T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

MICRO-INVERTER APPLICATIONS ADVANTAGES IN PV SYSTEMS

MASTER'S THESIS

Mir Alam Khan

Department of Electrical & Electronic Engineering

Electrical and Electronics Engineering Program

February 2021

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Advisor: Prof. Dr. Mehmet Emin TACER

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DECLARATION

I hereby declare that all information in this thesis document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results, which are not original to this thesis.

Mir Alam Khan

FOREWORD

In the name of Almighty ALLAH, the most merciful the most gracious, and may Allah's Peace and blessing be upon our Prophet MUHAMMAD P.B.A. Alhamdulillah after thanking to almighty Allah our creator, I would like to thank my Respectable Family specially My Father and Mother who raised me to become a good person, they always supported me and believed at me, Encouraged me and gave me the strength while I was totally lost. They were patient during my mistakes and my bad times. Today what I have accomplished is because of their effort. I hope I can make them proud and return even some of what they gave me during their Entire lives.

I would like to thank my thesis advisor Prof Dr. Mehmet Emin TACER for his guidance, support, and help during my work in the thesis. I thank him for everything I learned from him.

I thank all my teachers starting from my school time until today as they had great influence on me and made me love education and I hope I can become one day a good teacher as they were

February, 2021 **Mir Alam Khan**

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ABBREVIATIONS

AC	**:** Alternation Current
DC	**:** Direct Current
DERS	**:** Distributed Energy Resources
DG	**:** Distributed Generation
EMS	**:** Energy Management System
ESS	**:** Energy Storage System
ESUs	**:** Energy Storage Units
MG	**:** Microgrid
MPPT	**:** Maximum Power Point Tracking
MS	**:** Microsystem
PCC	**:** Point of Common Coupling
PID	**:** Proportional Integral Derivative
PSF	**:** Power Signal Feedback
PV	**:** Photovoltaic Panels
PWM	**:** Pulse Width Modulation
SC	**:** Solar Cell
SOC	**:** State of Charge

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MICRO-INVERTER APPLICATION ADVANTAGES IN PV SYSTEMS

ABSTRACT

The purpose of this thesis is to make an inverter for domestic purpose that uses boost topology by implementation of PWM (pulse width modulation). On the basis of this topology an inverter will be presented that will have improved PWM inverter and can be connected with PV system using P&O method for MPPT. MATLAB Simulink is used to simulate and analyze the work. The result of simulation shows that the presented inverter system has effective control of current waveforms from the PV system which tends to sine wave and achieve maximum power point tracking, besides it is able to put arbitrary power out to the load or to the grid, provided control system has a good stability.

Dual stage topology is used in which the DC-DC inverting circuit is decoupled, for DC-DC converting half bridge converter is used and for DC-AC converter H bridge inverter is used. The output of inverter will be 230V rms. Proposed scheme of micro inverter is system for domestic use.

Keywords: *MPPT, DC-AC converter, H-bridge inverter, micro inverter, Pulse width modulation.*

PV SİSTEMLERİNDE MİKRO İNVERTÖR UYGULAMASININ AVANTAJLARI

ÖZET

Bu tezin amacı, PWM (darbe genişlik modülasyonu) uygulamasıyla artırma topolojisini kullanan evsel amaçlı bir invertör yapmaktır. Bu topoloji temelinde, geliştirilmiş PWM invertörüne sahip olacak ve MPPT için P&O yöntemi kullanılarak PV sistemine bağlanabilecek bir invertör sunulacak. MATLAB Simulink, işi simüle etmek ve analiz etmek için kullanılır. Simülasyonun sonucu, sunulan invertör sisteminin, sinüs dalgası eğilimi gösteren ve maksimum güç noktası takibi sağlayan PV sisteminden gelen akım dalga biçimlerinin etkin kontrolüne sahip olduğunu, ayrıca yüke veya şebekeye keyfi güç verebildiğini göstermektedir. kontrol sistemi iyi bir stabiliteye sahiptir.
DC-DC ters çevirme devresinin ayrıştırıldığı, DC-DC dönüştüren yarım köprü dönüştürücü ve DC-AC dönüştürücü için H köprü çevirici kullanıldığı çift aşamalı topoloji kullanılır. İnverterin çıkışı 230V rms olacaktır. Önerilen mikro invertör şeması, ev içi kullanım için bir sistemdir.

Anahtar Kelimeler: *MPPT, DC-AC dönüştürücü, H köprüsü çevirici, mikro çevirici, Darbe genişlik modülasyonu..*

1. INTRODUCTION

Solar energy is one of the low-cost energy resources for electrical energy. The electric power is generated by the photovoltaic (PV) cells when radiation of the sunlight emits photon out of each cell, resulting into a direct current (DC). This DC voltage is converted to AC voltage by device called solar inverter. The basic inverters are two types.

i. Micro Inverters.
ii. String Inverters.

This thesis is compromised on the MPPT Micro Inverter and its priority on the other inverters like, string inverter and simple micro inverter. A few reasons are as follow.

i. Efficiency.
ii. Safety.
iii. Cost effective.

1.1 Motivation

The motivation behind this work is defined in this chapter. It also provides the basic points of this research and the organization of the thesis. In Future, because of the development in worldwide populace and the most extreme number of industries the demand for electrically energy will increase more. Due to this we will need our electrical resources to be expanded. Late investigations show that the universes net power age is been relied upon to ascend from 17.3 trillion kilowatt/hour to 24.4 trillion kilowatt/hour (2005-2030). Currently many electricity which is generated from fossils fuels mainly coal because of its cheapness. However, the use of more fossil fuel accounts for greenhouse gas emission and environmental pollution which are the primary explanations for the an unnatural weather change. For instance, the discharge of mercury and furthermore the carbon dioxide which are the fundamental explanations for the contamination are relied upon to increment by 8% and 35%, by year 2020.

To reduce the problems, which are linked with the electricity generation from fossils, the renewable energy should be used. One of the most remarkable and effectively open environmentally friendly power is the light from the sun, which can be effortlessly changed over to clean power by utilizing photovoltaic cells. Photovoltaic was utilized right off the bat began in the seventies of twentieth century and is as of now developing everywhere on the world. Numerous associations anticipate a major development in its utilization in almost future. As shown in figure 1 the European Photovoltaic industry association (EPIA) said that global cumulative capacity of PV will reach 800 GW by 2030. Additionally, a study by worldwide energy organization IEA reports that over 2.26GW PV limit was introduced in 2007, which shows increment of over half.

Figure 1.1: Expected global cumulative PV capacity: EPIA data

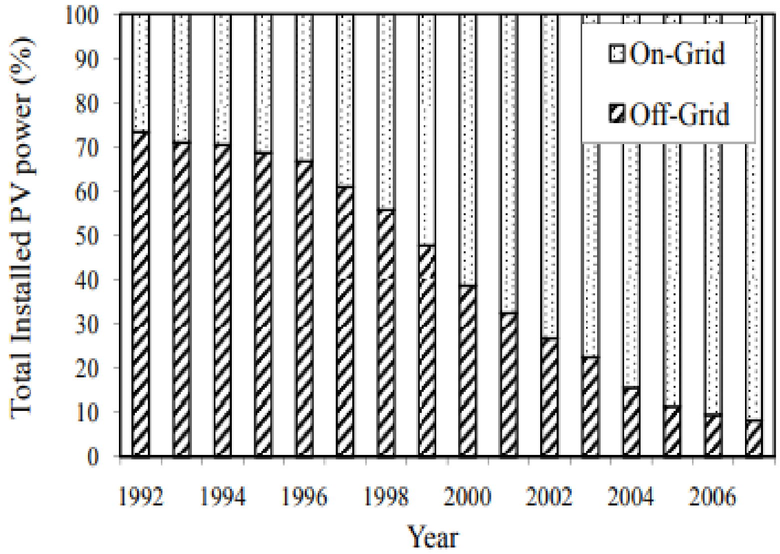


Figure 1.2: On-framework and off-lattice PV power in the IEA nations

PV systems are usually used in the following three fields,

1. Satellite applications.
2. Off-grid applications.
3. On-Grid.

1.2 Solar Power Syetem

It tends to be partitioned into two sections:

1.2.1 PV cells

These are linked together to form a PV panel which convert solar power to DC electrical power.

1.2.2 Power components system

For the most part alluded to control age framework), including DC/AC inverters, DC/DC converters, regulators, and so forth it changes over the voltage DC power into DC or AC power. The advancements of PV power framework depend on the specialized improvements of these parts independently.

1.3 PV Cell Technology

A lot of PV cell technology is in the market today, which uses different material types. Most of the research is based on the PV cells which are about 50% of the total system cost. It is based on the differences of commercial maturity and manufacturing cost the PV cells production is divided into three generations.

1.3.1 First Generation

In first generation crystalline silicone c-Si is used, which can be single crystalline or either multi crystalline. Single crystalline are more and better efficient than multi ones.

1.3.2 Second Generation

The second generation consists of thin film PV technology and is divided into mainly three parts which are 1. Amphoras 2. Cadmium-telluride 3.Copper Indium Selenide. Second generation technology is widely used in market now a day.

1.3.3 Third Generation

Third generation PV cells consist of technology such as concentrating PV dye sensitized, quantum dots and organic cells, these are under development and can become future option to reduce the costs of PV cells.

1.4 Why Renewable Energy Resources

In the recent past, due to the higher demand of electricity, the burden on the conventional energy resources like coal and gas is increased. The higher demand of electricity is due to the fact of ever-increasing population, greater number of appliances which have added comfort to the human life, industrial revolution and many more. So, to meet the requirements of demand to the supply, it was necessary to move towards the long lasting and cheap sources of power. Long lasting resources mean the sources that would be used for long period of time without any burden on them and that can be used again and again. Due to these circumstances, the world shifted towards the renewable energy resources. Renewable energy resources present many benefits as compared to the conventional energy resources. Due to sustainability, reliability, efficiency and to meet the increasing power demand, world is moving towards the renewable energy resources. These sources present many benefits compared to that of conventional resources as they are capable of environmental benefits, low carbon emission, higher efficiency, high power quality, fewer transmission and distribution (T&D) line losses, avoidance of T&D capacity upgrades and point of consumption in power system (A. e. a. Khamis, 2013). Most of the renewable energy resources like solar, wind, fuel-cell, tidal, bio-mass, and geothermal. RERs are regarded as the clean and environmentally friendly sources of electricity. Shifting towards the renewable energy resources from conventional ways of electricity generation is because of rising fuel costs, losses involved in grid, hazards of nuclear power generation and global environmental impacts (S. K. Z. a. B. M.-I. Abapour, 2013)

Some of the benefits are given below: -

- Environmental Friendly.
- Economical.
- Long lasting.
- No global warming.
- Reliability.
- No toxic effects on human health

1.4.1 Renewable Energy Resources

Renewable energy resources comprise of following sources. A brief introduction of each source is given.

1.4.2 Solar

Solar energy can be used as two ways i.e. solar thermal and solar photovoltaic cell. Solar thermal is employed to heat the water up and solar photovoltaic is use used for sake of electricity production. In photovoltaic, light is converted into electricity when photons of light hit the semiconductor material's atom and excite them to produce flow of electron leaving behind the holes. A photovoltaic cell innovation is utilized to change over sun based energy legitimately into electrical force and is a non-mechanical gadget generally made of semiconductor materials. Daylight is comprised of photons. These photons contain various measures of energy as indicated by the frequencies of the sunlight based range. At the point when photons strike on a photovoltaic cell, they might be reflected, passed, or absorbed. Only those photons give energy to produce power, which are consumed. At the point when adequate daylight is consumed by a semiconductor material, electrons are liberated from the iotas of semiconductors. Special assembling makes the front surface of the cell more open to free electrons, so the electrons normally move to the surface. At the point when the electrons leave their position, openings are formed. When numerous electrons, conveying a negative charge, go through the front surface of the cell, the subsequent unbalance of charge between the front and back surfaces of cell makes a voltage contrast like the negative and positive terminals of a battery. When the two surfaces are associated through an electrical burden, power streams.

1.4.3 Hydropower

An environmentally friendly power source is one that isn't spent in the creation of energy. Through hydropower, the energy in falling water is changed over into power without "spending" the water. Hydropower energy is eventually gotten from the sun, which drives the water cycle. In the water cycle, waterways are energized in a constant cycle. Due to the power of gravity, water streams from high focuses to depressed spots. There is dynamic energy exemplified in the progression of water.

Hydroelectric force (hydropower) frameworks convert the active energy in streaming water into electric energy.

1.4.4 Wind

The intensity of the electrical energy conveyed by a breeze generator relies upon the dynamic energy of its turbines, which rely upon the active energy of the breeze that turns its turbines. The active energy of the breeze, thus, comes from sun powered energy: the sun warms various pieces of the earth to variable temperatures, and this temperature distinction makes blistering air rise and cold air to fall in height. This outcomes in a weight contrast that causes an overall development of air, or wind. Warmth from the sun causes convection in the environment, which means the warmed air rises. These flows make zones of high and low pneumatic stress inside the environment. As the warmed air rises, it makes a low-pressure zone close to the ground. Air from encompassing cooler territories surges in to adjust the weight. These level weight contrasts represent the encompassing breeze and more serious tempest wind.

1.4.5 Geothermal

Geothermal is that renewable source in which earth's internal energy is extracted. It is delivered from normally happening steam and heated water caught in repository under the earth. Geothermal energy is warm energy that decides the temperature of issue. The geothermal energy of the Earth's crust originates from the first development of the planet (20%) and from radioactive decay of minerals (80%). The geothermal inclination, which is the distinction in temperature between the center of the planet and its surface, drives a nonstop conduction of warm energy as heat from the center to the surface. The high temperature and weight in Earth's inside reason some stone to soften and strong mantle, bringing about parts of mantle changing over upward since it is lighter than the encompassing stone.

1.4.6 Tidal

Flowing power or tidal energy is a structure of hydropower that changes over the energy acquired from tides into valuable types of intensity, chiefly power. In reality, tides are the waves caused because of the gravitational draw of the moon and sun. The Tidal Energy Power Plant normally will be around 1-kilometer-wide and generally be implicit regions that have a water profundity of between 20 - 50 meters. There exist two kinds of tides for example neap tides and spring tides. Neap tides occur when sun and moon (first and last Quarter), situated at right blessed messenger from one another their gravitational fascination pulls water in various ways, causing neap tides. On other hand, spring tides happens when sun and moon are in a line their gravitational fascination on the earth consolidates.

1.4.7 Bio-energy

Biomass assets incorporate any natural issue accessible on an inexhaustible premise, including devoted energy harvests and trees, rural food and feed crops, farming yield squanders and buildups, wood squanders and deposits, oceanic plants, animal squanders, civil squanders, and other waste materials. Material dealing with, assortment coordination's and framework are significant parts of the biomass asset gracefully chain.

Herbaceous energy crops are perennials that are gathered yearly ensuing to taking a couple of years to show up at full productivity. These join such grasses as switch grass, miscanthus (in any case called Elephant grass or e-grass), bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and others. Short-revolution woody yields are quickly developing hardwood trees gathered inside five to eight years in the wake of planting. These incorporate half breed poplar, cross breed willow, silver maple, eastern cottonwood, green debris, dark pecan, sweetgum, and sycamore.

Mechanical harvests are being created and developed to deliver explicit modern synthetics or materials. Models incorporate kenaf and straws for fiber, and castor for ricin oleic corrosive. New transgenic crops are being built up that produce the ideal synthetic compounds as a component of the plant creation, requiring just extraction and refinement of the item.

Horticultural harvests feed stocks incorporate the at present accessible ware items, for example, cornstarch and corn oil; soybean oil and dinner; wheat starch, other vegetable oils, and any recently evolved part of future product crops. They for the most part yield sugars, oils, and extractives, despite the fact that they can likewise be utilized to deliver plastics and different synthetic compounds and items.

A wide assortment of sea-going biomass assets exist, for example, green growth, goliath kelp, other ocean growth, and marine miniature vegetation. Business models incorporate monster kelp separates for thickeners and food added substances, algal colors, and novel biocatalysts for use in bioprocessing under outrageous conditions. Farming yield deposits incorporate biomass, principally stalks and leave, not gathered or eliminated from the fields in business use. Models incorporate corn stover (stalks, leaves, husks and cobs), wheat straw, and rice straw. With around 80 million sections of land of corn planted yearly, corn stover is required to turn into a significant biomass asset for bioenergy applications.

Ranger service buildups incorporate biomass not collected or eliminated from logging locales in business hardwood and softwood remains just as material coming about because of woods the board tasks, for example, pre-business diminishing and expulsion of dead and kicking the bucket trees.

Civil waste alludes to private, business, and institutional post-shopper squanders contain a huge extent of plant inferred natural material that comprise an environmentally friendly power asset. Squander paper, cardboard, wood waste and yard squanders are instances of biomass assets in civil squanders[3].

1.4.8 Fuel Cell

Power devices are electrochemical cells comprising of two anodes and an electrolyte which convert the substance energy of synthetic response among fuel and oxidant legitimately into electrical energy. Power device comprises of terminals, electrolyte and impetus to encourage the electrochemical redox response. In power device, synthetic energy is straightforwardly changed over into electrical energy. The effectiveness of power module is around 70 %.

1.5 Solar/PV as renewable resource

Now at present, solar or photovoltaic generation has attained special attention as renewable energy resource as it presents many benefits like not dependency of fuel, environmental friendliness, less maintaining work, no pollution because of absence of toxic gases, no noise pollution and many more. According to recent researches, out of all renewable energy resources, PV generation is estimated to maintain the largest contributor to electrical generation in all over the world (a. P. W. Quan Li, 2008). Because of benefits presented by photovoltaic, it is used widely as a source of renewable energy. Although their efficiency is around 33% but still they are being used to extract the energy of sun as this efficiency is more than the overall cost spend. Because of less conversion efficiency, to maintain the MPPT (Maximum Power Point Tracking) for PV module has get special attention. The electrical power generated by solar panel is rely upon the radiations from the sun. The PV cell attains its maximum efficiency when works on its MPPT (e. a. s. b. Kjaer, 2005).

