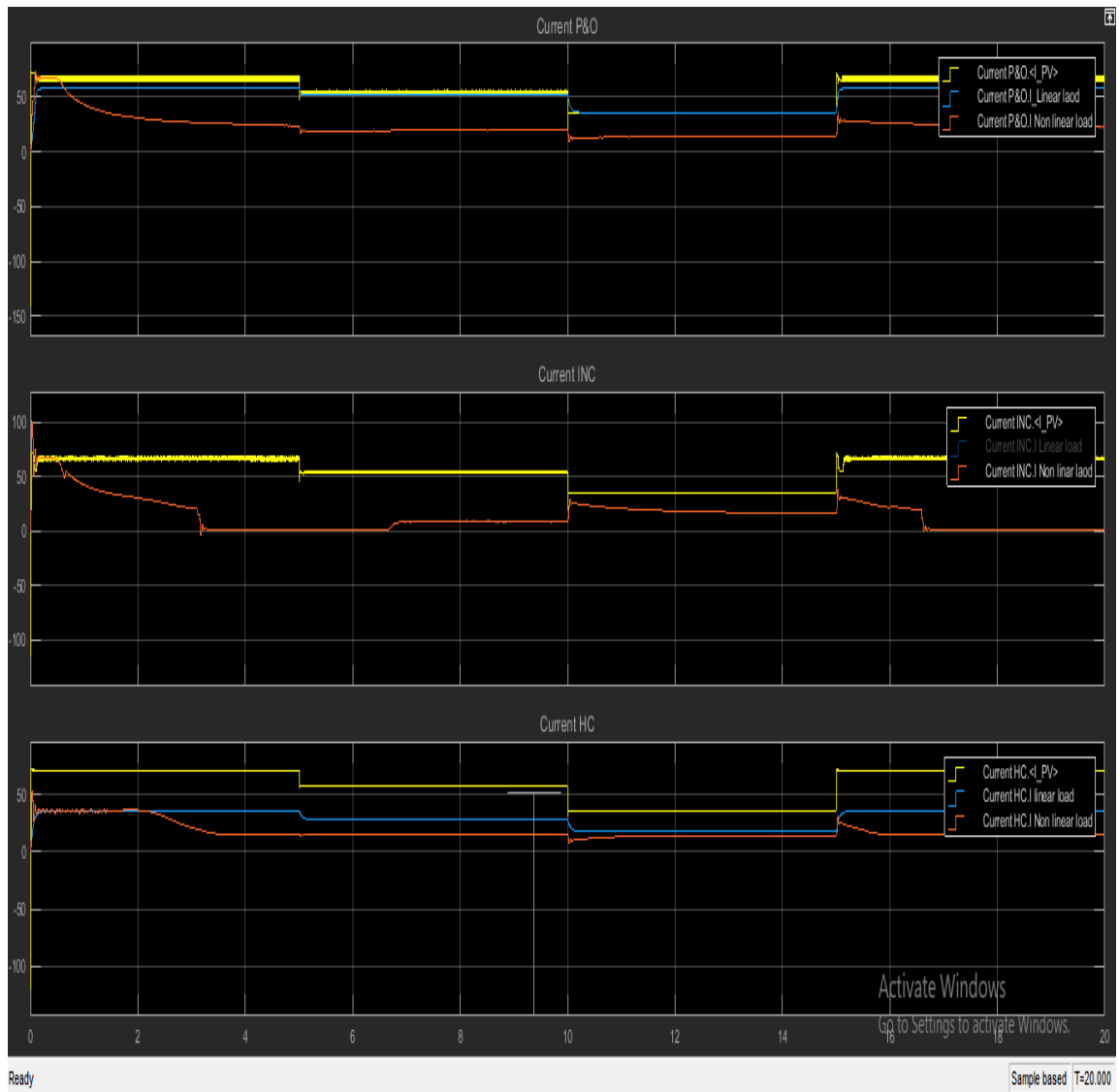
Figure 5.10: Current Under Variable Solar Irradiance temperature is fixed (1000,800,600,1000).

In figure 5.10 shows when the irradiance decreases the current is decreased. the effect of changing irradiance on current is greater than changing of temperature. The current in nonlinear load when INC algorithm is used the fluctuation is very high. Also, it can be noticed that the P&O is very stable and could find new Impp in a very short time.

In all cases when irradiance or temperature is changing for linear load, all algorithms quickly could find the new Vmpp and Impp but when the load is non-linear load the new output voltage and current differ between algorithms. in respect to the time needed to get steady-state and amount of voltage and current.

