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SUSTAINABLE DEVELOPMENT

**Title: DESIGN OF SOLAR POWER INVERTER WITH AN IMPROVED
EFFICIENCY BASED ON SIC MOSFET USE FOR NYIRABIRORI PRIMARY
SCHOOL**

By

HATEGEKIMANA Jean Bosco

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Supervisor's Names: **Dr. BIKORIMANA JMV**

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DECLARATION

I declare that this dissertation results from my work under Supervision of **Dr. Jean Marie Vianney BIKORIMANA** and has not been submitted for any other degree at the University of Rwanda or another institution. It has been passed through the
and found the complaint and this is the approved final vision of the dissertation.

Student names: HATEGEKIMANA Jean Bosco

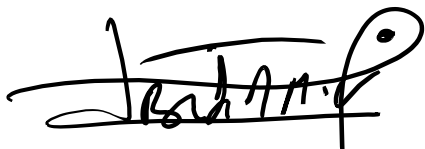
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This thesis has been submitted for examination with Supervisor as my approval.

Supervisor's Names: **Dr. BIKORIMANA JMV**

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DEDICATION

I dedicate this thesis to:

- The almighty God;
- My Supervisor;
- My Husband and my Children;
- My relatives;
- My friends and classmates;

The Staff of the African Center of Excellence in Energy for Sustainable Development, College of Science and Technology, the University of Rwanda for providing support, guidance, and advice, All May God Bless you for your support to me during the studies period.

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ABSTRACT

Renewable energies are exploited and it have been started to be used, many researchers have started to develop and designing inverter based the different topologies of power electronics devices such as BJT, GTO, MCT, SI IGBT and Thyristors. Most all of these inverters failed due inefficiency applied topologies used during inverter design which characterized by much power losses. In this research come with a design of a high solar power inverter based on SIC MOSFET use in order to reduce the system power losses and increasing efficiency of the System by applying SIC-MOSFET in topologies in inverter design.

The design of solar power inverter circuit has been performed using CAS100H12M1 1.2 kV SIC-MOSFET. The single-phase inverter circuit consisted of 4 SIC- MOSFET with LC filter and load, PWM block, PID controller to generate signal and then simulation have been performed using MATLAB/SIMULINK. However, the inverter had some losses in SIC- MOSFET and in diode. Therefore, this research presented calculations of those losses and total harmonic distortion (THD) where the inverter Efficiency have been increased up to 98% and total harmonic distortion (THD) with 5.01%. This research discussed the components used in designing and interpreted the simulation results.

LIST OF ABBREVIATION

DC – Direct Current

PV-Photovoltaic

BJT – Bipolar Junction Transistor

IGBT-Insulated Gate Bipolar Transistor

GTO –Gate Turn Off Switch

RE-Renewable Energy

PHSS- Pumped Hydroelectric Storage System

MCT – Metal Complementary Thyristor

MOSFET – Metal Oxide Semiconductor Field Effect Transistor

MPPT – Maximum Power Point Tracker

SPWM- Sine Pulse Width Modulation

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CHAPTER1: INTRODUCTION

1.1. Background

Now day's renewable energies are exploited, and it have been started to be used. In 2019, 11.2 percent of the energy used for heating, powering, and transportation worldwide came from modern renewables (biomass, geothermal, solar, hydro, wind, and biofuels), an increase from 8.7 percent a decade earlier [1]. By the end of 2020 more than 256 GW added of generation capacity, led by wind and solar PV, the total installed capacity of renewable power rose by about 10%, accounting for 29% of all electricity generated globally by the end of the year[2].

Similarly, in Rwanda this kind of renewable energy have being exploited where Currently Renewable sources of energy accounted for about 134.778 MW with the percentage of 57% of total energy consumption [3]. To be exploited many researchers have been developed different topologies based on different technology such: BJT, GTO, MCT, Power MOSFET, Thyristors and SI IGBT[4].