1.5.1 PV Panel based Micro inverter

In the recent past, for domestic and commercial applications PV based micro inverters gained special attention and a number of researches are being done for industrial applications.

1.5.2 Different Solar PV Inverter Topologies

A brief introduction about the topologies is presented here.

1.5.2.1 DC-AC converter for grid connection operation

This comprises of two parts; first part is about DC-DC power stage which is responsible to extract power from PV panels. The second part is responsible for creating the sinusoidal wave of current. This two-part scheme is shown in figure 3. It comprises of PV panel, capacitors, indictors and diodes. DC link capacitor is employed to make the input side voltage of capacitor constant. Inductor L2 is employed to connect inverter to the grid; high frequency switching harmonics are attenuated by LC filter.

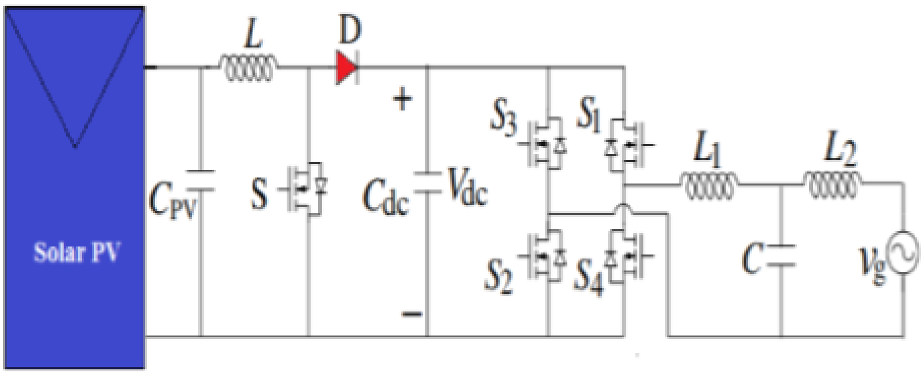


Figure 1.3: PV based DC-AC converter

1.5.2.2 Single Stage Multi-Port Converter Based {Micro-inverter}

This presents galvanic separation to the PV solar, battery, the load and presents maximum voltage gain (shown in figure 4.). Besides, battery doesn't have to do with the 100 Hz ripples acquired by the AC load irrespective of day or in night mode. In night mode to achieve this purpose no external circuit or module is required. It is done in a single stage and more efficiency is achieved with more battery life.

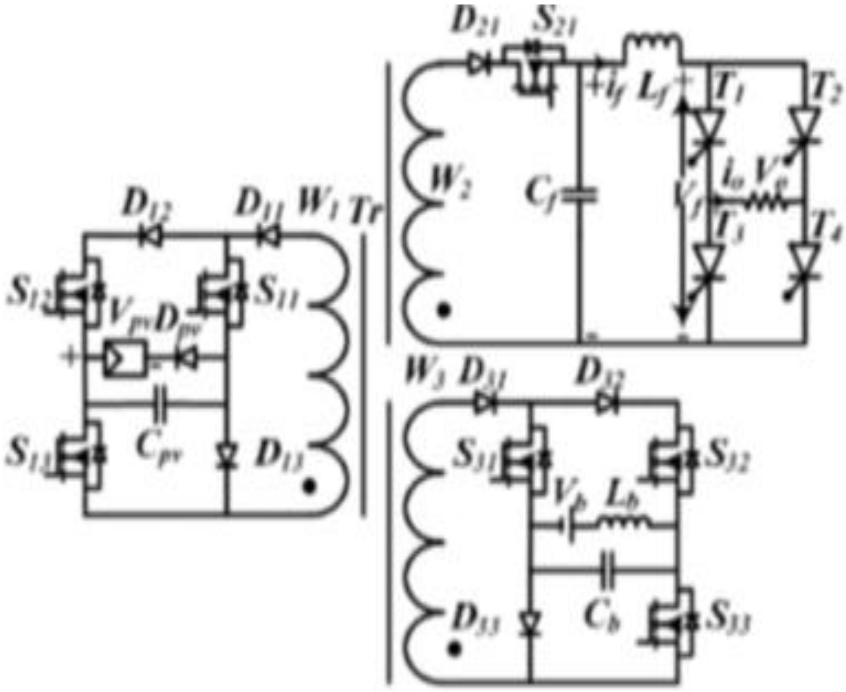


Figure 1.4: Single Phase Multiport Micro Inverter

1.5.2.3 Forward Micro Inverter [with Primary-Parallel Secondary-Series Transformer]

The highlight of this inverter is that it works with a consistent off-time limit control mode. It presents MPPT ability and near solidarity power factor. The multi transformer technique permits the utilization of low-profile unitary turn proportion transformers. It this inverter, transformers are coupled together to build the general effectiveness of inverter. This topology is shown in figure 5.

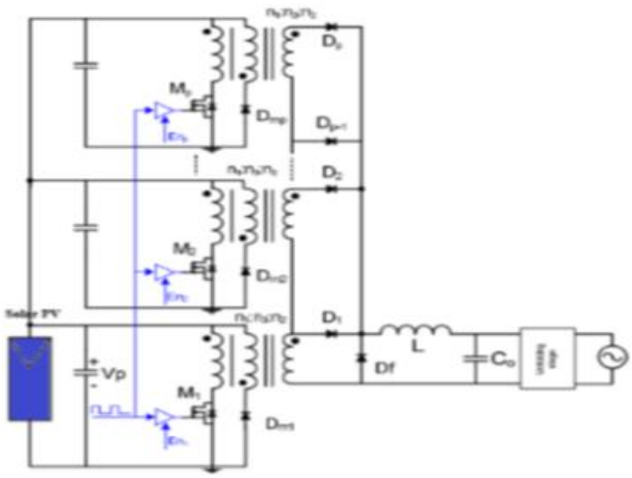


Figure 1.5: Forward Micro Inverter with Primary-Parallel Secondary-Series Transformer

1.6 Problem Statement

The need for solar renewable energy is increasing day by day, because of its low cost and high demand, it is becoming a necessary need in modern age. Photovoltaic converters, microinverters also known as solar inverters catched a lot of attention in the recent modern era with a suitable and consecutive renewable energy with fruitful prospects. There are many existing PV microinverter that have their own features with limitaion.

The goal is to develop a PV PANEL BASED MICROINVERTER USING BOOST CONTROL TOPOLOGY WITH PWM using P&O. This will present plug and play installation, maximization of MPPT, less point of failure and improved safety.

1.7 Methodology

The simulation of proposed scheme of PV Micro-inverter will be carried out using MATLAB Simulink. Simulation will be done in Simulink and waveforms of voltages and current will be obtained and analyzed. The result will be obtained, and hardware implementation of the mentioned invertor will be carried out.

1.8 Literature Review

1.8.1 Photovoltaic (PV) Inverters

A photovoltaic (PV) inverter is an electrical converter which converts direct current (DC) produced by the solar to alternating current (AC). The AC voltage is obtained from the output of photovoltaic (PV), it used in the commercial, on-grid or off-grid and local electrical system. There are two basic types of PV inverters.

1.8.2 String Inverters

The In a string inverter, the solar panels are connected in series combination to the inverter and collection of strings is called an array. The output DC voltage of the array is sum of the all the voltage of the panels connected in the series and this total DC voltage is converted to AC voltage by string inverter and the output current remains the same.

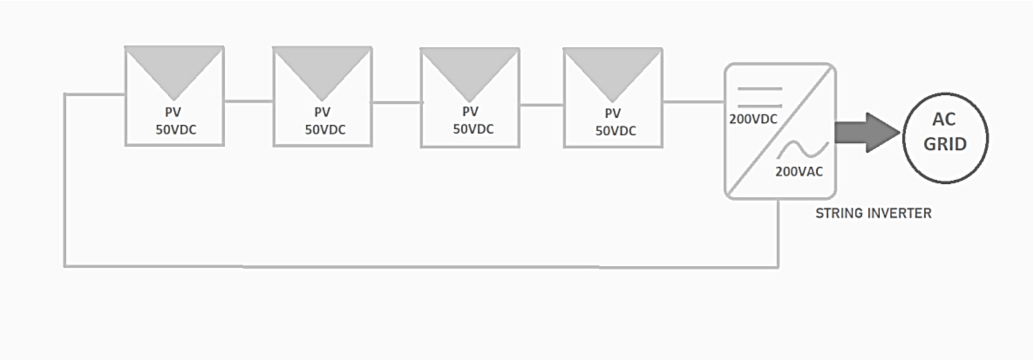


Figure 1.6: String inverter connect to PV panels

1.8.3 Micro Inverters

In this type of inverter, the PV panels are connected in parallel combination to the inverter. The DC voltage of output remains same as each panel and the current is sum of the current of each panel.

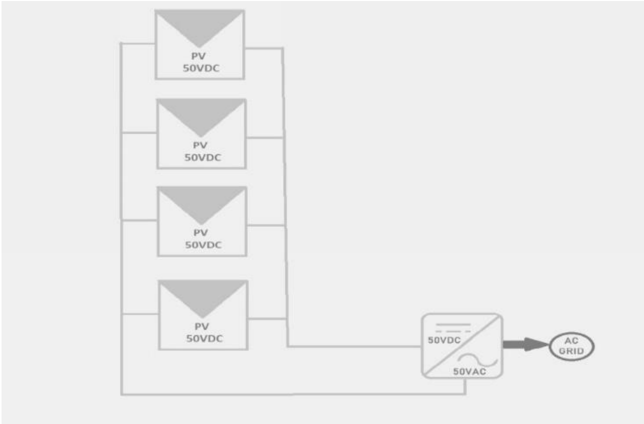


Figure 1.7: Micro inverter connect to PV panels

1.8.4 Why micro inverters are preferred to string inverter?

The solar radiation is not all-time uniform to the PV panels the reasons are multiple, it includes the different orientation of the panels, inclination and part shaded of the panel due to dust or snow covers. Output capability of the whole array is reduced even though a part of only one PV panel might be shaded but still it affects the overall output of the string array.

On the other hand, the output power or efficiency in micro inverters will not be affected if any of the panels are shaded. The micro inverter therefore improves the system's capacity by more than 20 per cent. The effect on the electric energy generated when the module is shaded by 50 percent is shown in figure 8.

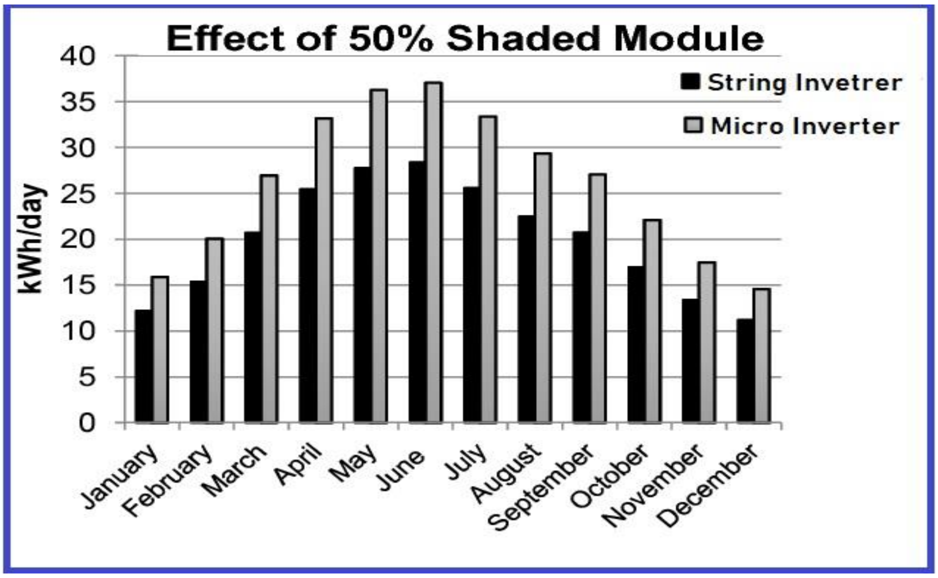


Figure 1.8: Micro and String Inverter Comparison

1.8.5 Power Conversion Stages of Micro Inverters

The micro inverter topologies may be classified as single stage and two stage configurations as shown in Figure 2.4.

1.8.6 Single stage micro inverter topology

Single stage inverters can boost the input voltage and convert it into ac voltage using in the same stage. Single-stage micro inverter used a single inverter part from DC input to AC output without any other converter part. The single-stage operating configuration can be shown in Figure 9a. The single stage micro inverter often needs to control the power gap between the PV system's input and output. In this way, a gigantic estimation of electrolytic capacitance is set in corresponding to the information sun-oriented module, which otherwise called input channel. These deterrents influence the unwavering quality and productivity of the general single-stage PV framework. Accordingly, it is beneficial to limit the estimation of electrolytic capacitance by utilizing film capacitor and received least phases of activity (single-stage power change) so as to accomplish smaller structure with higher productivity framework. As expressed in past segment, managing ordinary two-phase matrix associated PV arrangements experience the ill effects of a few downsides contrasted with single-stage network associated PV. The conspicuous disadvantages are huge force misfortunes, muddled controller, higher quantities of segment tally which all prompts greater expense and lower unwavering quality. Accordingly, late investigates center around how to decrease the quantity of intensity preparing stages by diminishing the quantity of part check and execute the streamlining of controlling technique. Along these lines single-stage power arrangements speak to great arrangement where MPPT, boosting and upsetting part is created between sun powered module and network framework. In this segment, classifications of various single-stage micro inverter topologies are described in grid-connected PV systems implemented by the researched.

1.8.7 Two stage micro inverters

Two arranged inverters comprise of two concurrent stages. The essential stage is a voltage help dc-dc converter and the ensuing one is an inverter. Two-stage power change structure has been extensively used in network related PV system. First stage including the DC-DC converter and MPPT fragment where PV voltage needs to help into certain reasonable level and most prominent power were followed. Second, the inverter action happens where DC power adjusts into AC power. This arrangement can be showed up in Figure 9b. A trial of two-stage little scope inverter is overseeing power interface when DC power from the sun-based module is moved to the AC-grid side. By suggesting Figure 9b, there is a capacitor called as DC interface, which related in equivalent among first and second stage to change the power contrast execution.

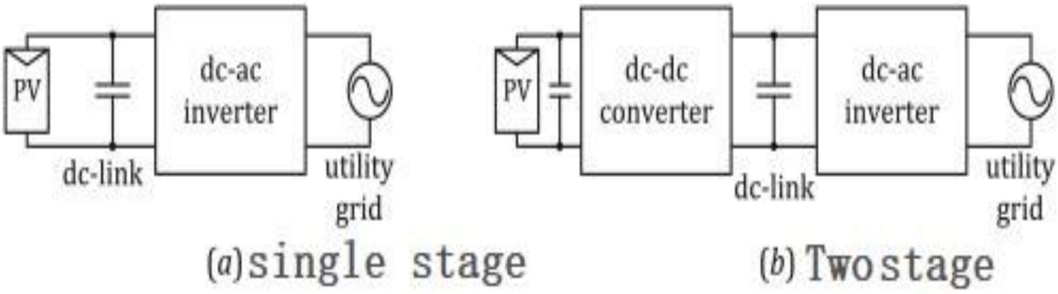
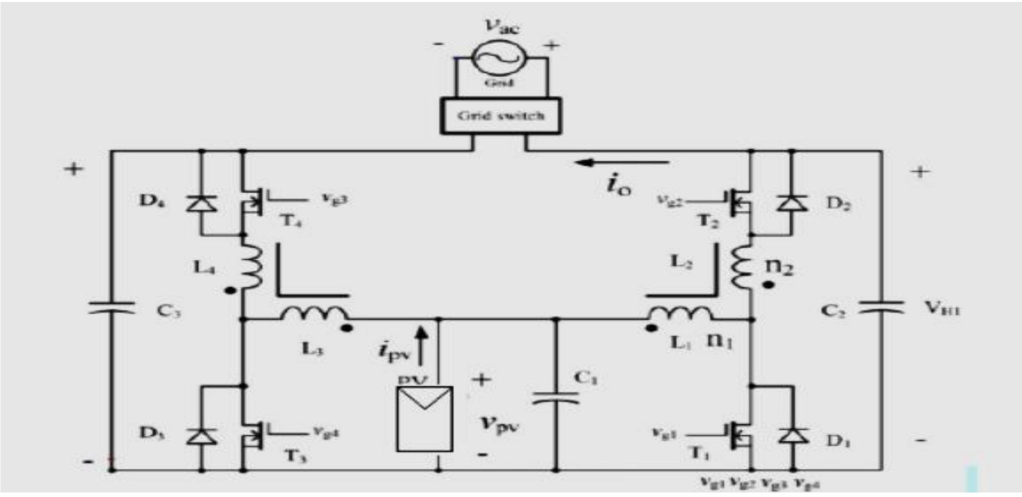


Figure 1.9: Single and two staged micro inverters

1.9 Classification of Micro Inverter Topologies

1.9.1 Coupled Inductors and Double-Boost Topology

The proposes of coupled inductors and twofold lift geography engineering for keeping up a steady voltage on the yield side and lessening the size and cost of the framework. This geography is utilized in both frameworks associated and independent mode. The coupled inductors and twofold lift geography include a lower number of circuit segments contrasted and common two-level inverters, lessening circuit measurements, and sparing creation costs. Additionally, this geography requires just four force semiconductors to alter dc power, considerably rearranging control plans. Be that as it may, each of the four force semiconductors are high-recurrence switches, which are defenseless against harm. Ordinary inverter frameworks contain two levels. The main level comprises of dc-dc buck-help converters and the subsequent level highlights dc-ac inverters for creating ac yields. This geography requires just two force semiconductors for high-recurrence exchanging and two other force semiconductors for low-recurrence exchanging, diminishing the force misfortune from exchanging activities (M. M. S.Sallem, 2009) (A. Betka and A. Moussi, 2004), (A. M. A. B. N. T. A. Terki, 2012). The info side is the wellspring of dc power the sun-based cells have. The correct side is liable for creating an inverter 's positive half-cycle waveform, while the left side is answerable for delivering an inverter 's negative half-cycle waveform. Next, it associates load Ro and the different sides of the circuit to deliver a total waveform yield. The voltage



gain, in this manner produced bigger AC yield voltage than DC input voltage.