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5.4 Under Variable Solar Temperature fixed Solar Irradiance

5.4.1 Power P&O Algorithm

The Figure 5.11 shows the effect of variable temperature Change in temperature (25, 35, 45, 25) at second 0, 5, 10, 15.
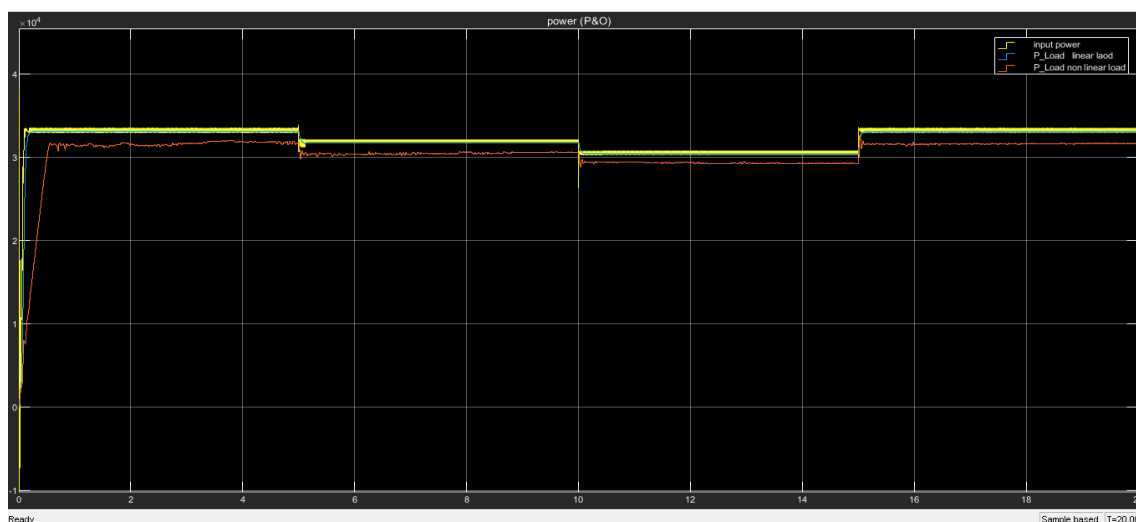
Figure 5.11: The powers output for P&O algorithm under variable temperature after (25, 35, 45, 25) at 0, 5, 10, 15 second, respectively.

In the P&O algorithm for changing temperature the output power is changing, the algorithm can find the MPPT in all cases of changing temperature. But in non-linear load, the oscillation is higher than the linear load. Also, the rising time is greater than the linear load.

5.4.2 Power Hill Climb (HC) Algorithm

The Figure 5.12 shows the effect of variable temperature on the output power for linear and non-linear load in HC algorithm.
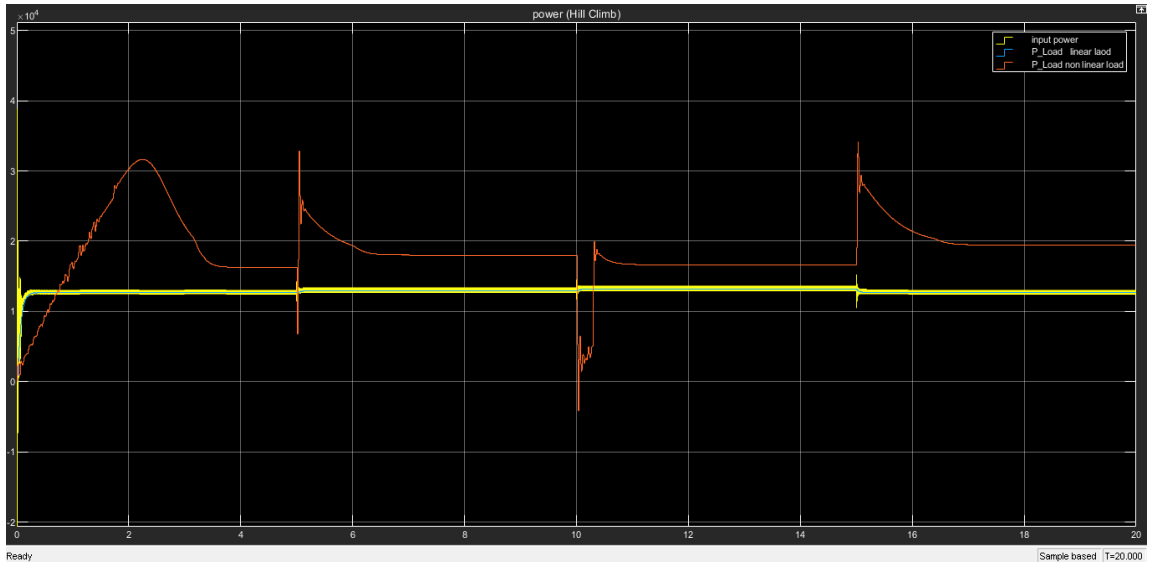
Figure 5.12: The powers output for Hill Climbing (HC) algorithm under variable temperature after 5 second (25, 35, 45, 25)