However, during the power conversion, renewable energies especial in solar power inverters has been challenged with the efficiency, power losses and even also their lifetime. These renewable energies don't show the efficiency because they don't use adequate topologies with high efficiency, most of the configuration used in solar power inverters Topology are based on: BJT, GTO, MCT, Power MOSFET, Thyristors and SI IGBT during the power conversion. Smaller switching loss, lower power losses, and lower switching frequencies are characteristics of these configurations in these inverter topologies, which leads to inefficiency of renewable energy power generation, particularly in solar power inverters[5].

To improve this, the new technology based on SIC MOSFET configuration should be good Topology to apply in inverters of renewable energy power conversion[6].These configurations in these inverter topologies have smaller switching loss, high power losses, and lower switching frequencies, which reduces the efficiency of renewable energy power generation, notably in solar power inverters[7].

1.2. Problem Statement

Many researchers had tried to develop, increase efficiency and the life time of solar power inverter based on different topologies[8]. However same weaknesses have been presented on solar power inverter performance, where the majority of solar power inverters used in renewable energy power conversion are using topologies such as BJT, Power MOSFET and SI IGBT which characterized by smaller switching loss, lower switching frequencies and high-power losses that result inefficiency and the life time of the inverters when silicon device are used

Those losses generate heat, resulting in a reduction in the efficiency of power-conversion systems and the requirement for expensive, substantial thermal control solutions. The usage of SI IGBTs or SI devices will result in a large increase in the system's size and weight due to the need for thermal management components, which can be a major problem when designing solar power systems. This case is happened to NYIRABIRORI Primary Schools where their inverter fails to supply their AC loads appliances even if the capacity of loads is low compared with primary Schools Inverter Capacity.

Therefore, to improve the inverter efficiency and their life time, silicon carbide MOSFETs should be a good Topology consist of SIC MOSFET Switches should be used where This limits the effectiveness of the power-conversion system and necessitates the use of expensive and substantial thermal control technologies. Due to the need for thermal management components, using a SI IGBT or SI devices can greatly increase the system's size and weight. This might be a big problem when designing a solar power system.

This results in a far more compact, weight-saving design overall as well as cheaper overall expenses. Additionally, silicon carbide MOSFETs are more durable than silicon IGBTs, which makes them perfect for severe environment applications on solar power systems where IGBTs would struggle.

1.3. Objectives of Research

1.3.1. The General Objective of the Research

The main objective of this study is to design a Solar Power Inverter for NYIRABIRORI Primary Schools in order to improve the efficiency with the use of SIC MOSFET switches. This inverter will be characterized by lower power losses, very high switching, Smaller switching loss, high switching frequencies and improved life time. The system simulated using Matlab/Simulink Software.

1.3.2. Specific Objectives of the Research

The following objectives should be accomplished to achieve the desired goal:

- i) Review issues of existing solar power conversion based on tradition power conversion method like power transistor BJT, Silicon IGBT and their switching characteristics Comparison between Si IGBT and SIC MOSFET switches configurations
- ii) Design an adequate a simple and high efficiency solar power inverter for AC Appliances based on Silicon Carbide SIC MOSFET Switches for NYIRABIRORI Primary schools.
- iii) Modeling and simulation of solar power inverter based on SIC MOSFET Switches using MATLAB/SIMULINK Software.

1.4. Scope of Project

This scope of research work is limited to designing of high efficiency solar power inverter based on SIC MOSFET use for increasing inverter efficiency for NYIRABIRORI Primary schools and reduction the system power losses. The designed inverter focused on a single-phase solar power inverter system based on loads parameters available on the site. The main party emphasized are Boost converter, Inverter Topologies Controlled by PID Controller, LC Filter circuit and it is finally given to the load. The simulation has carried out using MATLAB/Simulink environment because it has many features required in order to reach to the target.

1.5. Conceptual Framework

The Thesis framework reviewed different documentation and published journals on solar power inverter based on their topology and their modeling. The following is the conceptual framework of the research.