Figure 1.10: Double Boost Topology

Figure 10 demonstrates a traditional double-boost topology applied to the micro inverter PV system. This transformer-less-based topology provides mirror circuit on the right and left side of the circuit, enabling both waveform operation. Each mirror circuit consists of two boost converters, with a total of four power switches, two inductors and two capacitors. The modern topology boost circuit deals from additional losses from switching due to the device's simultaneously high frequency switch. In addition, the traditional double-boost micro inverter 's service cycle limits the voltage gain resulting in lower instantaneous output AC as opposed to DC input. Fang, Y. and X. Ma solved this problem successfully in 2010, by adding a coupled inducer to the traditional double-boost topology circuit. The proposed geography as appeared in Figure 10 make the confinement of voltage gain is not, at this point a controlling element. At the point when obligation cycle is around 0.5, the obligation cycle is relative to the yield power arrives at 217.8W with proficiency over 97.5%. Be that as it may, the proposed framework utilized DSP controller which is confused control hardware when a less complex computerized controller can be utilized for miniaturized scale inverter under 300W little application.

1.9.2 Isolated Buck-Boost Converter Topology

The circuit, which utilizes a dc-side buck-support interface and a half scaffold ac-side cyclo-converter, takes a shot at the rule of managing the measure of charge that is sent to the gadget over an exchanging period. The framework has favorable circumstances of the set number of modules, the utilization of delicate switches and the nonattendance of receptive force streams. This geography comprises of a high-recurrence transformer that is appended to a coordinated half-connect help converter followed by a half-connect leg at its essential side. What's more, on that side the geography of the circuit appears as though fell math of the buck-support. The transformer is mounted onto a cyclo half-bridge converter's secondary side. The basic key idea of this topology is the current (iL) in the inductor L constant by adjusting the duty-ratio of the front-end buck converter (A. M. A. B. N. T. A. Terki, 2012), (L. K. P. S. S. Sumathi, 2015), (E. O. A. B. a. A. L. V. Salas, 2006). The other center idea is to utilize this current to control the measure of charge provided to the yield (throughout an exchanging time Ts) and to change it sinusoidally over the length of the air conditioner line. A charge-mode control calculation, used to gauge and control gradually throughout an exchanging time the measure of charge communicated to the air conditioner yield side. Due to the nonattendance of responsive power stream the conduction mishap is diminished.

A buck-support microinverter circuit is one more case of transformer-less based geography. This geography for miniature inverters utilizes the LC-channel on which the current sounds produced by semiconductor exchanging are focused. In 2001, as appeared in Figure 11, an inferred buck-help geography circuit was executed comprising of 4 force switches, 2 diodes, capacitor, and 2 inductors. The proposed geography utilized ideal number of switches, where all switches were turned on in the upper circuit and all switches in the lower circuit were stopped, and the other way around. This gives this type of geography a favorable position of lower misfortunes when exchanging.

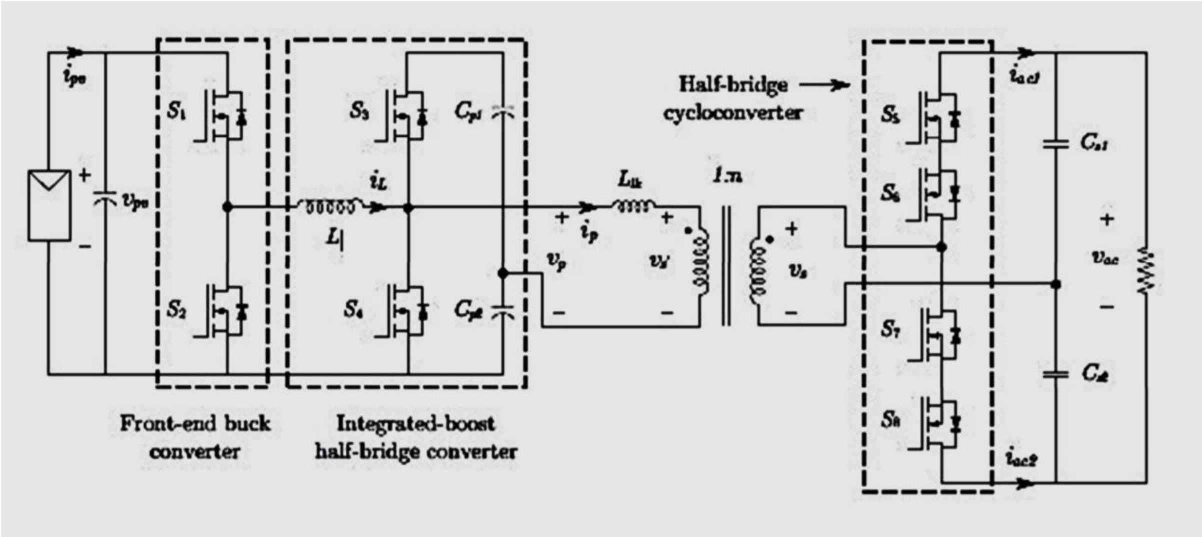


Figure 1.11: Isolated Buck Boost Topology

1.9.3 Pseudo-dc link Topology

This architecture consists of conventional two-stage solar Microinverter (R. D. Lalouni S, 2011), (S. K. P. DEBASHIS DAS, 2011). With the support of pseudo - dc connect topology, high conversion efficiency and maximum power point tracking precision can be achieved, and the studied solar microinverter circuit topology is shown in Figure 9. Multiple PVs are normally connected in series to provide a high voltage output. In any case, because of various board directions and shadowing impacts, the PV boards regularly work in confusing conditions. This irregularity issue subsequently diminishes the force yield of the whole PV arrangement. The pseudo-dc-connect geography is utilized to comprehend the downside.

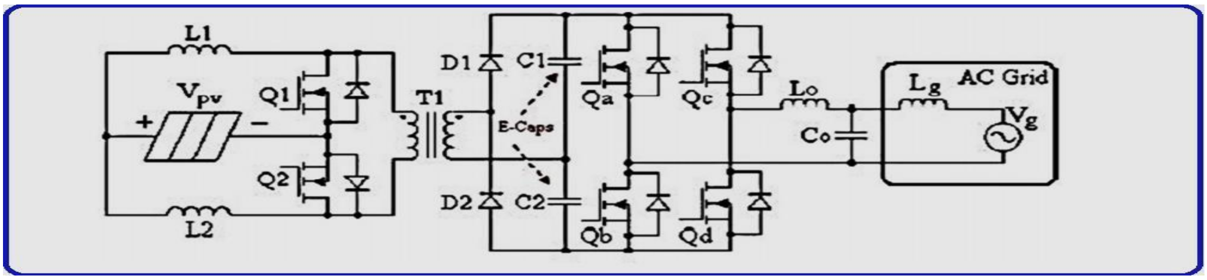


Figure 1.12: Pseudo-Dc Link Topology

1.9.4 Push-pull converter Topology

We planned a converter with an even plan utilizing push-pull structure to upgrade the lift converter 's worldwide productivity dependent on the previously mentioned old style inverters. The issue is that the yield voltage given by this converter is steady and relies just upon the change proportion of the transformer, instead of on a more appropriate current transformer for this kind of utilization. Illustration. The Fig. 13 Reflects the electronic scheme proposed to raise voltage converter using push pull structure. Furthermore, the symmetrical configuration of the push-pull stage allows the two quadrants of the magnetic cycle of the transformer to be used, the main advantage being the optimization of the coil size. A lower air gap can be obtained with a well-dedicated magnetic circuit which induces a high inductance of Al, thus avoiding possible saturation of the magnetic component.

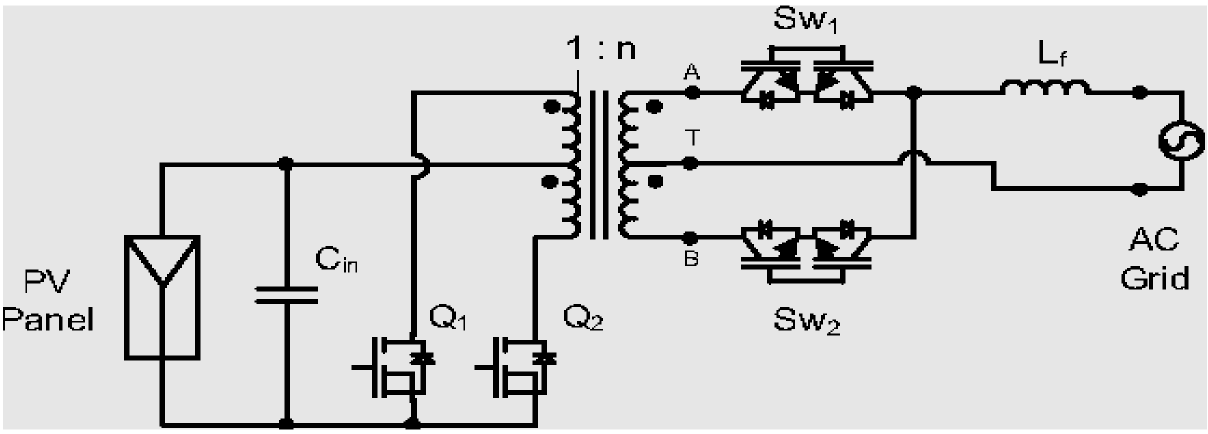


Figure 1.13: Push Pull Converter Topology

1.9.5 Single-Stage Fly-back Converter Topology

A solitary stage flyback PV microinverter equipped for accomplishing power decoupling without the utilization of electrolytic condensers. The issue is alleviated in two phase miniature inverters, because of the unequivocal accessibility of the moderate high voltage dc transport that fills in as the force decoupling port. In such cases, the important dc transport capacitance regard is brought down to the extent that long-life film capacitors can be used for imperativeness buffering. the voltage over the fly-back transformer basic during stage 2 is extensively more in size stood out from that during stage 1 and this relative befuddle augments as vdc increases. M. Ka Lilian et. al in 2015 proposed a similar geography with extra assistant circuit at the essential side of the transformer. The proposed geography as appeared in Figure 14 has extra parts: diode, capacitor and inductor. The 100W fly back-helper circuit geography doesn't have assistant switch, along these lines by one way or another permitting the switch and diode at the essential side could be turn on utilizing delicate exchanging activity. Nonetheless, geography plan without transformer is progressively attractive and offer greats advantage as far as cost, more noteworthy execution and minimized structure.

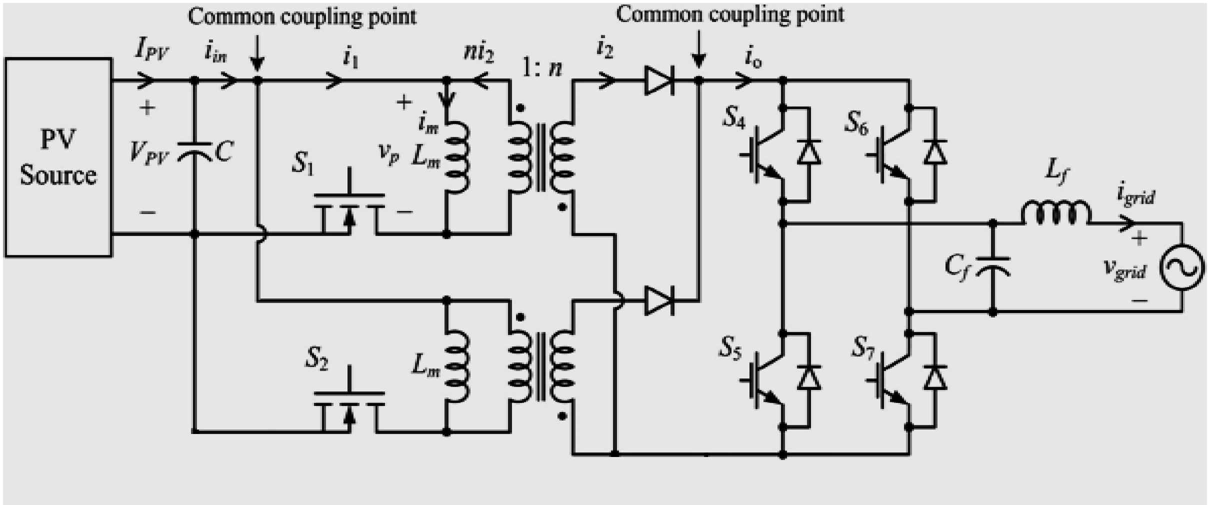


Figure 1.14: Single Stage Fly-back Converter Topology

1.9.6 Single-Stage series-resonant Topology

Figure 15 shows the miniature inverter for photovoltaic (PV) utilizing the full geography of a solitary stage high recurrence ac connect arrangement. The inverter has two dynamic extensions: one at the front finish of the PV module and the other at the front finish of the yield or utility side. The dynamic scaffolds are interfaced by a blend of full tank and high recurrence transformers. An epic stage moves balance procedure to direct the current into utility is proposed "TOSHIBA," [Online]. Consistent state investigation utilizing sinusoidal estimation is introduced to decide the extent of yield current into utility. Delicate exchanging activity is guaranteed in all switches in the converter because of thunderous nature of the circuit. The inverter has points of interest of negligible force transformation stages, high-exchanging recurrence activity and low exchanging misfortunes and henceforth unmistakably appropriate for low influence module coordinated applications.

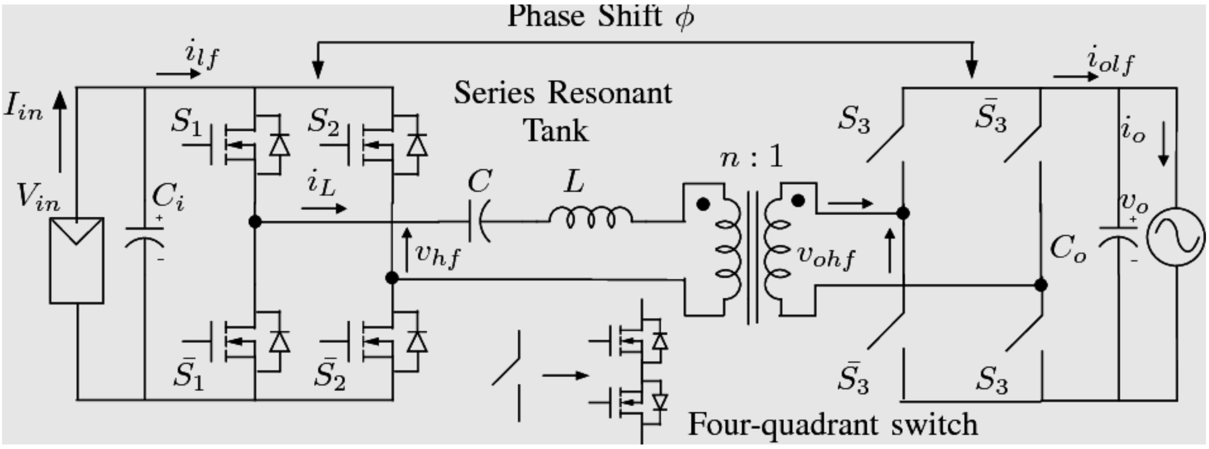


Figure 1.15: Single Stage Resonant Topology

2. CIRCUIT DESIGNING OF PV BOOST CONVERTER

2.1 PV Boost converter

PV boost converter is a Dc/DC power converter that increases voltage from its source (input) to its output (load). The theoretical transfer function of the boost converter is in continuous conduction mode (current through the inductor never falls to zero): $Vout/Vin = 1/(1 - D)$

where D = duty cycle

In this example, the converter feeds a 24 V source RC load and the frequency of the PWM is set at 20 kHz. Due to the instability induced by the parasite materials, the service cycle duration is between 0 and 75 percent.

2.2 Purpose

Model a DC-DC boost converter, with consistent yield voltage, for framework associated photovoltaic gadget organization. The lift converter is intended to support a fluctuating sun-based board's voltage to a more noteworthy consistent DC voltage. Utilizations voltage input to keep yield voltage stable. To do this, a microcontroller is utilized as the focal point of the control framework it screens and gives a heartbeat width-regulation sign for controlling electronic force gadgets in the lift converter. The lift converter ought to have the option to coordinate couple with lattice tied inverter for framework associated photovoltaic organization. Reproductions to depict the proposed configuration were led. Exploratory works were completed with the planned lift converter which has a force rating of 100 W and 24 V yield voltage worked in nonstop conduction mode at 20 kHz exchanging recurrence. The test outcomes show that the proposed configuration displays a decent exhibition.

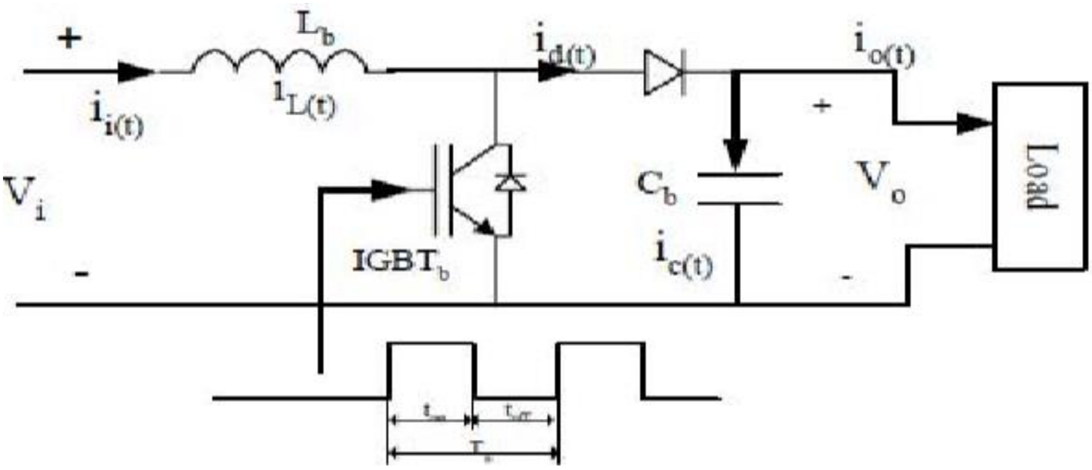


Figure 2.1: Boost Converter Circuit

2.3 Boost converter circuit

The figure shows a stage up boost converter, increment the yield voltage with no utilization of transformer. It consists of dc voltage as input source „Vs‟, inductor L it is also called boost inductor, filter capacitor „C‟, diode D and power semiconducting device as switch „S‟. The power is delivered to load resistance „R‟ at a higher voltage than input voltage. The control or the change of voltage can achieve by varying or changing the duty cycle of switch.