The change in temperature shows that in P&O and INC the time needed to saturate is very small compared to the HC algorithm. In HC algorithm for changing temperature the output power is changing, the algorithm cannot find the MPPT any case of changing temperature. in non-linear load the oscillation is higher than the linear load. Also, the rising time is greater than the linear load.

5.4.3 Power Incremental Conductance (INC) Algorithm

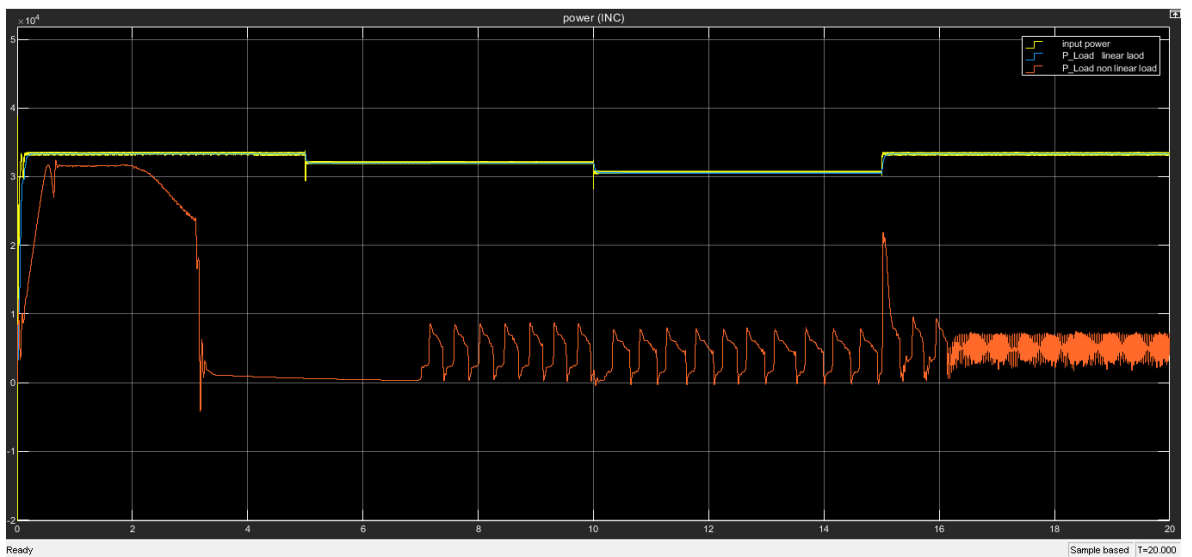**Figure 5.13:** The powers output for Hill Climbing (HC) algorithm under variable temperature after

Figure 5.13 shows the power of non-linear load has a very large oscillation. The INC algorithm has no ability to find MPPT when the temperature is changing in all cases when connected to the non-linear load in the time limit.