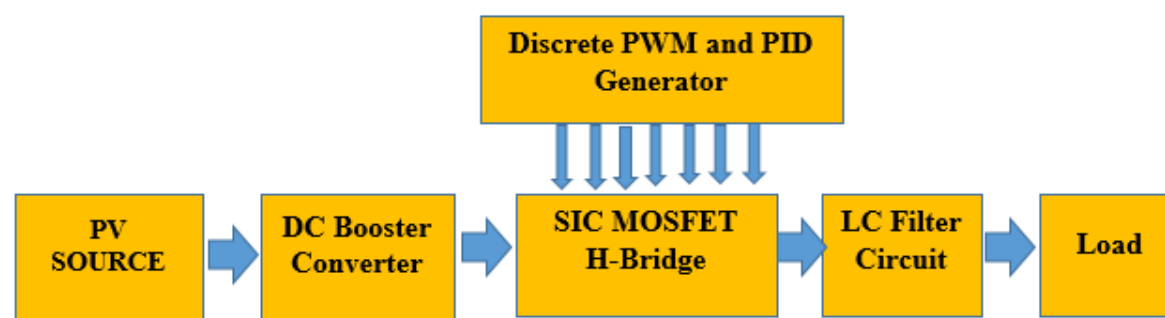


Figure 1. 1:Conceptual Framework

Solar radiation is converted into electrical energy by the solar PV system, although this depends on the state of the sun. PV cells produce the most power when the sun is shining at a 90-degree angle to them. When a boost converter is employed, the voltage level sent to the inverter is increased and the voltage is kept on. In inverter, the SIC MOSFET Configuration is used, in order to be converted from dc to ac signal but in this time, the SIC MOSFET switch driver, is provided by pulse width modulation (PWM) with PID controller and LC filter to remove harmonics content and then the system be connected to the distribution network.

1.6. Significance of Project

The significance of this project work is to reduce solar power inverter losses in renewable energy power generation especial in solar power converter. The design of NYIRABIRORI Primary school inverter is preferred where their inverter power losses are at maximum level which affect whole system to be fail.

1.7. Thesis Outline

This project is organized as follows with different chapters where chapter 1 is about the introduction of the project. Chapter 2 describes a brief review where Past Research on Solar Power Inverters Reviewed, Trends, Performance, Challenges of Power Electronic Devices and applying SIC MOSFET and WBT Technology. Chapter 3 shows data collected in the selected site with a clear presentation of the average daily load profile for NYIRABIRORI Primary school. Chapter 4 presents the modeling and simulation of the designed Solar power inverter for NYIRABIRORI Primary school, then final Chapter 5 shows the conclusion and recommendation.

CHAPTER2: LITERATURE REVIEW

2.1. Introduction

This section discusses the literature review of previous research related on the inverter design based on different topologies, Trends (evolution) of power electronic devices, challenges happened during use of these power electronic devices (switch) where they characterized by high power losses, the way to overcoming these challenges during the applications of power electronic devices, the reason why the researchers immigrated to the use of SIC MOSFET Switch.

In this section also we recognizing the work done by many researchers on different inverter design based on different topologies, and identifying the gaps to be addressed in their publications.

2.2. Review of Past Research on Solar Power Inverters

In this section, we are going to recognize the research done by the past researchers on solar power inverter based on different topologies by appreciating their finding and identifying the research gaps to be addressed.

Sun et al,(2014)[9] reported “an improved model of medium voltage Power MOSFET with wide temperature range operation” The on-state resistor, internal gate resistor, temperature dependent sources, and a few capacitors were among the main characteristics that were determined and evaluated in detail in this study. The experiment results show that the suggested model demonstrates great accuracy throughout a broad temperature range.

However, the authors in their research were focusing on MOSFET with wide temperature range operation, but reducing of the thermal management requirements of systems were not studied that resulting lower switching speed application.

Zhiling Liao, Chenchen Cao et al, (2019) [10] works on “Single-Phase Common-Ground-Type Transformer less PV Grid-Connected Inverters” Five power switches, one capacitor, and one filter were used in this research to achieve the following goals: completely eliminating leakage current; using few, inexpensive devices; achieving high efficiency and low loss; and being able to realize reactive power when the system is connected to the grid. Half-bridge IGBT-type topologies were used in comparison with conventional topologies such as Power Transistors, GTO, BJT, and SI IGBT. The results demonstrate that the proposed topology's ability to reduce leakage currents and its effectiveness are superior to those of the

conventional topologies. The next step is to present the computational and experimental findings from a 1kVA prototype, which validate the suggested topology for PV grid-connected systems.