DC-DC converters can be used as changing mode regulators to change an unregulated dc voltage over to an oversaw dc yield voltage. The rule is usually refined by PWM at a fixed repeat and the trading device is all things considered BJT, MOSFET or IGBT. The base oscillator repeat ought to be around various occasions longer than the semiconductor changing occasion to increase capability. This obstacle is a result of the trading adversity in the semiconductor. The semiconductor trading setback increases with the trading repeat and along these lines, the efficiency lessens (S. K. P. DEBASHIS DAS, 2011).

There are double methods of tasks of a lift converter, the charging mode activity when the switch is shut, and releasing method of activity when the switch is open.

2.3.1 Charging Mode Operation:

The semiconductor switch comprises of diodes, inductors and limit components. Exactly when the switch is sent, the source voltage completes the circuit through the inductor and the switch. It stores some energy on the inductor. For this situation, the diode is backward extremity and heap of yield feeds to the capacitor. The current of the capacitor is high.

2.3.2 Discharging Mode Operation:

At the point when the switch is cut, the charging current experiencing the inductor starts to flow through the diode towards the condenser and the pile. The inductor releases its energy and the extremity of the voltage on the inductor is equivalent to the extremity of the voltage source and is associated with the heap through the diode. This increases the output voltage. In this way, the diode goes to the cut off and the circuit is divided into two different parts. The output voltage remains constant as long as the time constant of the RC circuit is much greater than the switching period.

2.3.3 Design Consideration of Switch:

In dual stage boost topology MOSFET and IGBT are used for switching purpose.

2.3.3.1 IGBT

IGBT stands for insulated gate bipolar transistor. Figure 10 shows the symbol of an IGBT. It is a power transistor that combines an input MOS and an output bipolar transistor.

An IGBT is basically a bipolar convergence semiconductor (BJT) with an entryway structure for the metal oxide semiconductor. This allows the IGBT entryway to be controlled, using voltage as opposed to current, similar to a MOSFET. Being a BJT, an IGBT has better capacity to handle current than a MOSFET.

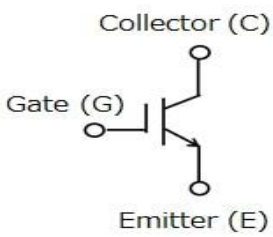


Figure 2.2: Symbol of IGBT

2.3.3.2 IGBT structure

A P region is formed on the drain side of the MOSFET. The resistivity of the high-resistance N- drift region decreases when holes are injected from this P region at turn-on. This phenomenon is called conductivity modulation. Consequently, an IGBT is a switching transistor with low ON voltage even at high breakdown voltage. "TOSHIBA," [Online].

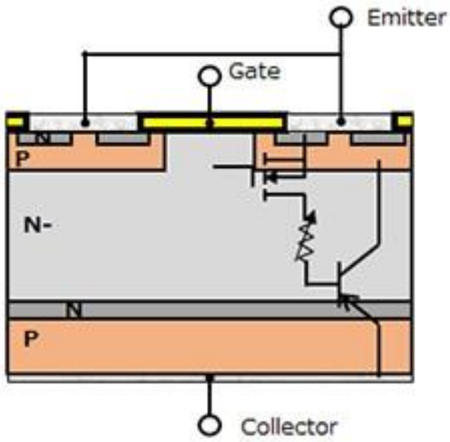


Figure 2.3: Structure of IGBT

Although its internal equivalent circuit is complicated, it can be simplified as consisting of an N-channel MOSFET with variable on-resistance and a diode connected in series as shown in Figure 12.

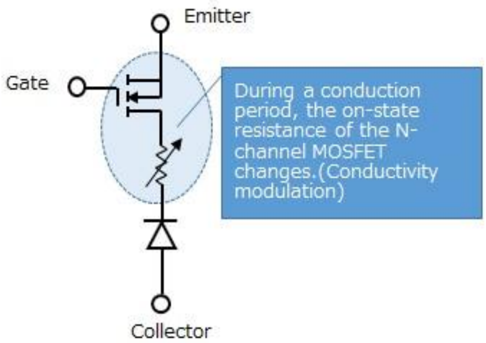


Figure 2.4: Equivalent Circuit

2.3.3.3 Application of IGBT

IGBT is generally utilized for mechanical applications, for example, inverter frameworks and uninterruptible force supplies (UPS), buyer applications, for example, climate control systems and enlistment cookers, and car applications, for example, electric vehicle (EV) engine controllers.

IGBTs with up to 6 kV and up to 4500 additionally accessible for railway, high-voltage direct-current (HVDC) transmission, and other huge applications.

2.3.3.4 Application of IGBT

An IGBT is likewise a minority transporter framework, for example, a BJT, which means the speed with which the IGBT kills is directed by how quickly the minority transporter recombines, the mood killer period on an IGBT is a tradeoff with its voltage drop (VCEON). A ultrafast IGBT has a higher VCEON than an IGBT of default speed. A super quick sort, be that as it may, turns off a lot quicker than a standard speed type, considering similar IGBT with similar measurements and produced using a similar cycle innovation. The tradeoff is accomplished by managing the life expectancy of the recombination pace of the IGBT minority transporter which influences the mood killer period.

2.3.4 Importance in Solar Inverter

An ordinary usage of a sun-oriented inverter utilizes a full-connect geography utilizing four switches. Here, Q1 and Q3 are assigned as high-side IGBTs while Q2 and Q4 are assigned as low-side IGBTs. The inverter is intended to create a solitary stage ac sinusoidal voltage waveform at a recurrence and voltage that rely upon the market application for which the inverter is expected. One such market is inverters for private establishment attached to the force framework, with net metering benefits in certain districts. This application requires the inverter to deliver a low-sounds ac sinusoidal voltage, since power is being infused into the network. (W. Chou, 2008).

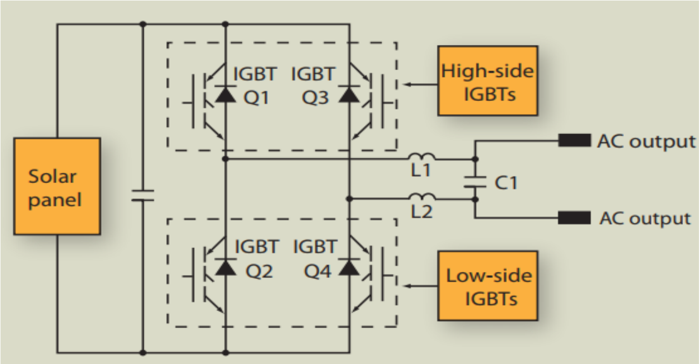


Figure 2.5: Full Bridge Topology

Fig. 14 shows an average gate voltage signal. Here, Q1 utilizes beat width adjustment while Q4 is continued during the positive half-cycle. Q2 and Q3 are kept off during this positive half-cycle period. During the negative half-cycle, Q3 is beat width balanced while Q2 is kept on. Q1 and Q4 are kept off during this negative half-cycle. Fig. 3 likewise shows the subsequent ac sinusoidal voltage waveform across yield channel capacitor C1(W. Chou, 2008).

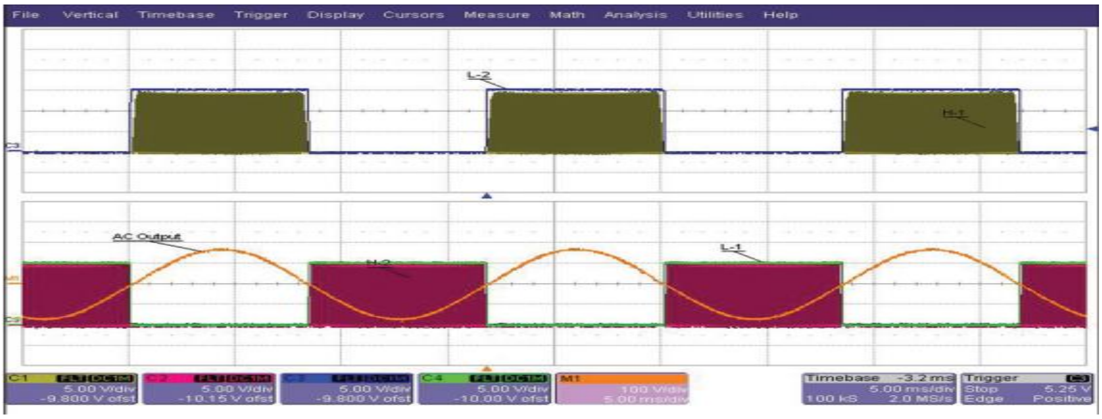


Figure 2.6: Gate-drive signals for IGBTs Q1 to Q4 in Fig. 12 and the output ac sinusoidal voltage at the filter formed by L1, L2 and C1

2.3.5 What is the great way to pulse-width modulating these IGBTs that will give the lowest-possible power dissipation?

One task is to modulate the high-side IGBTs by pulse-width only, and to turn the opposite low-side IGBTs at 50 Hz or 60 Hz.

One way to meet this requirement is to modulate the IGBTs at or above 20 kHz at a fixed modulation frequency of 50 to 60 Hz by pulse-width. By utilizing beat width regulation, yield inductors L1 and L2 can be kept sensibly little and will smother the sounds adequately. Discernible clamor from the inverter likewise can be limited since the exchanging recurrence is over the ordinary human hearing range.

2.4 This switching technique has several advantages

The

• On high-side co-pack diodes, the current does not freewheel, thus minimizing unnecessary losses.

• Low-sided IGBTs only switch at 50 Hz or 60 Hz line frequencies; these IGBTs are dominated by conduction loss.

• Bus shoot-through is not feasible because IGBTs on the same leg never turn complementary fashions.

• Co-pack diodes can be balanced through low-sided IGBTs to reduce the losses.

2.4.1 High- and Low-Side IGBTs:

One can see that the ultrafast planar IGBT has the most reduced all out-force scattering contrasted with the other two planar IGBTs.

This is clearly because of the way that at 20 kHz, exchanging misfortune turns into a significant part to the all-out influence dispersal of the IGBT. As can be seen, the standard-speed IGBT has the most reduced conduction misfortune, yet its most elevated exchanging misfortune makes the gadget unsatisfactory for the high-side IGBTs.

The most recent 600-V channel IGBT is advanced for exchanging at 20 kHz. It tends to be seen that this IGBT has lower all out-force dispersal contrasted with the past age planar IGBT. We can presume that the most elevated productivity feasible for a sun-based inverter plan, a channel entryway IGBT, is the gadget of decision for the high-side IGBTs.

A similar inquiry emerges for the low-side IGBTs. Which IGBT is the best gadget that will give the least force dissemination?

Since these IGBTs switch at just 50 Hz or 60 Hz, a standard-speed IGBT will give the least force scattering level.

Albeit a standard-speed IGBT shows some exchanging misfortune, the misfortune esteem is unimportant to the point that the complete influence dispersal of this IGBT isn't influenced by its exchanging misfortune part. Truth be told, the most recent channel door IGBT still highlights higher force dissemination, since this age is focused at high-recurrence applications with adjusted exchanging and conduction misfortunes. Along these lines, for low-side IGBTs, a standard-speed planar IGBT is as yet the gadget of choice.

The Insulated Gate Bipolar Transistor (IGBT) is used in VFD inverter modules as the preferred electronic power switch for the following reasons.

- It can have a high capacity to hold current. IGBT modules are available with a maximum current level collector Ic(max) of more than 100A. And if this is in sufficient, it can easily overlap two or more IGBTs.
- IGBTs are compatible with Vceo's open-circuit voltage collector level of up to 1.6kV. This means that models from 110Vac to 690Vac are suitable for operating off rectified single and three phase mains.

- An IGBT's high impedance gate means turning it ON and OFF quickly by controlling the gate is comparatively easy.
- The IGBT has a relatively low on-state voltage which keeps losses of conduction low.
- The IGBT has speed of switching fast. It minimizes switching losses and allows high switching frequencies, which is perfect for harmonic motor and reduction of noise.
- The IGBT has a large Reverse Bias Safe Operating Area (RBSOA) which means that desaturation detection circuits can provide reliable protection against load short circuits.

2.4.2 IGBT and MOSFET:

Therefore, MOSFETs available today are used in the Inverter segment of VFDs. But those are small VFDs that don't need a considerably large current to supply. So, it's common to find MOSFETs in their drive sections for small motor drives. The reason for using MOSFETs, and not IGBTs, is essentially logistics and economics. MOSFETs are readily available and at a lower cost than an IGBT counterpart, which means simpler construction and a cheaper and easier product to maintain.

Thus, IGBTs, which can be switched on or off simply by properly gating the device, have encroached on some of the previously reserved SCR segment. These also take up the space of application which MOSFETs were previously unable to manage. So IGBTs have a sweet spot of their own.

2.4.3 IGBT and SCR:

Now, in my view, IGBTs can completely displace SCRs, as IGBTs are becoming more and more effective in VFD applications for inverters. But SCRs still can take up a niche in the very high current department, or in legacy systems. For high-current designs SCRs were usually preferred. While old gating issues have standard solutions these days, the issue of SCR turn off is inherent in the system. So, in inverter drives that require a DC supply, using SCRs.

2.4.4 Why we select IGBT:

For sun oriented inverter applications, it is notable that protected entryway bipolar semiconductors (IGBTs) offer favorable circumstances over different sorts of

intensity gadgets, for example, high-current conveying limit, door control utilizing voltage rather than current, and the capacity to coordinate the IGBT co-pack diode.
A solar inverter is a force electronic circuit that changes over dc voltage from a sun based exhibit board to ac voltage that can be utilized for fueling burdens, for example, home machines, lighting and force instruments. To capitalize on such a geography, notwithstanding, needs cautious thought and an appropriate decision of an IGBT 's high-side and low-side mix. It additionally calls for more understanding into how an IGBT works.

2.5 Design Consideration of Inductor and Capacitor

The inductance and capacitance selection basically is based on the output voltage and the current required by a boost converter load. The values of these components are obtained with the following formulae:

$$L = \frac{(1 - D)^2 * D * R}{2f}$$

It is attractive to work the DC-DC converter as near the most extreme obligation cycle as conceivable the time-frame ought to be as far as might be feasible to decrease exchanging losses. The tradeoffs between a more drawn out exchanging period and a bigger inductance (D. P. P. A. Altaf Mudhol, 2016).
The Capacitor C value is calculated from:

$$\mathrm{C} = \frac{D}{R\left(\frac{\Delta V_o}{V_o}\right)f}$$

The boost converter is used at the DC/AC inverter input at the module output to increase the DC voltage at the output of the photovoltaic module in the grid-connected photovoltaic system simulation as shown in Figure Boost Converter Circuit; It consists of inductor, diode, IGBT, resistor and capacitor.

2.6 Diode selection

Diode invert voltage rating is the fundamental thought for choosing the diode. Other significant thought is its capacity to impede the needed off–state voltage stretches and have adequate pinnacle and normal current taking care of ability, quick exchanging qualities, low converse recuperation, and low forward voltage drop (D. P. P. A. Altaf Mudhol, 2016).

2.7 Circuit of PV Module

The voltage and current generated by a single PV cell are very low. So, Solar cells are interconnected in a series-parallel combination to achieve the desired power. Desired voltage is generated by connecting the solar cells in series and the desired current is generated by connecting the cells in parallel. The series connection of cells known as PV modules usually

has 28, 36 or 54 cells in it and array is the parallel connection of modules.

The equivalent circuit of an ideal PV cell consists of a current source and a diode connected in anti-parallel with it. A general model of the solar cell is the combination of current source (Ipv) connected in anti-parallel to a diode 'D', series resistance (Rse) and parallel resistance (Rp). Fig.16 shows the general model of solar cell.

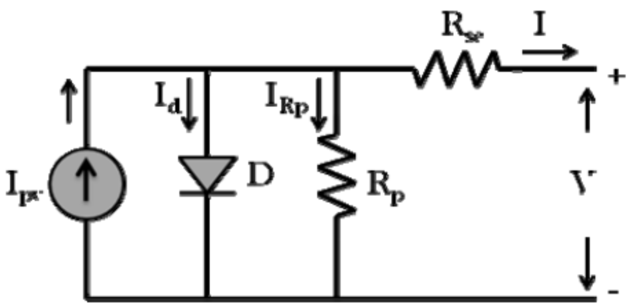


Figure 2.7: General Model of Solar Cell

The PV system has nonlinear I-V and P-V characteristics. The two main factors which affect the output of PV system are temperature and irradiation level. The change of temperature and irradiation level results in change of voltage and current generated by PV system. The nominal operating condition of the solar module is 250C temperature, 1000 W/m2 (G=1) irradiation at AM of 1.5 (D. D. D. Mr. S. Sheik Mohammed, 2014).

2.8 I-V and P-V characteristics

I-V and P-V characteristics of PV cell are shown in Fig. 17. Open circuit voltage (Voc) is the maximum voltage a cell can generate under open circuit condition at I=0 and the short circuit current (ISC) is the current corresponds to short circuit at V=0. Through the operation, the PV cell generates maximum power at only one point and this point is called as Maximum Power Point (MPP) (D. D. D. Mr. S. Sheik Mohammed, 2014).

Im, Vm and Pm in the graph are maximum current, maximum voltage and the maximum power of the solar cell respectively.