5.4.4 Voltage of All Algorithms for linear and nonlinear load.
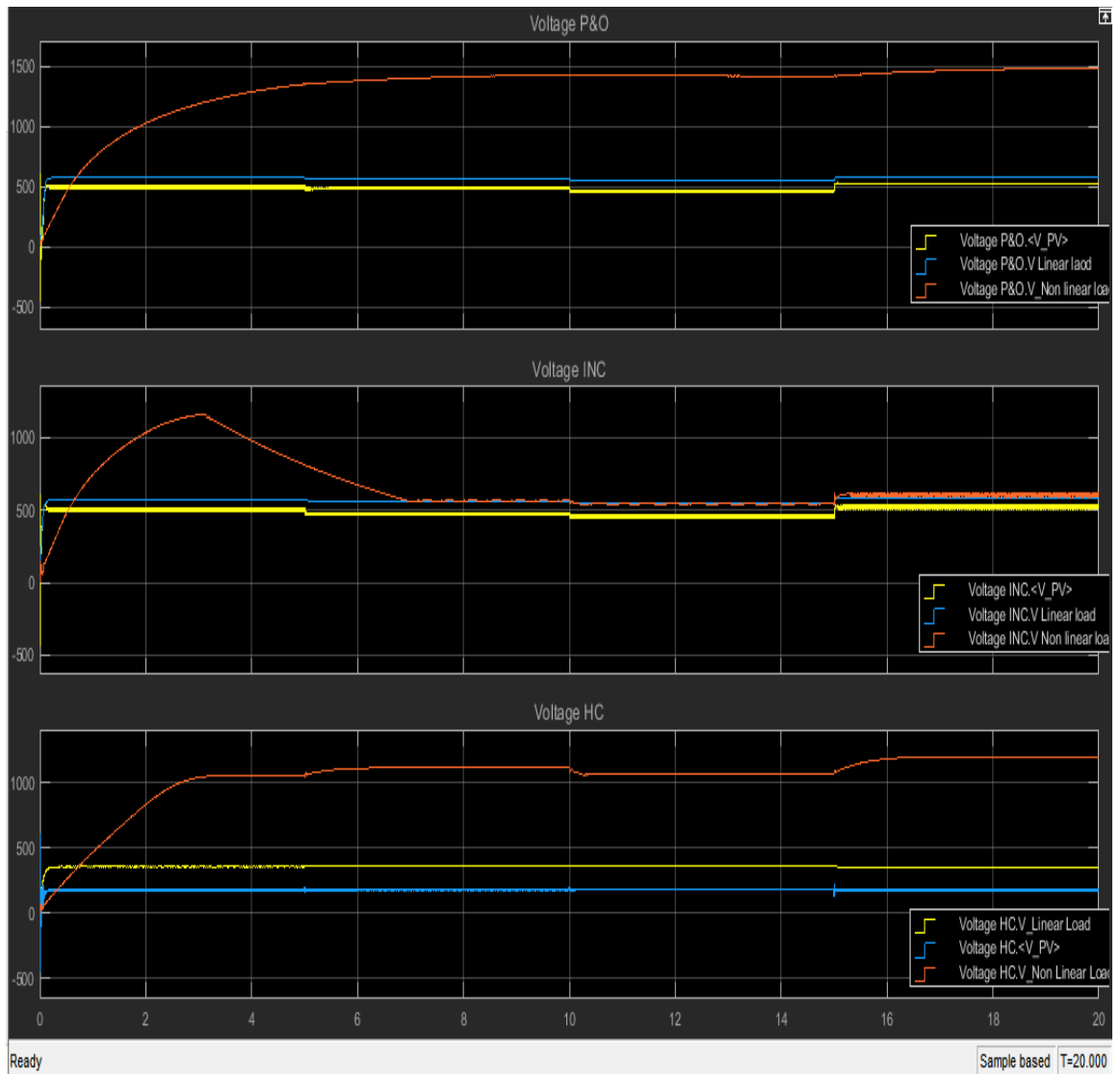
Figure 5.14: Voltage Under Variable Solar Temperature fixed Solar Irradiance (25^0, 35^0, 45^0, 15^0).

Figure 5.14 shows the effect of changing temperature on the output voltage which is clear when the temperature is increased from 25^0 the output voltage is decreased but in the HC algorithm the change in voltage is smaller than the P&O, INC but when the temperature goes down to 15^0 the output voltage is increase. As mentioned before the voltage in HC is lower than INC, P&O. to

respond to the changing temperature to get a steady state the INC algorithm is better than the P&O, HC.