However, this research has achieved successfully but the used Topology of half-bridge IGBT-type has come with high switching losses when silicon is used. Those losses generate heat, resulting in a need for costly and large thermal management solutions and a limitation on power-conversion system efficiency.

Nurul Farhana, Abdul Hamid et al, (2020)[11] worked on “Design and simulation of single phase inverter using SPWM unipolar technique” Switches have been made using Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The Matlab/Simulink software will be used in the project to design, evaluate, and control switching for inverter circuits. The system is made up of a microcontroller-based control circuit that generates SPWM pulses. The full bridge circuit or an inverter circuit will then be used to provide the output. In order to produce a sine wave signal, the LC filter was utilized to remove harmonics. The step-up transformer, which raises the voltage to 230V, comes last. However, the researchers use MOSFETs in full bridge Topology but not considering that it cannot work efficiently at high voltage levels as it creates instability in the device and since it has a metal oxide layer it always runs the risk of damage through electrostatic changes.

Akif Karafil, Harun Ozbay et al, (2019) [12]. The researcher’s works on “Design and Analysis of Single-Phase Grid Tied Inverter with PDM MPPT Controlled Converter” Using PDM control technique, the planned series resonant converter was run at resonant frequency under various solar radiation conditions. The maximum power point was used as a tracker to increase system efficiency. Performance, simulation, and application tests were conducted on a full bridge series resonant power converter using a 600 W PV panel and PDM control approach while operating at resonant frequency. For the single-phase inverter circuit, IRFP 460N MOSFET power switches were utilized instead of the IRFP 260N MOSFETs in the series resonant converter circuit. Both inverter and resonant converter circuits employed the TC4429 drivers. The PI current regulated single-phase inverter's switching frequency was established as 10 kHz, and application experiments were carried out using this frequency. the PDM signals. Even if the resonant converter and the single-phase inverter circuits used in the system were analyzed, designed, simulated, implemented and desired output was obtained but IRFP 460N MOSFETs used in power switches used for single phase inverter circuit and for series resonant converter has high switching loss that result the system inefficiency and low power delivered to the grid.

Yasar Birbir, Kaner Yurtbasi et al, (2018) [13] works on “Design of a single-phase SPWM inverter application with PIC micro Controller” The purpose of this study was to compare unipolar voltage switching and bipolar voltage switching techniques for investigating low level harmonic content. The Peripheral Interface Controller (PIC) microcontroller was in charge of controlling this single-phase full-bridge inverter application design. The PIC16F877 microcontroller was used in conjunction with an inverter to carry out these two separate procedures in order to obtain a sinusoidal control signal and control of the inverter settings for a single-phase full-bridge Si IGBT. Even if the application of PIC based control technique, total harmonic amount was decreased and a smaller size inverter was designed with very high reliability, safety, and low cost but the conversion of AC to DC, IGBTs were used has lower switching performance and lower power losses compared to SIC MOSFET were used.

Hendi Matalata1,Venny Yusiana1,(2020)[14] In their study, "New Topology Multilevel Inverter Type Diode Clamped Five Level Single Phase," the researchers described a method that extends the number of levels by using diodes to clamp the intermittent voltage levels. These multilevel inverters are referred to as "diode clamped inverters" because the voltage levels affect how much voltage the clamping diodes must be able to block.

These inverters are known as Clamped –Diode Type inverters. Most of them use these types of diodes where the voltage blocking capability of faster devices is like for IGBT and the switching speed of high voltage devices is like Thyristors where are limited.

2.3. Basic Concepts of Power Electronics Devices

2.3.1. Trends of Power Electronic Devices

In 1952 power semiconductor devices first appeared invention of the power diode

In 1957, the first thyristor was produced. Thyristors have a great current carrying capacity and a very good reverse breakdown voltage tolerance. One issue for switching circuits is the thyristor's inability to be switched off by external control once it has been "latched-on" in the conducting state.[15].

The 1960s saw the introduction of the first bipolar transistors with significant power handling capabilities. Due to their ability to be turned on or off with a control signal, these components circumvented some thyristor constraints[16].