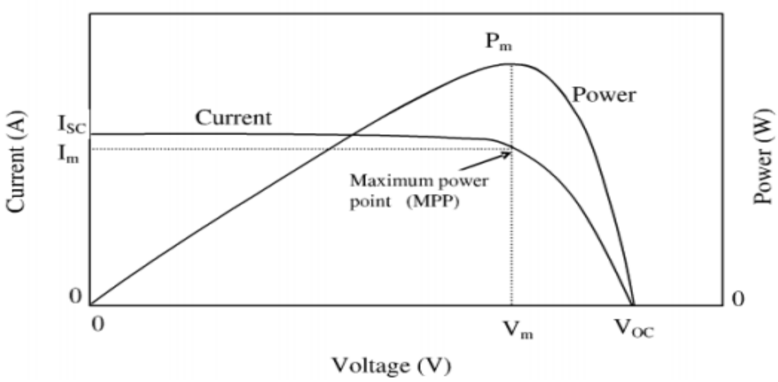


Figure 2.8: IV and PV Characteristics

3. MPPT CONTROLLERS

3.1 Introduction

This chapter sheds light on the most common method and algorithm that is used for MPPT in PV applications. The three types of proposed controllers used for MPPT are:

Perturb & Observe, Increasing Conductance with Integral Regulator, Fuzzy Logic. As previously mentioned, MPPT techniques are always used to ensure the maximization of the system's output power. Our only concerned is about Perturb and Observe method all others are out of scope so we will only discuss P&O method for MPPT.

3.2 Perturb & Observe Algorithm

The first control method used in this thesis is one of the most used in PV MPPT, which is a hill-climbing algorithm called Perturb and Observe (P&O) algorithm. As shown in Figure 4.1, the algorithm's function is to adjust the operating voltage to push the power level to the top of the graph and maintain it. Figure 4.1 shows a simple power versus voltage MPPT graph under constant conditions, thus not taking into consideration partial shading and its effects.

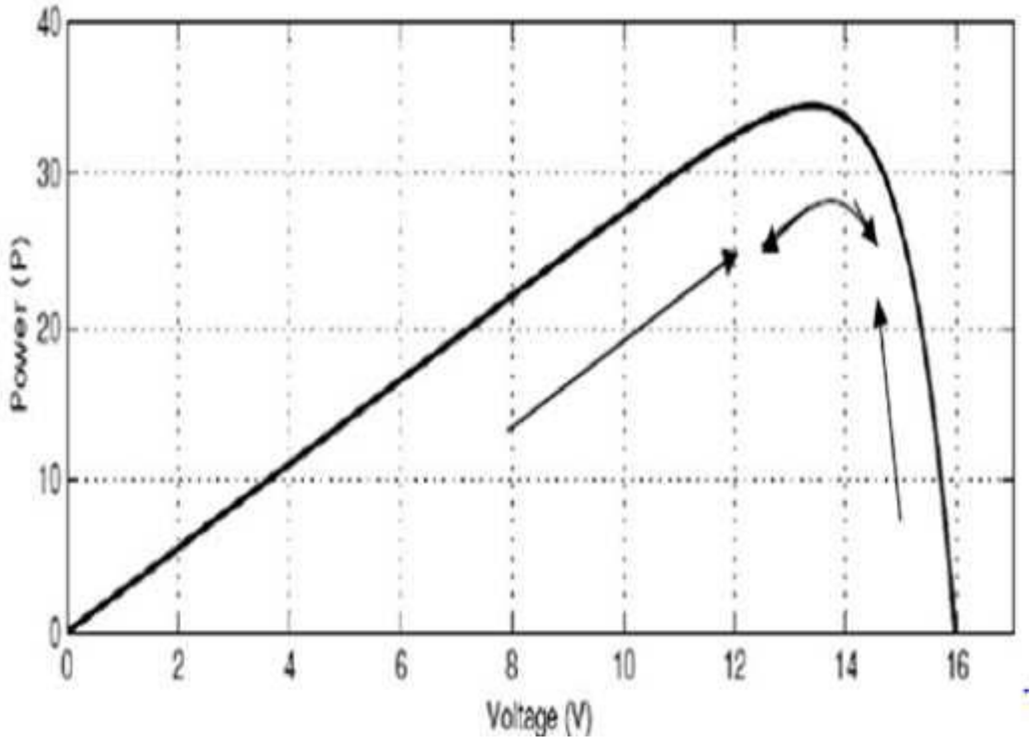


Figure 3.1: Power Versus Voltage Curve Showing P&O's Operation (D. D. D. Mr. S. Sheik Mohammed, 2014)

This method perturbs the voltage and observes the effect that it has on the output power till it reaches the desired point. This is the simplest and easiest method to reach the MPP and is similar to a trial and error method. The algorithm adjusts the operating voltage level by small increments either higher or lower and if the power output increases it continues to do so until the power stabilizes and then stops just before the power starts dropping, which is the knee point in the graph, otherwise known as the MPP. The voltage changes are done through the manipulation of the DC-DC converter's internal resistance by using the Duty Cycle that the MPPT controller outputs as will be discussed later in this chapter.

3.3 Method of Operation

As previously mentioned, this is one of the simplest methods to implement and only requires a voltage and current sensor to calculate the power and compare it to the previous cycle power. The algorithm's method of operation is presented in the flow chart Figure 4.2.

First, power is calculated using voltage and current and then compared to the previous value of the power. If the difference is equal to zero, then the same voltage will be returned, and the algorithm will try to oscillate around the same MPPT. If there is a change in power, the algorithm will then go forward and check the difference in voltage levels. In the case of a positive power difference, the algorithm will notice and direct the voltage to the same direction (increase or decrease) as the previous case. Hence, if the voltage difference is positive then the algorithm will keep increasing the voltage and vice versa. However, in the case of negative power difference, the algorithm will do the complete opposite and will direct the voltage to the other direction. This means that if the voltage change is negative then the algorithm will increase the voltage and finally if the change in voltage is positive the algorithm will decrease the voltage. Thus, the four cases that the algorithm is required to evaluate and react to are as follows:

1. $\Delta P > 0$ and $\Delta V > 0$ a Increase the voltage.
2. $\Delta P > 0$ and $\Delta V < 0$ a Decrease the voltage.
3. $\Delta P < 0$ and $\Delta V > 0$ a Decrease the voltage.
4. $\Delta P < 0$ and $\Delta V < 0$ a Increase the voltage.

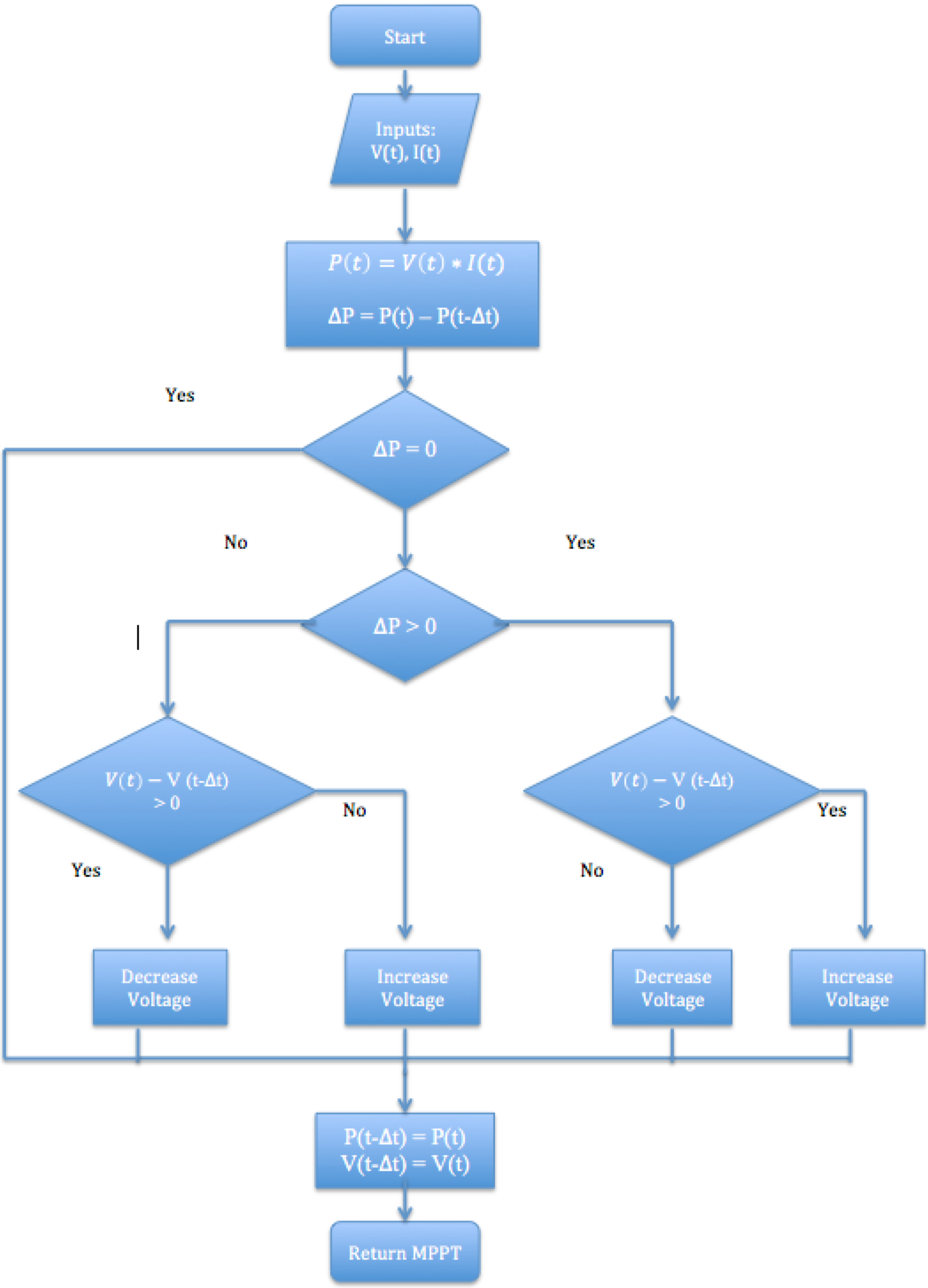


Figure 3.2: Perturb and Observe Flow Chart [18]

The algorithm can manipulate the operating voltage freely by varying the duty cycle ratio. Any change in the duty cycle will consequently have an inverse effect on the input resistance of the DC/DC converter and thus will alter the operating voltage to satisfy the four cases mentioned above. Table 3.1 illustrates the relationship between the cycle, input resistance, output power, and the voltage in the next cycle as shown below.

Table 3.1: Effect of Duty Cycle on Input Resistance, Output Power, and the Next Cycle's Voltage

Change in Duty Cycle	Change in Input Resistance	Effect on Output Power	Next Cycle's Voltage Change
Increase	Decrease	Increase	Decrease
Increase	Decrease	Decrease	Increase
Decrease	Increase	Increase	Increase
Decrease	Increase	Decrease	Decrease

As shown in Table 3.1, any change in the duty cycle will have an inverse effect on the input resistance of the converter and hence have an inverse effect on the operating voltage. The algorithm then observes the effect of that change in the duty cycle on the output power to calculate the right command in the next cycle. The output power can increase or decrease depending on whether the current operating voltage level is before or after the knee point in the power graph as shown in Figure 3.1. If the operating level is beyond the knee point or the MPP, then an increase in the voltage will decrease the output power and vice versa. For example, in the third case in Table 3.1, a decrease in the duty cycle causes an increase in input resistance or operating voltage and results in an increase in the output power. This means that the current operating level is before the MPP and by increasing the voltage the output power will increase and thus in the next duty cycle the algorithm will opt to increase the voltage which can be achieved by reducing the duty cycle.

3.4 Advantages and disadvantages of P&O method

Perturb and Observe method is a widely known hill-climbing method for several reasons. Firstly, it is the most simplistic algorithm for MPPT and only requires one voltage sensor. For that reason, it is a fast, inexpensive, and easy to implement option.

Secondly, unlike the other MPPT algorithms, P&O method is a short computing time and a low computing complexity as it does not require any calculations. Only a comparison of the current and old voltage and power peek is required. This enables P&O to decide which side the current level is on with the knee dot and to move the voltage in the correct direction swiftly. However, this simplistic approach has its failures especially when dealing with a complex system such as a PV array. The first downside to this algorithm is that, given its method of operation, the voltage level never stays in the same level even when the Maximum Power Point is reached similar to the power level. The algorithm cannot help but continue to perturb. Once it reaches around the MPP it decreases the perturb magnitude but that still causes significant power loss compared to the other algorithms. Another disadvantage of using P&O is the way it responds to the continuously changing weather conditions. As the weather changes and the irradiance hitting the panel's surface increases, the MPP automatically shifts to the right as shown in Figure 4.3.

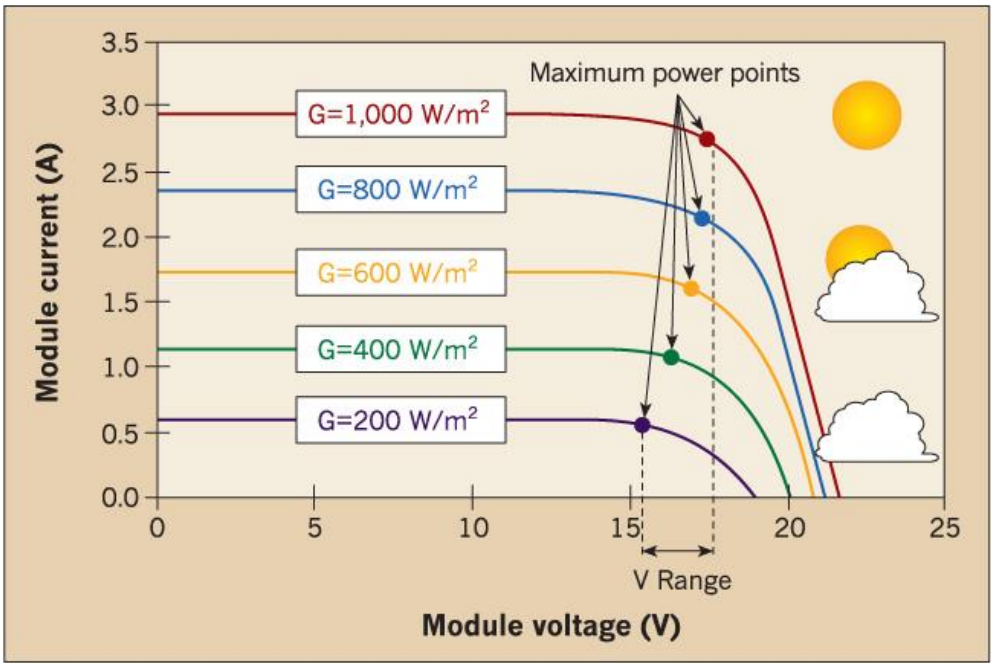


Figure 3.3: MPP Voltage Shift when Varying the Irradiance

The difference in the voltage level between the 200-W per square meter and the 1,000-W per square meter irradiance is not very high but is high enough to trick the algorithm. Once the MPP shifts to the right or gets further away from the algorithm's point of view, it understands it as a change due to the perturb and will automatically cause the next cycle to move in the other direction which is in fact the wrong direction and it is moving away from the MPP.

3.5 Briefing

Perturb This chapter presents the Thesis design of the solar PV system with MPPT controller integration. There are two types of solar PV systems: standalone and grid connected. In this Thesis, the standalone system is chosen because the focus is on the generation of the supply side and how to enhance it rather than the demand or load side. The four main components of any PV architecture are: solar panel array, MPPT controller, converter, and finally the load. The system is shown in image 4.4 below.