5.4.5 Current of All Algorithms for linear and nonlinear load.
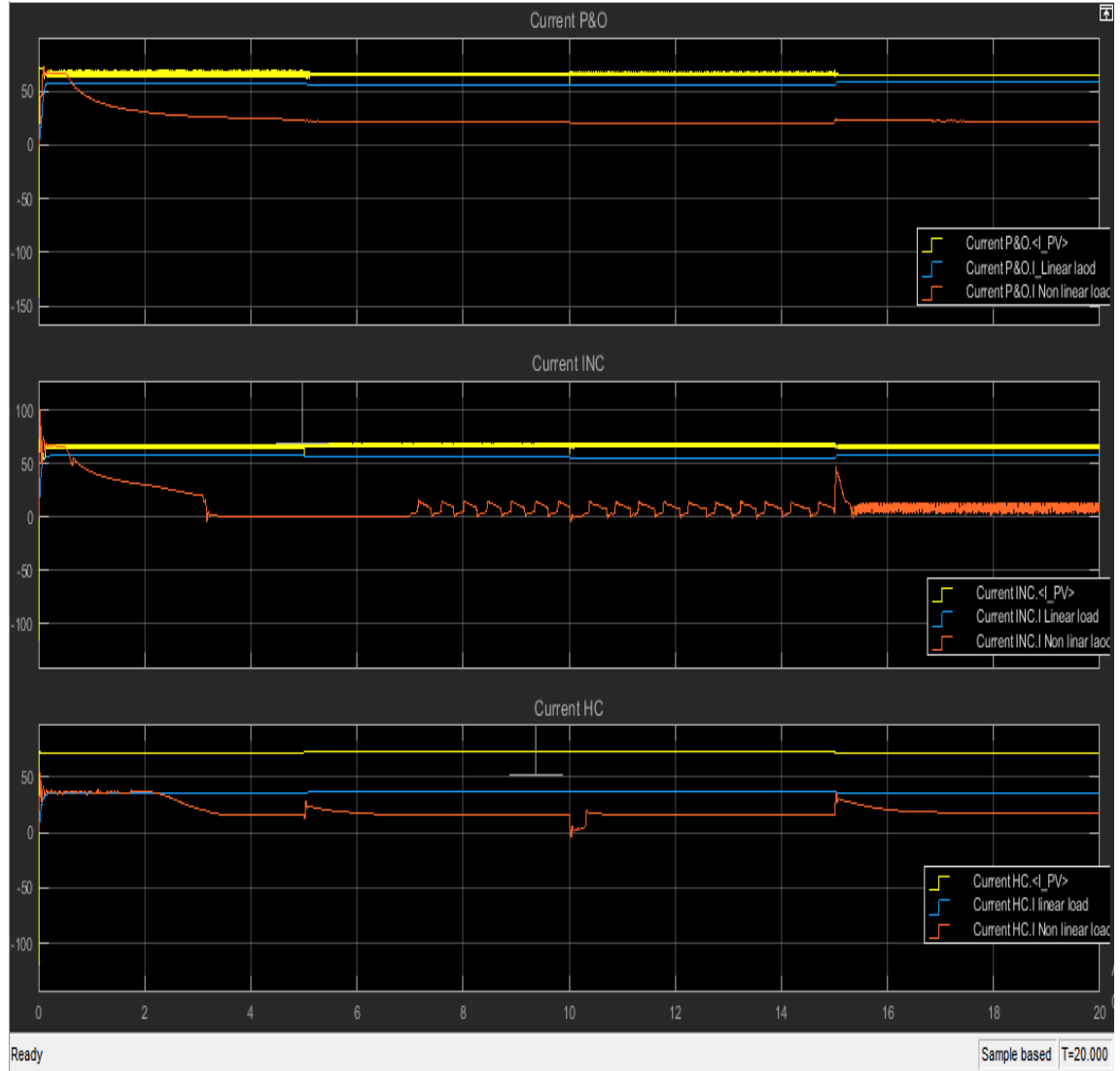
Figure 5.15: Current Under Variable Solar Temperature Fixed Solar Irradiance (25^0, 35^0, 45^0, 15^0).

In figure 5.15 shows when the temperature increases the current is increases but very small compared to the voltage. The current in nonlinear load when INC algorithm is used the fluctuation is very high. Also, it can be noticed that the P&O is very stable and could find new Impp in a very short time.

In all cases when irradiance or temperature is changing for linear load, all algorithms quickly could find the new Vmpp and Impp but when the load is

non-linear load the new output voltage and current differ between algorithms. in respect to time needed to get steady state and amount of voltage and current.

6. CONCLUSIONS

In this study, the most three popular MPPT have been described. which are perturb and observation (P&O), Incremental Conductance (INC), and Hill Climb (HC) algorithms. the load used are Linear and non-Linear loads. the DC-DC converter is a boost DC-DC converter switched capacitor. Comparing to the output of all algorithms when connected to the load and shows the effect of changing irradiance and temperatures. To show, the effect of the different MPPT when connecting to the load three scenarios has been shown. those algorithms which are discussed more popular than the other because it is simple and easy to implement.

- Under Standard Test Condition (STC).
- Under Variable Solar İrradiance temperature is fixed.
- Under Variable Solar Temperature Fixed Solar Irradiance

The PV power and output power for three separate MPPTs can be seen in three scenarios. Clearly, it is possible to note the effect of linear and nonlinear loading on all algorithms.

The non-linear load had a greater effect on the performance, especially on the INC Algorithm, and in some cases when the temperature or irradiance changed, the INC could not find MPPT or tack for a long time.

Finally, as irradiance and temperature change, the P&O algorithm outperforms the other two algorithms in terms of finding MPPT. In addition, the output power is higher, and the time to achieve steady state is shorter.

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RESUME

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