In the late 1970s, the development of Metal Oxide Semiconductor technology made power MOSFETs commercially feasible. These devices are restricted to low voltage applications yet enable operation at greater frequencies than bipolar transistors.

Power MOSFETs became economically viable in the late 1970s as a result of advancements in Metal Oxide Semiconductor technology. Even though they can only be used in low voltage applications, these components can function at greater frequencies than bipolar transistors.[17].

In the 1990s, the Insulated Gate Bipolar Transistor (IGBT), created in the 1980s, was widely accessible. This component combines the benefits of an isolated gate drive from a power MOSFET with the power handling capacity of a bipolar transistor, Figure 2.1 shows the introduction of Modern Power Electronics Devices.

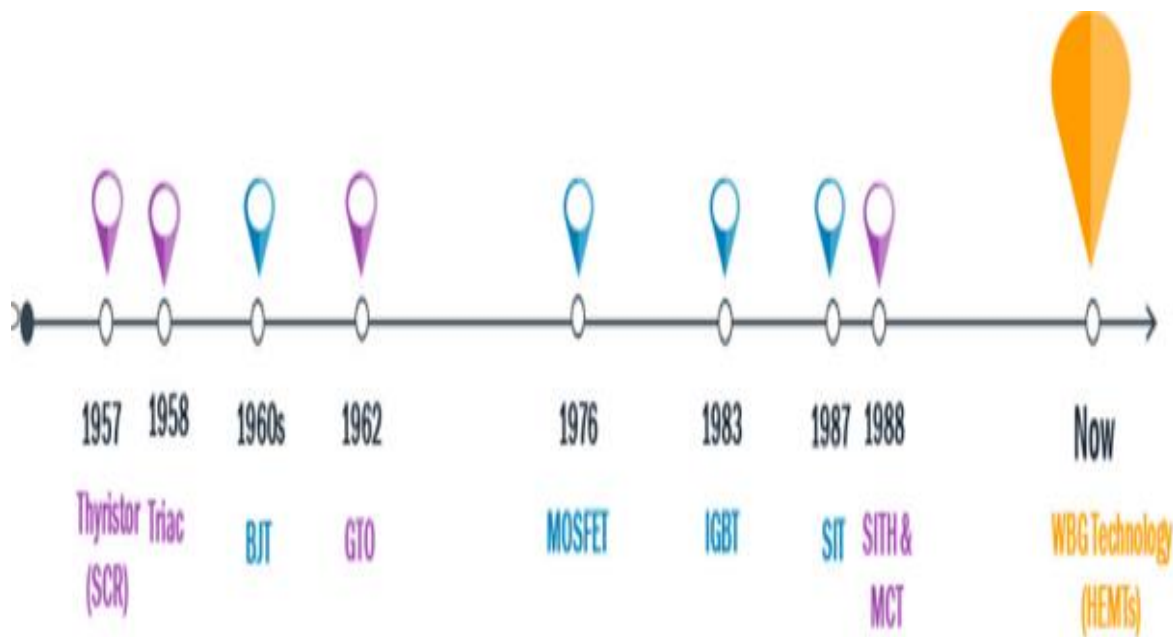


Figure 2. 1:Timeline of the Introduction of Modern Power Electronics Devices

Figure 2-2 illustrates the four crucial stages that power semiconductor device development went through. Due to their abundant material supplies, affordable production costs, and straightforward manufacturing

procedures, semiconductor devices based on Si materials have dominated the power electronic device market since the 1950s, when the Thyristor was first developed.