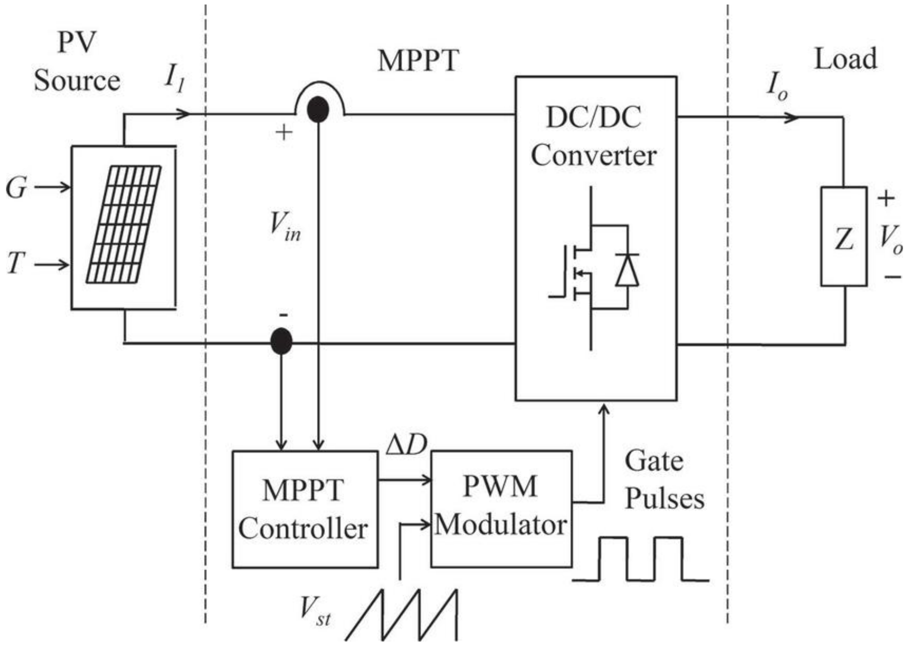


Figure 3.4: Solar PV System with MPPT Controller (M. Quamruzzaman, , Nur, Matin, Mahmud, Alam 2014)

3.6 System Architecture

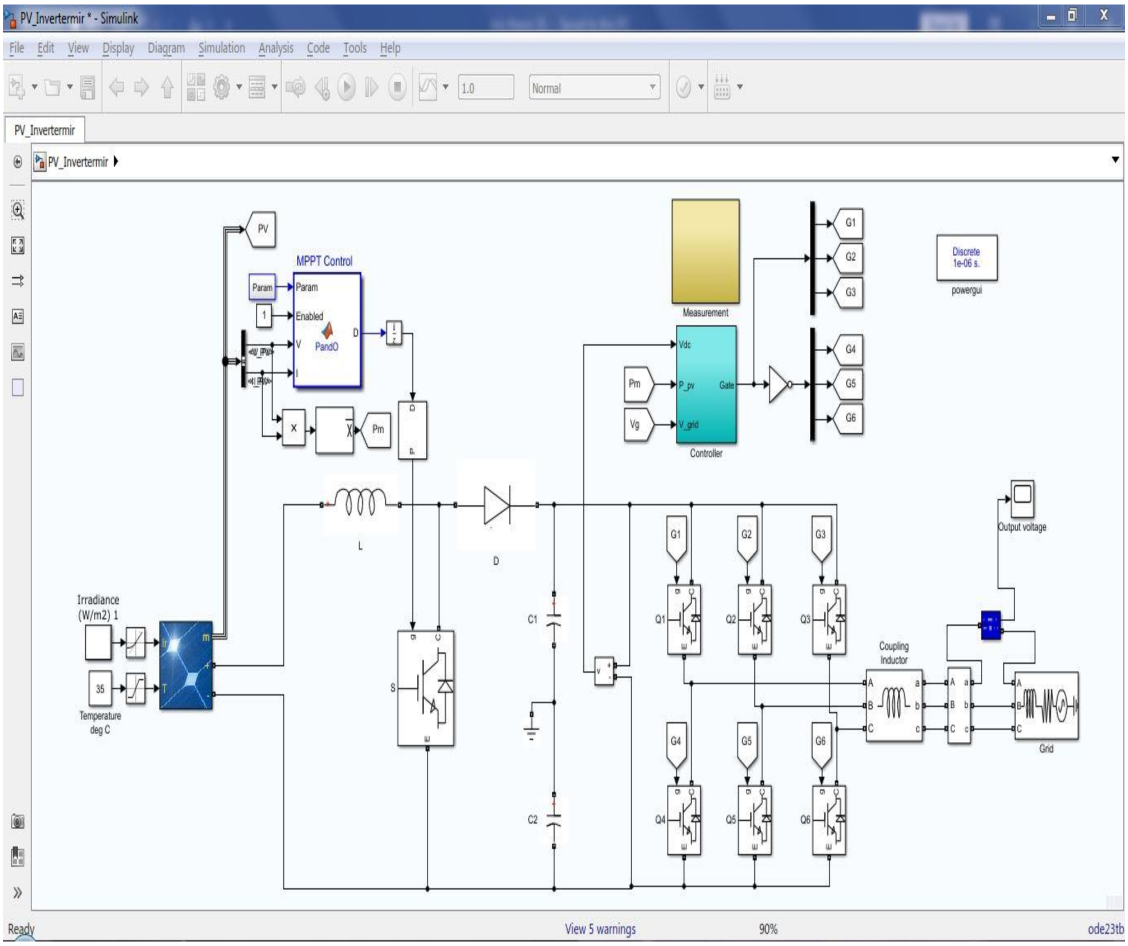


Figure 3.5: PV Solar System Design on MATLAB

Figure 3.5 shows the architecture of the PV solar system designed for this thesis. This design is common for all algorithms except for the MPPT controller block, where it differs for each of the algorithms in use. The three algorithms are: Perturb & Observe (P&O), Incremental Conductance with Integral regulator (INC), and finally Fuzzy Logic.

Figure 3.5 shows the components of the system, which are:

- PV Array (Model: Sun Power SPR- 440NE-WHT-D, 6S and 57P)
- MPPT Controller
- Boost Converter
- 2 Capacitors
- 2 Resistors
- 1 Inductor
- DC to AC invertor

The PV framework configuration begins with a Ramp-up/down module that controls and changes the estimation of the temperature and the irradiance to reproduce genuine conditions. These qualities are being taken care of to the PV exhibit block, which yields a specific voltage and current relying upon the estimations of the temperature and irradiance. The voltage and current qualities taken from the PV exhibit are utilized as contributions to the MPPT regulator while the yield of the cluster is associated with a DC-DC Boost converter. The MPPT regulator utilizes the info PV voltage and current incentive to consistently compute the obligation cycle, which is then taken care of to the lift converter. The boos converter consistently controls the voltage level as indicated by the obligation cycle to continue following the Maximum Power Point. At last, the yield of the lift converter is then associated with a resistive burden, which goes about as an interest side burden for the independent framework.

3.6.1 Photovoltaic Module

There are various PV technology types including mini-crystalline silicon cells, multi-crystalline silicon, and amorphous silica cells. The type chosen in this Thesis is the mono-crystalline silicon cell for their high efficiency. The solar panel that was chosen in this design is the Sun Power SPR- 440NE-WHT-D. Sun Power is a well-known manufacturer of solar panels and among the best in the market when it comes to a solar panel's performance.

Using MATLAB, the Sun Power SPR- 440NE-WHT-D module has the following specifications as shown in Table 3.2 [20]:

Table 3.2: PV Module Specifications

Number	Data	Value
1	Maximum Power	440.316 W
2	Cells per module	128
3	Open circuit voltage (Voc)	86.5 V
4	Short-circuit current (Isc)	6.5 A
5	Voltage at MPP (Vmp)	72.9 V
6	Current at MPP (Imp)	6.04 A
7	Temperature coefficient of Voc	-0.326 % / Deg.C
8	Temperature coefficient of Isc	0.019308 % / Deg.C

The modules in a PV system can be in series or in parallel depending on the output or power required. Wiring them in series increases the voltage while wiring them in straight increases the current. The power, voltage, and current values are utilized to calculate the number of modules to be connected in series in a string and how many parallel strings are needed to reach the targeted output power. Therefore, using the values given in Table 3.2, the design must have six modules connected in series in a string and 57 parallel strings to reach the required output power, which is 150 kW.

3.6.2 Hill-climbing algorithm

The first type of MPPT is the hill-climbing algorithm. This Thesis uses two types of hill-climbing algorithms, which are P&O and INC+IR. Figure 4.6 shows the P&O function used in the MATLAB design. It has four inputs: (i) ‘param’, a parameter that has four variables, which are: initial, maximum, minimum, and increment values of the duty cycle; (ii) a constant 1 signal, to enable the function to operate; (iii) the PV voltage; and (iv) the PV current. This Simulink block utilizes a MATLAB code to calculate the duty cycle, PV output power, and PV output voltage.

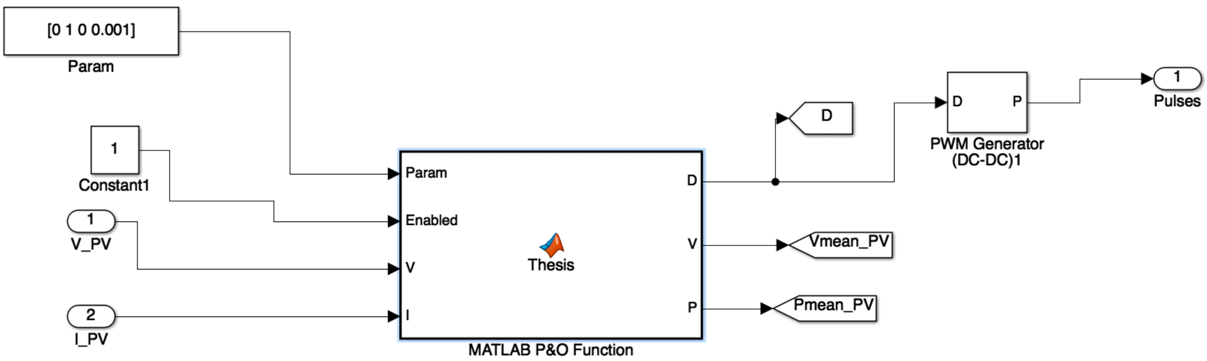


Figure 3.6: Simulink/MATLAB P&O Function

3.6.3 DC-DC Converter

The converter used in the design of this Thesis is a special type of DC-DC converter called boost converter. The boost converter is used to boost the output voltage and hence reduce the output current. This reduces the thermal losses due to the current. Figure 3.7 displays the basic components of a boost converter, which are: a diode, a switch, and at least one energy storage device. Normally, a Mosfet is used as a switch and the energy storage device is an inductor.

The operation of the boost converter is simple. There are two modes, one when the switch is closed, and the other when the switch is opened. Firstly, when the switch is closed, this means that the resistance in that wire is much lower than the load and thus the current will flow from the source and through that branch wire charging the inductor. The second state is the open state, which means that the diode is forward biased, and all the current will be flowing through the diode and to the load including the energy that was stored in the inductor in the previous mode. This on-and-off switching goes on continuously, and by adding the capacitor at the end, the output ripple due to switching can be filtered and can be approximated into DC output voltage (A. Pradhan and B. Panda, 2019).

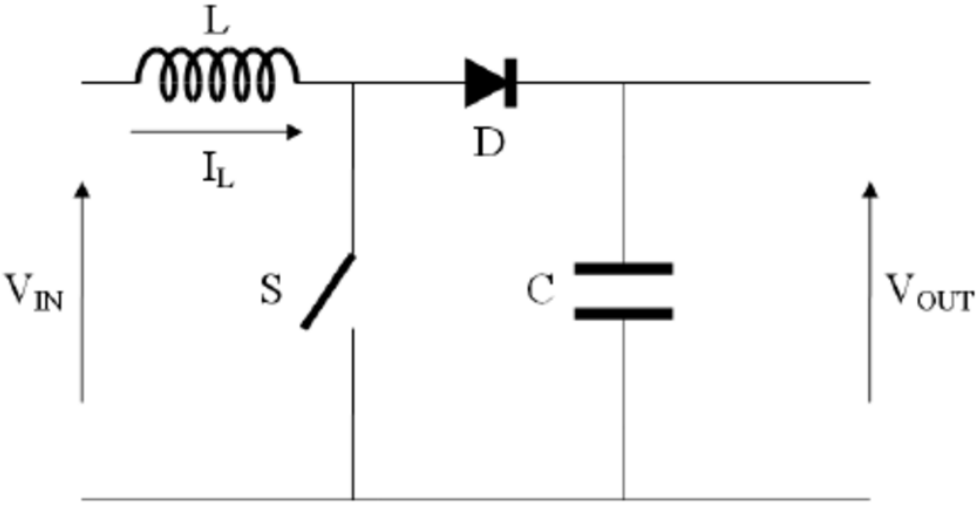


Figure 3.7: Boost Converter Circuit Diagram

Another major characteristic of the boost converter is that when it is used with an MPPT controller it is not only used to boost the voltage but also control it freely to reach the MPP. The MPPT controller uses different algorithms to produce the correct duty cycle value that is then fed to the boost converter to instruct it to manipulate the voltage to a certain direction to reach the MPP as fast and as accurate as possible. The duty cycle value of the boost converter along with the capacitor and the inductor can be calculated using the Equations 4.1, 4.2, and 4.3 (R. Erickson and D. Maksimović, 2004) :

$\frac{V_{out}}{V_{in}} = \frac{1}{1-D}$ (4.1)

Where:

V_{out} is the boost converter output voltage

V_{in} is the boost converter input voltage

D is the duty cycle

Moreover, both the inductor and capacitor in the model can be designed using Equations 4.2 and 4.3:

$L = \frac{V_{in}*T_{on}}{\Delta I_L}$ (4.2)

Where:

L is the minimum value of the inductor

V_{in} is the boost converter input voltage

T_{on} is the turn on time of the transistor

ΔI_L is the desired change in current ripple

C = $\frac{I_{load}*T_{on}}{\Delta V_c}$ (4.3)

Where:

C is the value of the capacitor

Iload is the current going through the load

Ton is the turn on time of the transistor

ΔVc is the desired change in voltage ripple

3.7 Effect of Temperature and Irradiance on the PV Output Power

There are several factors that affect the output of the PV system. Among these factors are: geographic location, meteorological conditions (such as amount of sunlight and snow), shading, dust and debris, irradiance, and temperature. Although all these factors have an effect on the output of the PV, the main factors that affect the operating conditions are the irradiance hitting the surface of the solar panel and the temperature of the panel itself.

This section presents the effect the temperature and irradiance have on the output parameters of the PV array. Figures 4.8 and 4.9 show the theoretical response of the chosen PV panel Sun Power SPR- 440NE-WHT-D with its specifications shown in Table 3.1 under varying temperature and irradiance.

The first factor discussed is the temperature, which may vary drastically in some parts of the world.

Figure 3.8 demonstrates the effect the module temperature has on the output power when the irradiance is kept constant at a value of 1000Watts per s/m. The change in temperature of the module can occur due to numerous reasons. Some reasons include a change in atmospheric conditions such as the atmospheric temperature and degree of shading, or an artificial reason such as overheating as a result of improper maintenance of the panels. This change in the temperature usually affects the voltage output.

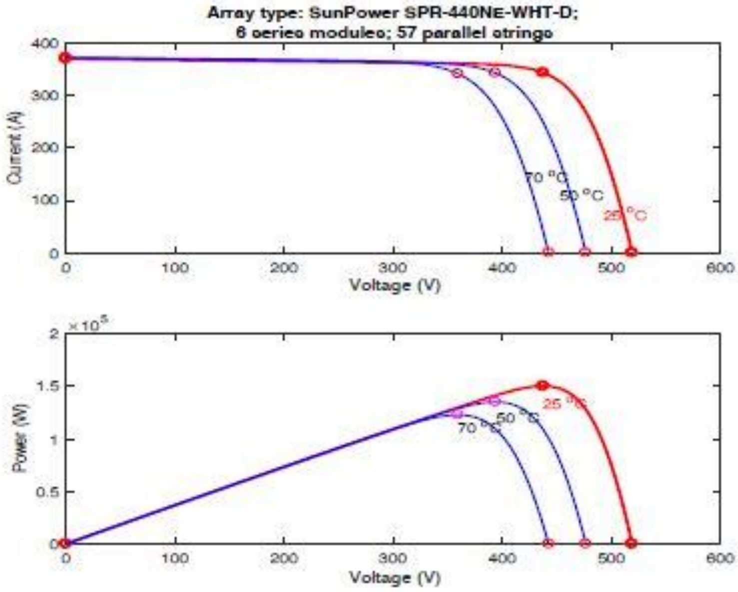


Figure 3.8: Effect of the Temperature on the Output Voltage, Current, and Power

As shown in Figure 3.8a, as the temperature increases, the output voltage drops significantly and this voltage drop is translated in Figure 3.8b as the effect on the output power. The output voltage and power were recorded using three different module temperatures, which are 25 °C, 50 °C, and 70 °C. These temperature values were not randomly chosen but are actually the values in extreme conditions (25 °C and 70 °C) as well as the average temperature value (50 °C).

Normally, the temperature of the solar module is about 20 °C higher than the ambient temperature, so a temperature of 70 °C can be found in areas with an ambient temperature of 50 °C such as the Middle East during the summer. The other extreme is the panel temperature of 25 °C, which would require an outside temperature of five degrees much like the Nordic countries. Finally, a temperature of about 40 °C to 50 °C is the common temperature of a panel at normal conditions. In Figure 4.8a, the voltage is highest at a value of higher than 500 Volts when the ambient temperature is 25 degrees, and drops down to roughly 480 and 450 Volts at temperatures of 50 and 70 °C respectively. The effect this current drop has on the power is shown in Figure 4.8b, where the power is again highest at temperature 25 °C with a value of 150 kW and reduces to 130 kW at 50 °C and drops even lower at 70 °C.

The second factor discussed is the irradiance. Although it generally varies throughout the day and between different days, the total energy received from the sun each year is constant. As presented in Figure 4.9, the irradiance affects the cell's current value and they are directly proportional to each other.

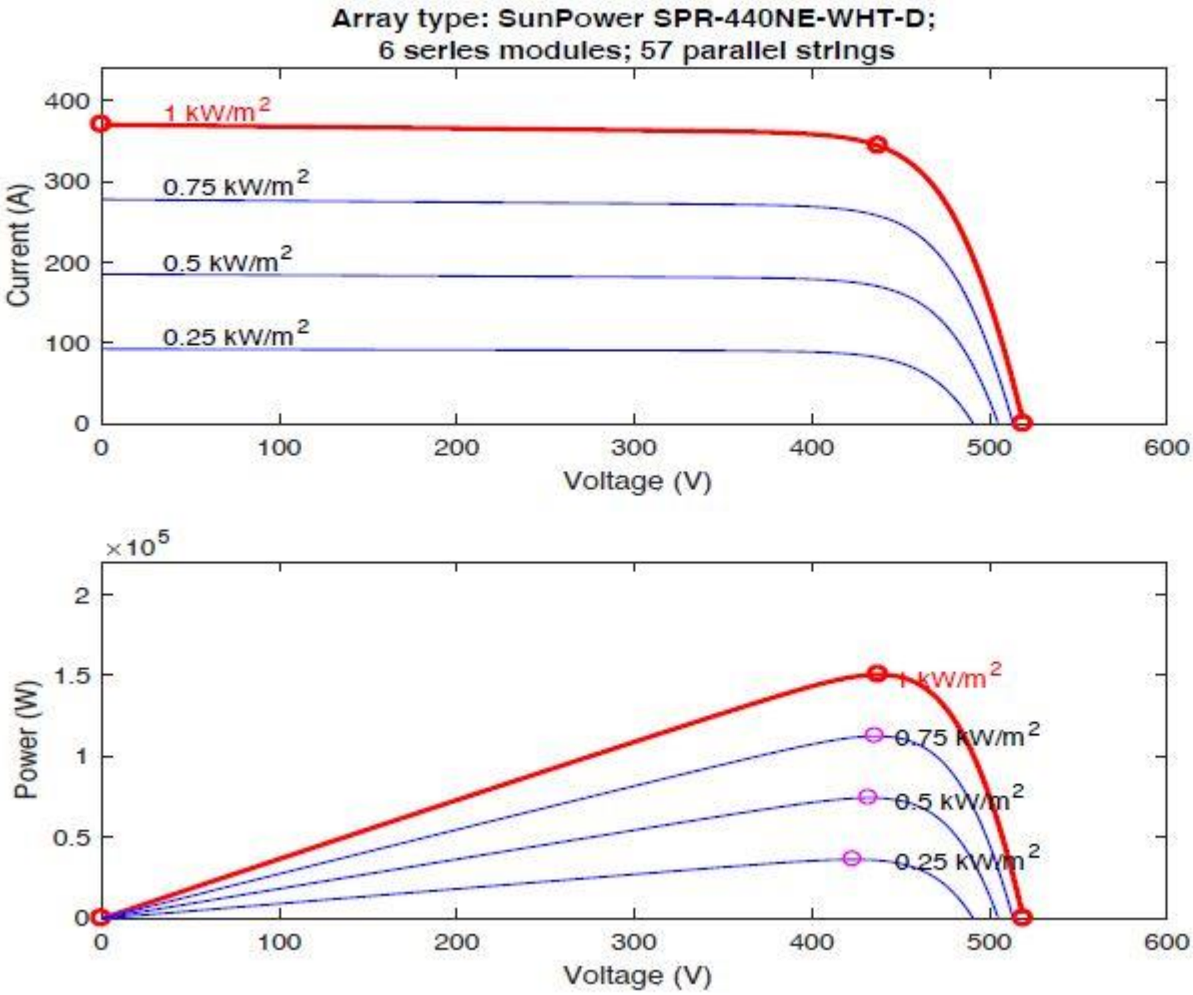


Figure 3.9: Effect of the Irradiance on the Output Voltage, Current, and Power

In Figure 3.9a, the effect the irradiance has on the current is shown where the current drops gradually from about 380 Amperes at 1000 W per square meter of irradiance to about 100 Amperes at 250 W per square meter of irradiance. The drop in irradiance results in a massive impact on the output power where it drops from 150 kW of power at 1000 W per square meter to 25 kW at an irradiance of 250 W per square meter.