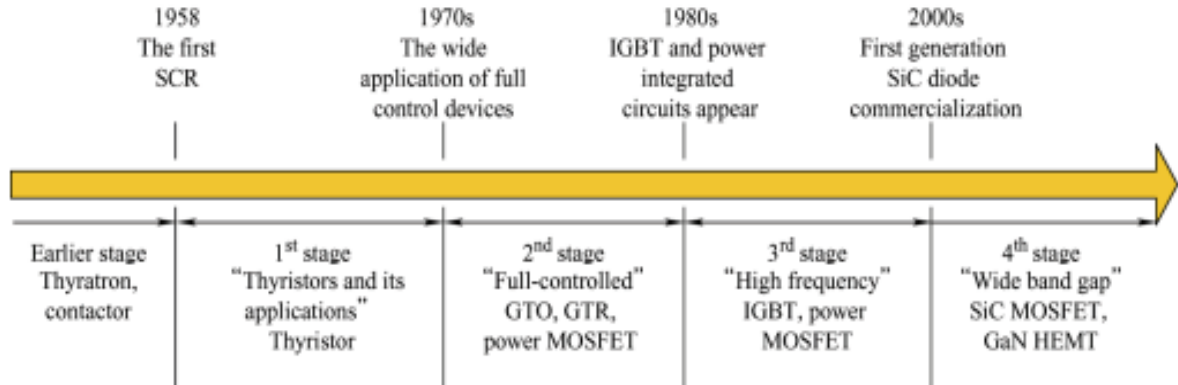


Figure 2. 2: Development of Power Devices [18]

2.3.2. Classification of Power Electronics Devices

Power Electronics Devices are categorized according to how controllable they are: fully controllable switches (BJT, MOSFET, JFET, IGBT, GTO, MCT), partially controllable switches (Thyristors), and uncontrollable switches (diodes). Fig 2.4 shows Classification of Power Electronics Devices Based on Degree of Controllability.

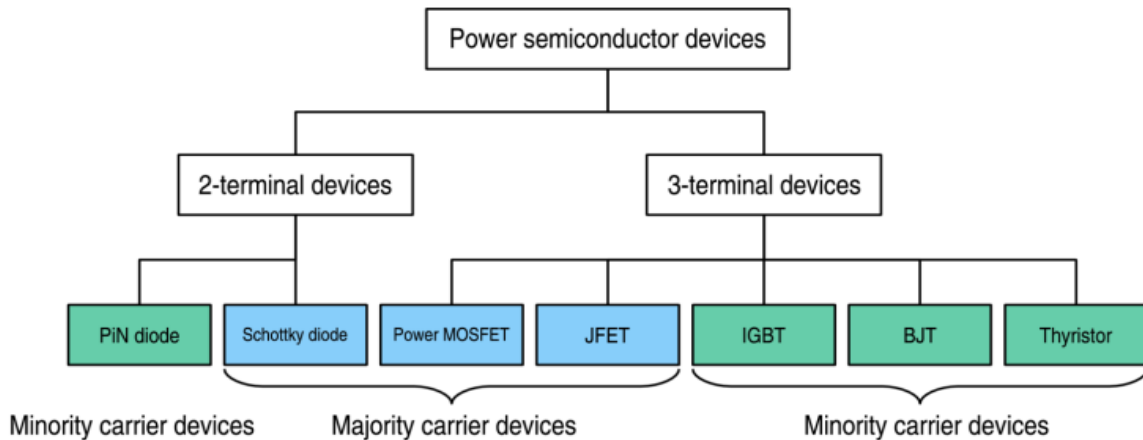


Figure 2. 3: Classification of Power Electronics Devices Based on Degree of Controllability [19]

2.3.3. Semiconductor Switching-Power Performance

Fig. 2.4 presents a summary of the power frequency ranges of the various semiconductors covered in the preceding sections. It is evident that with relative low frequency, the Thyristor dominates the ultra-high-power zone. When it comes to power handling capabilities that go up to frequencies of a few hundred Hz,

the GTO is the next device. The MOSFET has very high switching frequencies at medium power operation, while the IGBT operates in the area of medium power with the capacity to function at considerably higher frequencies.

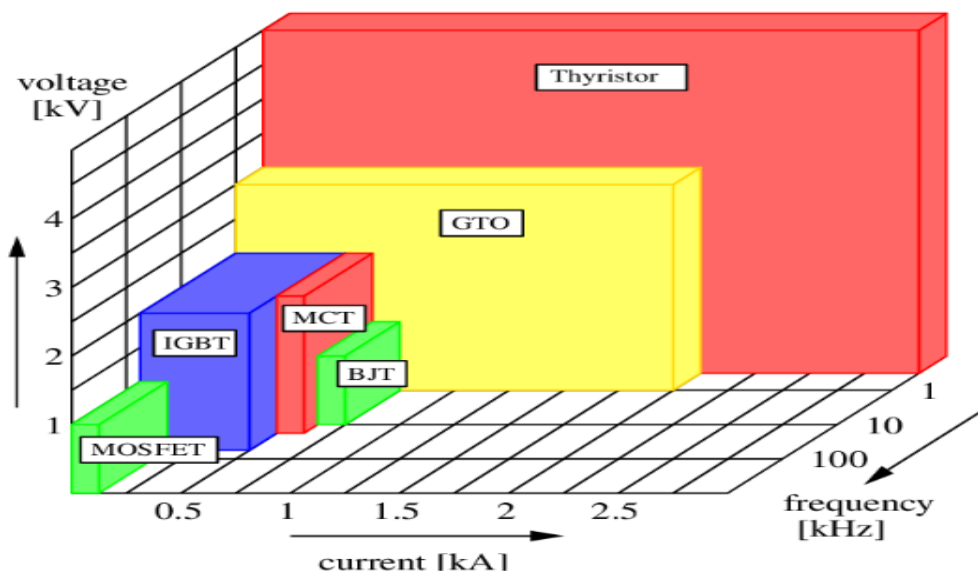


Figure 2. 4: Current/Voltage/Switching Frequency Domains of the Main Power Electronics Switches [17]

2.4. Challenges Facing of Power Electronic Devices

Many researchers have been tried to find to develop power electronics component in order to solve the problem faced by using traditional switch application where many solutions have been tried such developing power electronics component like: BJT, MCT, FET, GTO. Additionally, the many advantages have been combined such as IGBT+MOSFET or IGBT paralleled MOSFET and Diodes to find strong component. The following are Technical Challenges Facing of Power Electronic Devices

Costs of Power Electronics Devices: The Costs of power electronics Devices dominate the total cost of a system. Lower device costs should be the main priority. This requires higher power and faster switching devices. At the same time, it is necessary to improve standardization and modularity of devices in order to reduce the costs of equipment and maintenance.

Reliability active passive components: Reliability in Power Electronics Devices, including both active and passive components, is an important issue, especially for operations that involve the transmission and distribution (T&D) network.

Component Packaging and Thermal Management of Power Electronics Device: As requirements of applications improve, high-power, high-temperature, and high-speed devices are desirable.

Cooling methods Power Electronics Devices: Advanced cooling methods in Power Electronics Devices need to be considered in order to reduce the footprint of power electronics systems.

Efficiency Power Electronics Devices: Efficiency in Power Electronics Devices needs to be as high as possible in order to save energy, lower cooling requirements, and improve device performance.

Power Electronics Devices Control: Advanced hardware and control strategies in Power Electronics Devices are needed to take full advantage of power electronics [20].

2.5. To overcoming Power Electronic Device Challenges

The way to overcoming these challenges, the researchers have been tried to find the solution by combining the many advantages such as combining IGBT+MOSFET or IGBT paralleled MOSFET and Diodes to find the solution. However in all of these solutions applied by many researchers did not find the solution of power losses reduction on power electronic switches where were still the high problem even if they have combined these the different advantages, that why the researchers immigrated to the use of WBG devices SIC devices [21]. These WBG devices could enable the use of medium and high frequency-based modulation methods for high-power converters, which are currently constrained by switching losses and the cooling system design making the filtering stage bulky and expensive. These WBG devices also have fast commutations, a high maximum working temperature, and very low power losses.

2.6. Applying Silicon Carbide Power MOSFET and WBG Technology

Silicon Carbide Power MOSFET Because of its superior qualities, such as higher breakdown voltage, higher thermal conductivity, higher operating frequency, higher operating temperature, and faster saturation drift velocity, silicon carbide (SiC) has drawn a lot of interest from researchers and the industry for decades [22]. Thanks to developments in material science and processing technology, SiC power devices are being employed in a wide range of power applications, such as new smart energy vehicles, power converters, inverters, and power supplies [23]. SiC MOSFETs in particular have been widely marketed recently and are regularly used as power devices because they can achieve lower on-resistance, smaller switching losses, and higher switching speeds than their silicon counterparts [24].