4. DISCUSSION AND RESULTS

4.1 Simulation Results

The characteristics of the chosen MPPT algorithm (P&O) in the design model have been explained in Chapter Three. The outcome of using algorithm in the solar system MPPT design is presented in this chapter.

There are three sections in this chapter that describe the results. These sections will highlight the performance of each individual controller under two separate scenarios. In the first scenario, the solar panel will be subjected to a constant solar irradiance of 1000 W per square meter and will have a constant internal temperature of 25 ℃ as shown in Figure 1. This allows for a simple and reliable comparison of the algorithms' performance in terms of accuracy and speed to get the desired power output, which is 150 kW.

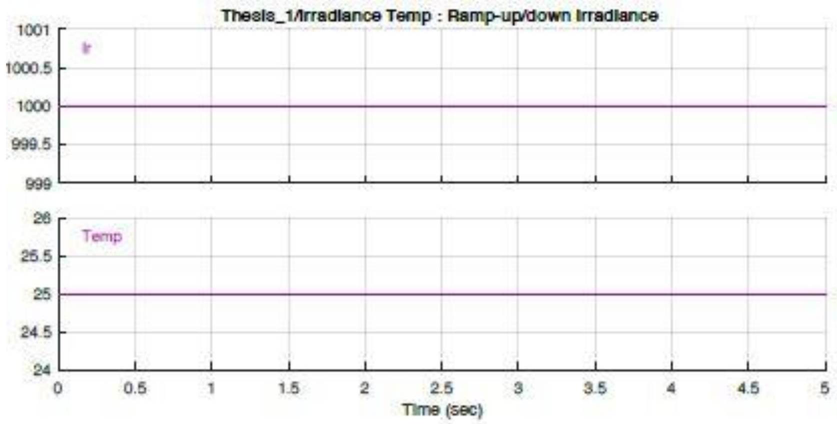


Figure 4.1: Constant Irradiance and Temperature Signals

Figure 4.1 illustrates the second scenario where the panel is subjected to variable irradiance and variable temperature to document the behavior of each algorithm when experiencing conditions similar to those in real life. The irradiance will vary from 1000 W per square meter to 250 W per square meter and the temperature will vary from 25 ℃ to 50 ℃. There is also a period of time where the temperature is constant, and the irradiance is changing and vice versa and the reason behind that is to capture the effect of each of these variables on the output power separately.

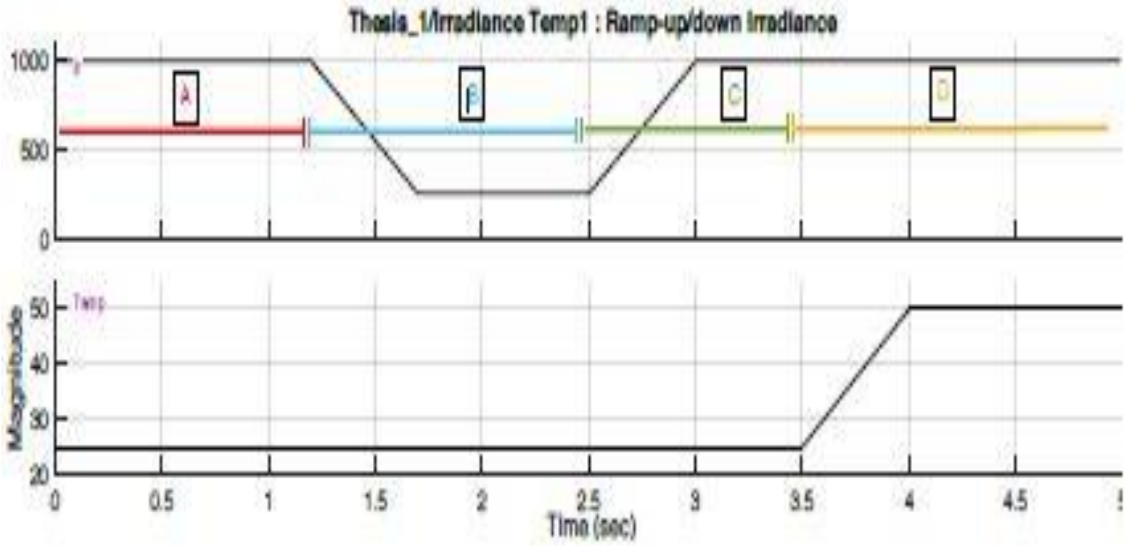


Figure 4.2: Varying Irradiance and Temperature Signals

These periods are shown in Figure 4.2. There are four periods labeled A, B, C, and D. Each of these periods represents a change occurring in either the irradiance or the temperature. Table 4.1 summarizes each period or stage:

Table 4.1 Comparison Between the Four Periods in the Design

Period	Color Code	Irradiance Value (W/m^2)	Temperature Value (℃)	Time range (Sec)
A	Red	1000	25	0 – 1.2
B	Blue	250 ≤ IV < 1000	25	1.2 – 2.5
C	Green	250 < IV ≤ 1000	25	2.5 – 3.5
D	Yellow	1000	50	3.5 – 5

As shown in Table 4.1, period A has a fixed value of irradiance and temperature at 1000 W per square meter and 25 ℃ respectively. In Period B the temperature remains unchanged, however, the irradiance drops from 1000 to 250 W per square meter and remains this way from the 1.7-second mark until 2.5 seconds. Period C commences after the 2.5 second mark, increasing the voltage back to 1000 W per square meter. Finally, in period D, the first change in the temperature is witnesses from 25 ℃ to 50 ℃ while having an irradiance of 1000 W per square meter. Sections 2, 3, and 4 contain two scenarios. In order to evaluate the results, each of these scenarios will contain the following three graphs:

- Change in Solar Irradiance and Ambient Temperature Versus Time

- System Output Power, Voltage, and Current Versus Time
- Duty Cycle, PV Voltage and Current, and System Output Voltage and Current Versus Time.

4.2 Perturb & Observe Algorithm Results

4.2.1 Scenario One: Constant Irradiance and Temperature

This section describes the simulation of the PV MPPT system under constant solar irradiance and module temperature where the irradiance is kept constant at 1000W per square meter and the temperature at 25 ℃ (refer to Figure 1). When both variables are kept constant, the result will be as shown in Figure 3. The plot shows three lines using different color codes. As shown in the legend, blue is for the output power, red is for the output voltage, and finally, yellow is the output current.

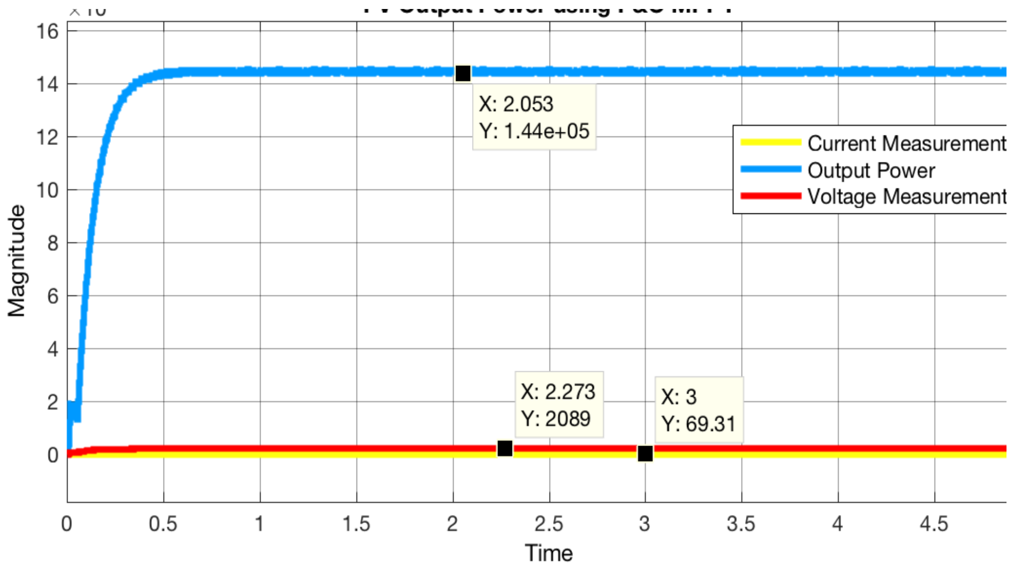


Figure 4.3: Output Power Under Constant Conditions Using P&O MPPT

Using the P&O algorithm yields a fast response as expected where the rise time is about 0.197 seconds or approximately 0.2 seconds and the settling time is about 0.26seconds. The output power starts from zero and reaches a maximum value of 145,500W at time 4.15 seconds. However, as shown in Figure 3, the P&O method results in continuous oscillations around the Maximum Power Point. This is clearly presented in figure 4 where a segment of the output power was magnified to illustrate these oscillations. The chosen segment is an interval of about 0.3 seconds where it starts at time around 3.4 seconds and ends at about 3.7 seconds. During this interval, the power fluctuates between the values of 144,000 W and 145,400 W with a mean value of about 144,800 W.

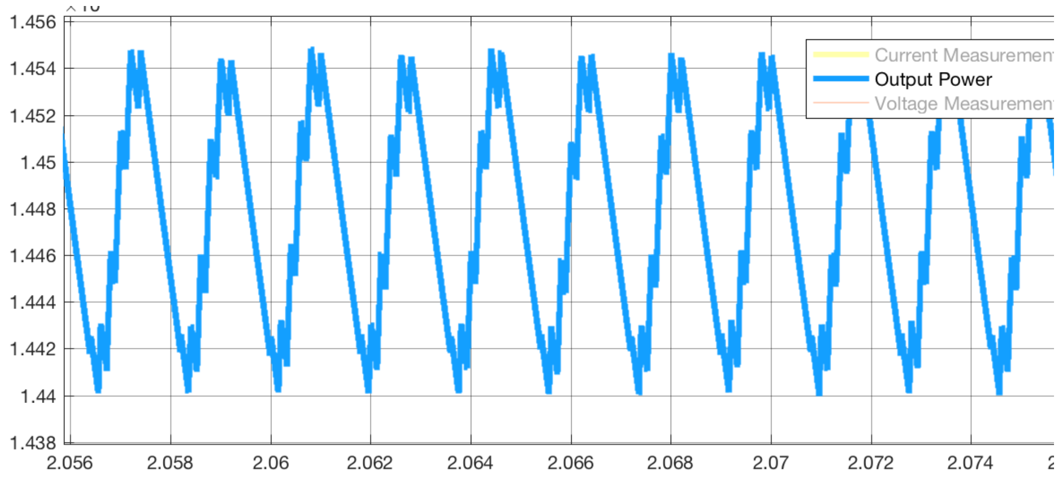


Figure 4.4: Output Power Oscillations when Using P&O

The mean for the curve was calculated to be about 144,600 W. The target output power is 150,000 W and hence the system's efficiency when using P&O method at constant irradiance and temperature is 96.4%. Figure 5 is divided into 5 plots, which are; the duty cycle (DC), the PV output voltage, PV output current, system output voltage, and current on the load side. The first graph shows the duty cycle oscillations. The DC starts oscillating between 0 and 1 in the beginning, but as the output voltage and current reach their respective steady state value, the DC is confined between 0.4 and 1. The second and third graphs represent the voltage and current produced by the PV panel. The voltage oscillates heavily around the value of 400 Volts and similarly the current oscillates around 300 Amperes. The last two graphs are the output or the load side voltage and the current, which are the voltage and current output from the PV panel after passing through the boost converter. The function of the boost converter is to increase the voltage, decrease the current to reduce the current losses, and reduce both the voltage and current ripples caused by the constant switching. This matches with the results where the voltage was amplified to 2000 Volts, the current reduced to about 60 Amperes, and both curves were smooth and non-oscillating.

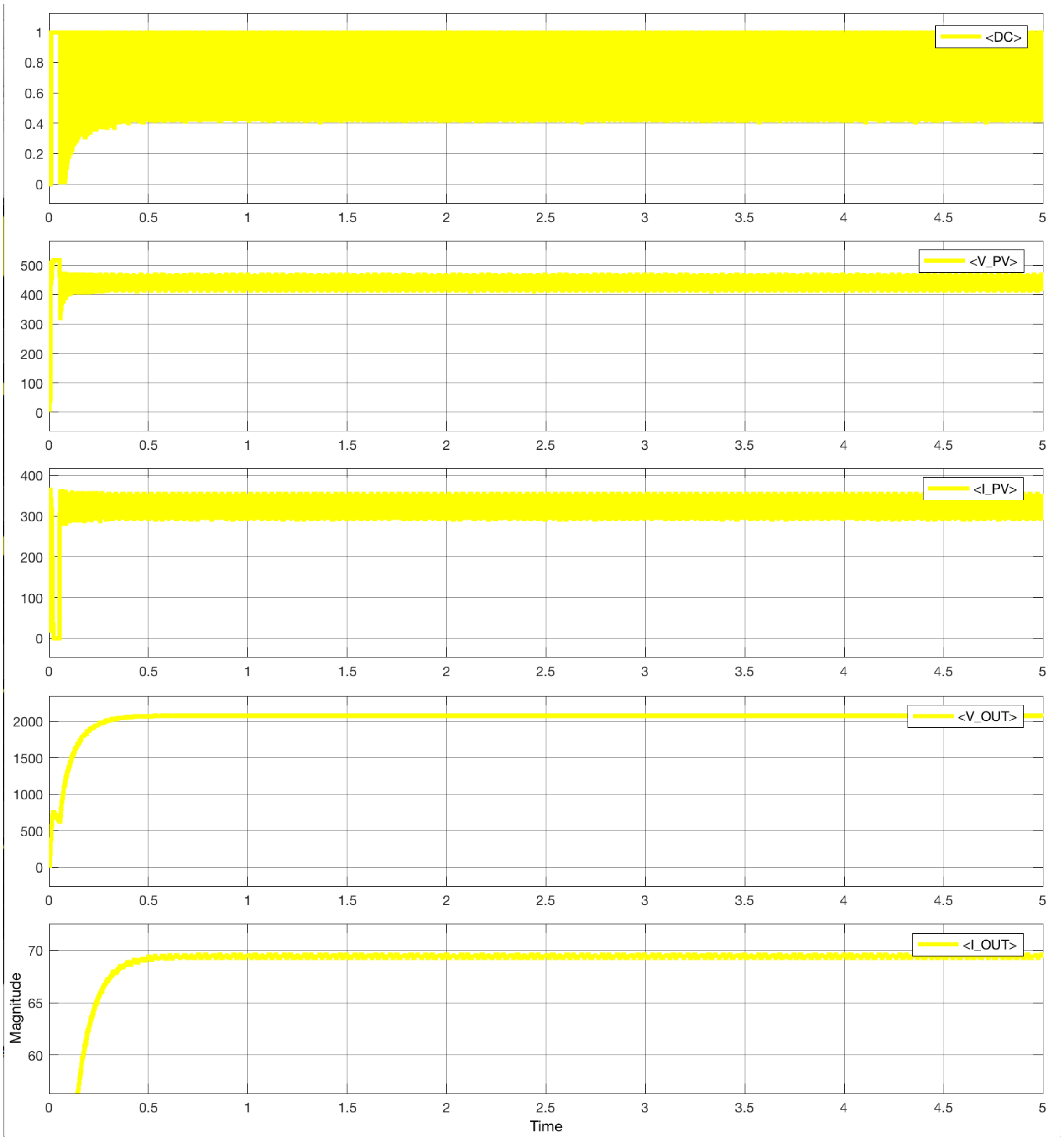


Figure 4.5: P&O DC, Voltage and Current Diagrams Under Constant Conditions

4.2.2 Scenario Two: Varying Irradiance and Temperature

As explained in section 1, there are 3 periods in the second scenario. Each period has either the irradiance or temperature varied from the previous period as shown in Figure 6. There are two conclusions that can be drawn from this scenario; the first is regarding the effect of the irradiance and temperature individually on the output power, and the second is about the efficiency of the MPPT algorithm used. In this case, it is the P&O used in generating power under varying conditions.

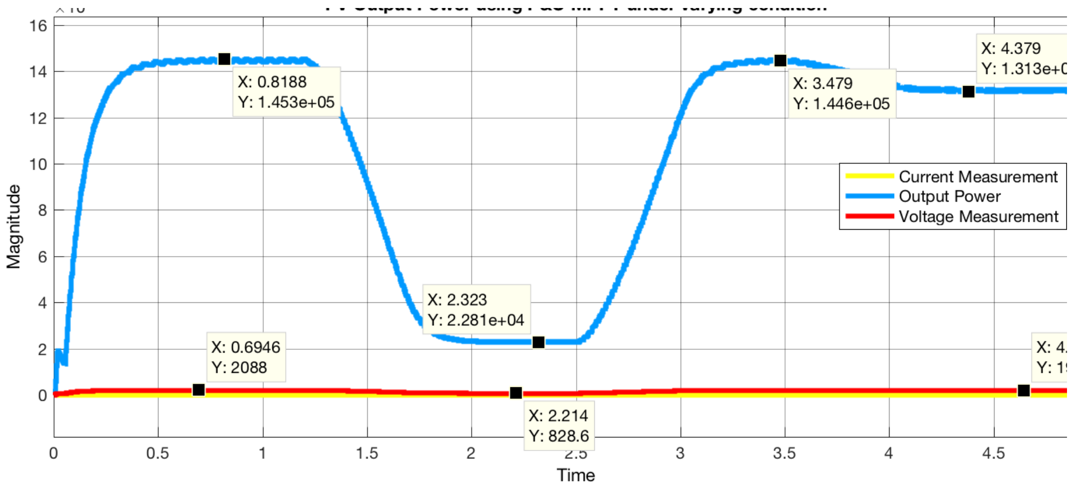


Figure 4.6: Output Power Under Varying Conditions Using P&O MPPT

In Figure 6, period A has an irradiance of 1000 W per square meter and module temperature of 25 ℃ and has the output power curve increasing from zero to 144,700W of power. It drops down to about 22,990 W in period B when the irradiance is dropped to 250 W per square meter and the temperature is kept constant. In part C, the irradiance is increased again to 1000 W per square meter and thus the power output is close to that in part A which is 144,400 W. Part C is done in preparation for part D, where the irradiance is kept constant at 1000 W per square meter and the temperature is increased from 25 to 50 ℃. This results in a power output drop from 144,400 W to 131,600W.

As expected, the irradiance has a substantial effect on the output power where a 75% decrease in the irradiance causes about an 84% drop in the output power as shown in part B. Moreover, when the module temperature doubles from 25 to 50 ℃, the power output reduces by about 9%. Even though the drop in power output in the two cases where the irradiance decreases or where the module temperature increases were anticipated, it is how efficient the actual output of the P&O is compared to the theoretical values when the variations occurred.

Table 4.2 shows the actual output power measured at each of the periods along with the theoretical output powers that are calculated using the MATLAB solar panel block. This block calculates the theoretical output power at given irradiances and module temperatures. The efficiency of the PV system using the P&O method can be calculated using Equation 1:

$$EFF = \frac{AP}{THP} * 100\% \quad (1)$$

Where:

EFF is the Efficiency percentage

THP is the theoretical power

AP is the actual power

Table 4.2: P&O Efficiency Percentages of each Period

Period	Irradiance Value (W/m^2)	Temperature Value (℃)	Actual Output Power (W)	Theoretical Output Power (W)	Efficiency Percentage %
A	1000	25	144,700	150,600	96.08
B	250	25	22,900	36,460	62.81
C	1000	25	144,400	150,600	95.88
D	1000	50	131,600	135,300	97.27

Using Equation 1 results in an efficiency of about 96% in period A, 62.8% in period B, 95.88% in period C, and 97.27% in period D. This shows that while the irradiance is at a high level, the efficiency of the MPPT is quite high at approximately 96% even at times of increased temperature. On the other hand, when the irradiance value drops so does the efficiency percentage where the reported percentage is 62.8% at an irradiance level of 250 W per square meter.

Figure 4.7: P&O DC, Voltage and Current Diagrams Under Varying Conditions

The last part of this scenario (and section) is Figure 4.7. This figure shows the duty cycle values, PV output voltage and current, and the system output voltage and current. Like the first scenario, the PV output voltage and current oscillate heavily until they pass through the boost converter, which allows for a boost in voltage, a drop in current, and removing the oscillations from both curves. Moreover, an observation in the PV voltage and current curves is that while a decrease in irradiance affects both these variables as shown in period B, the PV current is affected more. The current drops from an average of 320 Amperes to an average of

80 Amperes, while the voltage only drops from an average of 450 Volts to about 350Volts. On the other hand, an increase in the temperature affects the PV voltage where it drops from 450 Volts to about 400 Volts; however, the temperature spike from 25 ℃ to 50 ℃ has an insignificant effect on the current that does not manifest on the curve. Finally, the voltage and current of the output system seem to react in a similar manner where they are both affected similarly during the drop in irradiance and rise in

temperature. The output voltage starts at 2100 Volts in period A, drops to about 850 Volts in period B, goes back up to 2100 Volts in period C and finally reduces a bit more to 2000 Volts in period D. Likewise, the output current starts at 70 Amperes, drops to 28 Amperes, back to 68 Amperes, and finally reduces to about 66 Amperes.

Output Graphs Using PWM Controller

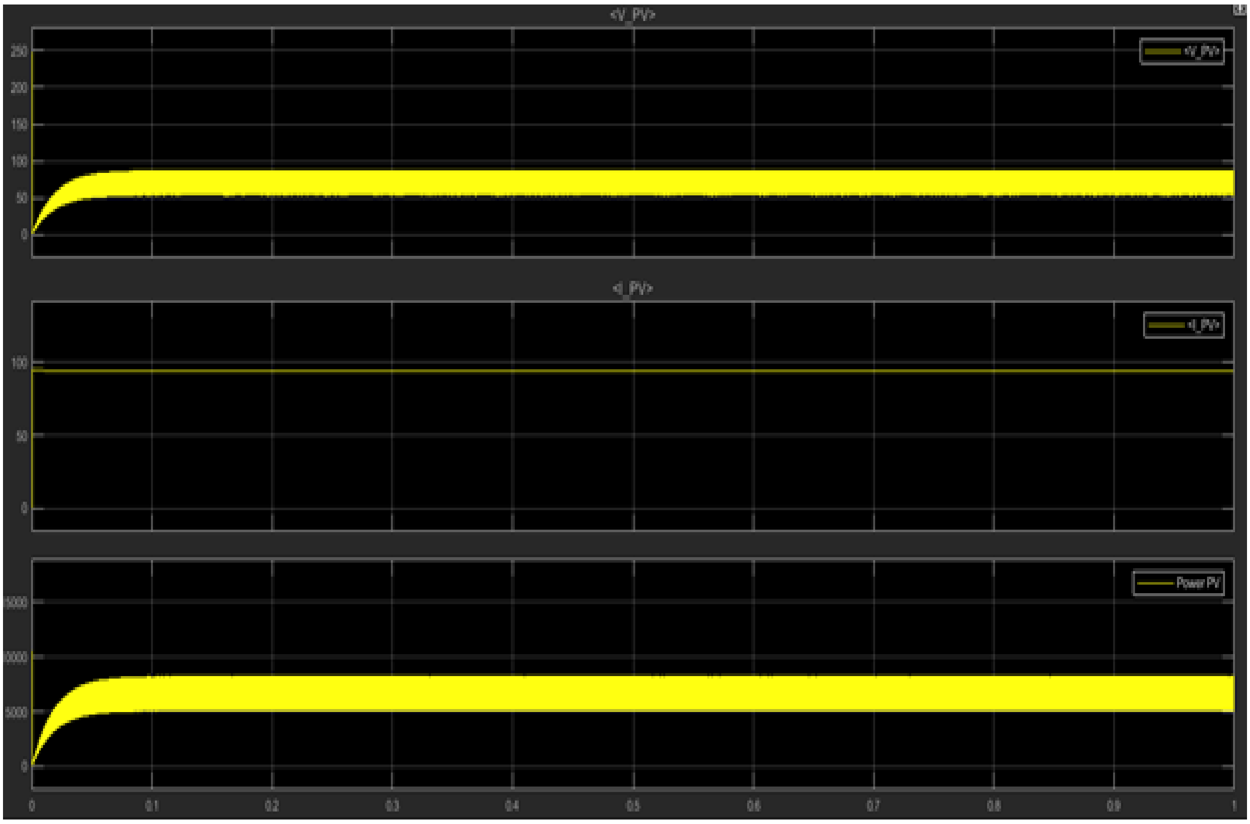


Figure 4.8: PWM DC, Voltage and Current Diagrams Under Constant Conditions

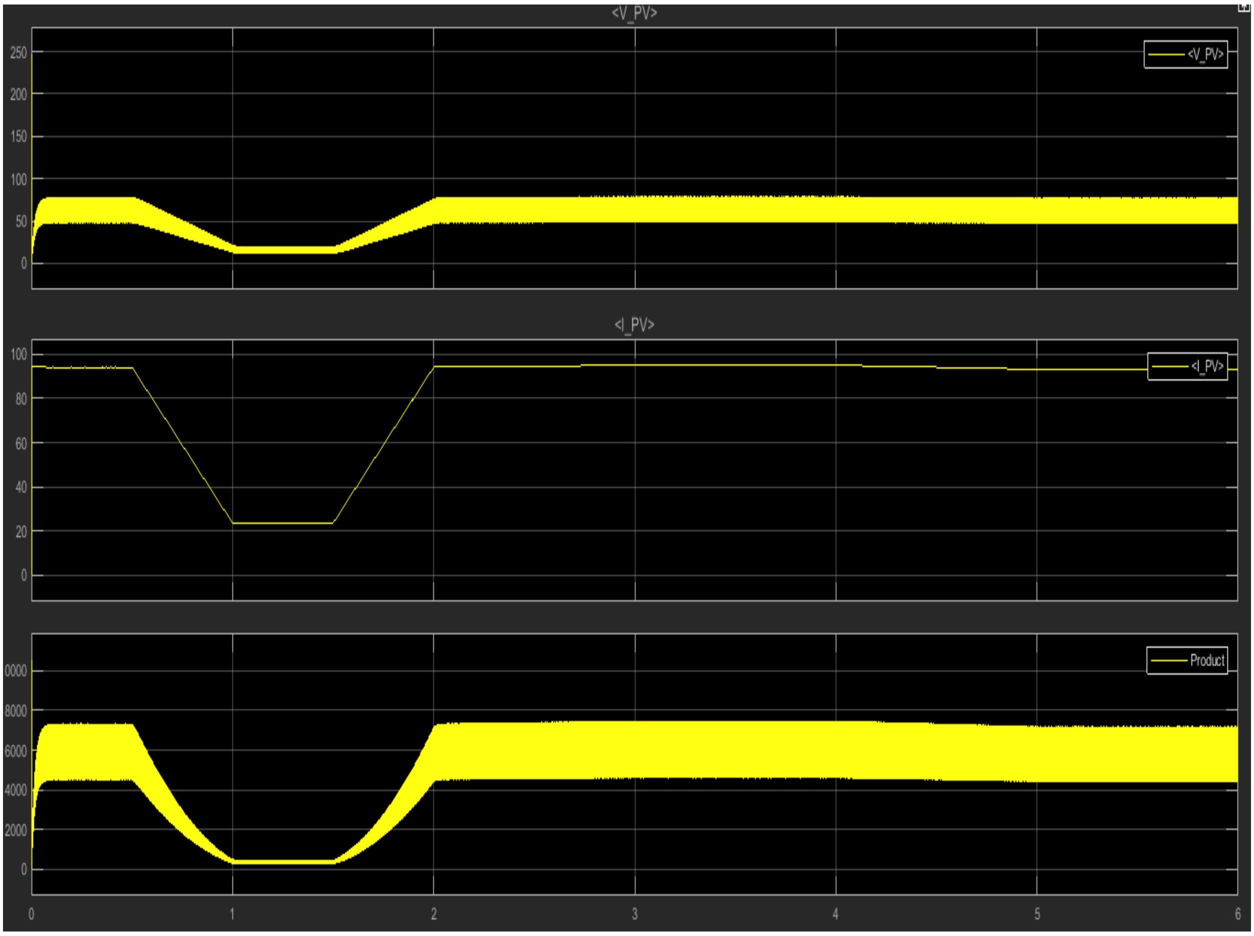


Figure 4.9: PWM DC, Voltage and Current Diagrams Under Varying Conditions

Now we have used PWM controller for the same microinverter circuit and compared the results. We have implemented two scenarios which are same as discussed with P&O MPPT controller. It is clear from the graphs that the MPPT controller is much more efficient than the simple PWM controller. We are getting more output voltage and current value in MPPT.

4.3 Recommendations for Future Work

Recommendations for future work include expanding the testing range of the atmospheric temperature below 25 °C and above 50 °C as some parts of the world reach these temperatures such as some countries in Europe and in the Middle East respectively. Another point is to study the effect of changing both the temperature and irradiance at the same time as that may occur in some instances and study its effect on the output power. Moreover, another recommendation is to enhance and compare the results of both the P&O algorithm and FLC by adding an integral regulator to P&O and adding PID controller to FLC and making it an adaptive FLC. Another,

recommendation is to increase the number of rules used in FLC and study the effect on output efficiency. A final further work recommendation is to connect the PV standalone system to the grid and make the necessary adjustments to the system, so that a more comprehensive result of the actual generated electricity can be reached.

4.4 Program for MPPT

```
function D  = PandO(Param, Enabled, V, I)

% MPPT controller based on the Perturb & Observe algorithm.

% D output = Duty cycle of the boost converter (value between 0 and 1)
%
% Enabled input = 1 to enable the MPPT controller
% V input = PV array terminal voltage (V)
% I input = PV array current (A)
%
% Param input:
Dinit = Param(1);  %Initial value for D output
Dmax = Param(2);   %Maximum value for D
Dmin = Param(3);   %Minimum value for D
deltaD = Param(4); %Increment value used to increase/decrease the duty cycle D
% ( increasing D = decreasing Vref )
%

persistent Vold Pold Dold;

dataType = 'double';

if isempty(Vold)
   Vold=0;
   Pold=0;
   Dold=Dinit;
end
P= V*I;
dV= V - Vold;
dP= P - Pold;

if dP ~= 0 & Enabled ~=0
   if dP < 0
      if dV < 0
         D = Dold - deltaD;
      else
         D = Dold + deltaD;
      end
```

```
    else
        if dV < 0
            D = Dold + deltaD;
        else
            D = Dold - deltaD;
        end
    end
else D=Dold;
end

if D >= Dmax | D<= Dmin
    D=Dold;
end

Dold=D;
Vold=V;
Pold=P;
```

5. CONCLUSION AND FUTURE DEVELOPMENT

5.1 Advantages of Using Microinverters

Microinverters can offer substantial benefits to homeowners contemplating switching to solar, more so than traditional string inverters. Here’s a look at the advantages of microinverters:

The most significant advantage of microinverters is that they are designed to determine each system’s optimal voltage and generate maximum peak power voltage or Vpp. Known as Maximum Power Point Tracking (MPPT), this feature allows the microinverter to track real-time solar intensity and cell temperature as it varies throughout the day. Obviously, this translates to better value over time for homeowners. For instance, if a solar system is shaded, partially shaded, or there is dirt or debris on the array, the installation may fail to produce maximum power. Microinverters offer a much more efficient solution since a single microinverter is connected to each separate solar module and is thus independently controlled. Therefore, the other modules not affected by shade or debris can still produce optimal power no matter what might be happening to their neighboring solar panels San Diego. In comparison, however, string or central inverters are paired together so if shade or debris is on just one module of the system, the output of the entire solar installation can be drastically reduced. Besides a more efficiently performing system, other benefits of microinverters include:

Monitoring: Microinverter systems are designed to allow for individual per-panel monitoring, which in turn can help to inform solar panel owners or solar panel installation companies in San Diego of under-performing systems so that they can do something about it rather than let potential under-performing panels go unnoticed.

Reliability: Most high quality microinverters have undergone rigorous testing in extreme weather conditions.

Enhanced Safety: Microinverters convert DC power to AC instantly, eliminating the exposure to high voltage DC electricity.

Longer warranties: Typically, microinverters have a 25-year warranty opposed to 5 years for string inverters.

Overall better value and investment over time.

5.2 Conclusion

This work has introduced a novel PWM inverter utilizing P&O MPPT procedure dependent on double looking for photovoltaic applications. The characteristics of the chosen MPPT algorithm (P&O) in the design model have been explained. The outcome of using algorithm in the solar system MPPT design is presented. We have implemented two scenarios which are same as discussed with P&O MPPT controller. Moreover, effect of irradiance on PV voltage and current curves is observed. Finally, the voltage and current of the output system seem to react in a similar manner where they are both affected similarly during the drop in irradiance and rise in temperature.
The proposed calculation was actualized and explored on a SEPIC converter. Both reenactment and exploratory outcomes show that the P&O strategy offers higher proficiency, exactness, stable and combination speed, instead of using simple PWM technique. In our work, we have also used dual stage voltage rectifier for stable and harmonics free output voltage. Moreover, in our research work we have used passive LCL filters to reduce the effect of noise on the sensitive devices which are affected by the harmonics and unwanted noise signals. Feasibility and test results are explained in this thesis to show the actual results. The control feedback error is considered as difference between the reference voltage and input voltage. The rate of change is used as inputs for the PWM block which will then determines the duty cycle of switch. Graphs have been shown in this thesis.

5.3 Future Work

As we have already discussed, the method used in this thesis work is P&O for MPPT with PWM for switching of IGBT. We have seen in our graphical results that this method is fast and reliable. On the other hand, it has also drawbacks. For example, it is slow, and efficiency is less. We have other methods to use for tracking of maximum power output of a PV panels. That are open circuit voltage method and short circuit current. They are more accurate, and efficiency is better than perturb and observe method. But on the inspire of having these benefits they have also difficult to implement and we must consider a lot of characteristics while implementing. That is why we have chosen P&O method for our research work.

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