2.6.1. Silicon Carbide Power MOSFET Applications

SiC MOSFET is a suitable option for use in switching systems such three-phase inverters, digital power supplies, as well as electronic AC-to-DC or DC-to-DC converters due to its lower on-resistance and output

capacitance[25].The converters' switching frequencies are also improved by SiC devices' lower switching losses. Because of this, SiC power devices are crucial for high-performance power device applications.

Currently, SiC-based converters are employed in high voltage applications, solar inverters, EV/HEV drivers, railway traction inverters, SiC MOSFETs in Tesla Model 3 EVs, and uninterruptible power supply (UPSs). Utilizing SiC diodes and SiC JFETs allowed for a 20% power reduction in the price of a solar inverter. Figure 2.6 present the classification of various application categories based on Si and WBG devices. According to the diagram, SiC devices are used for higher power, higher voltage switching applications like trains, electric vehicles and their battery chargers, and industrial automation.

GaN-based devices, on the other hand, are used for lower voltage, lower power high-frequency applications like data centers and consumer systems.

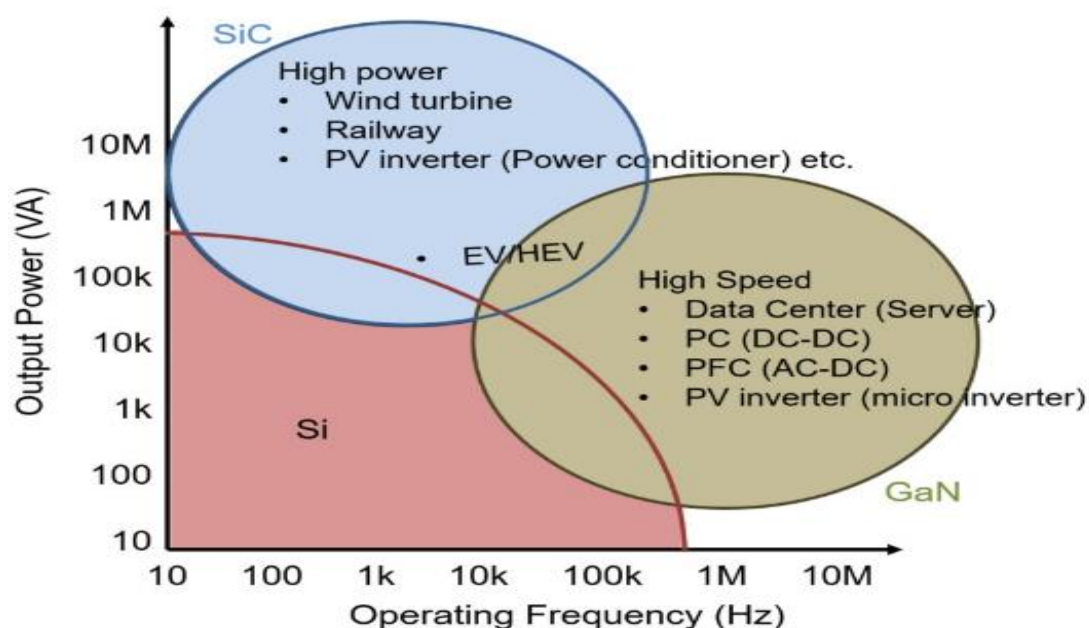


Figure 2. 2:Applications based on WBG Materials[26].

SiC power devices also significantly contribute to meeting the growing demand for solar energy. Fast switching, low loss, high power, and a dependable component are required for photovoltaic energy sources to increase efficiency, dependability, and power density. SiC power devices have been used to implement the desired performances. Power modules are also developed using SiC power electronics.

2.6.2. Comparison of Si and WBG Devices

Based on Development of power devices as it is shown in previous chapter, it can be concluded that Si-based power semiconductor devices have significant limitations in high-frequency and high-power conditions. Owing to a high breakdown voltage, the ability to withstand a high temperature, fast switching speed, and low conduction loss, WBG devices are the key to improving the efficiency and power density of power converters in the future[27]. Fig 2.6 shows the limitation of the commonly used semiconductor power devices.

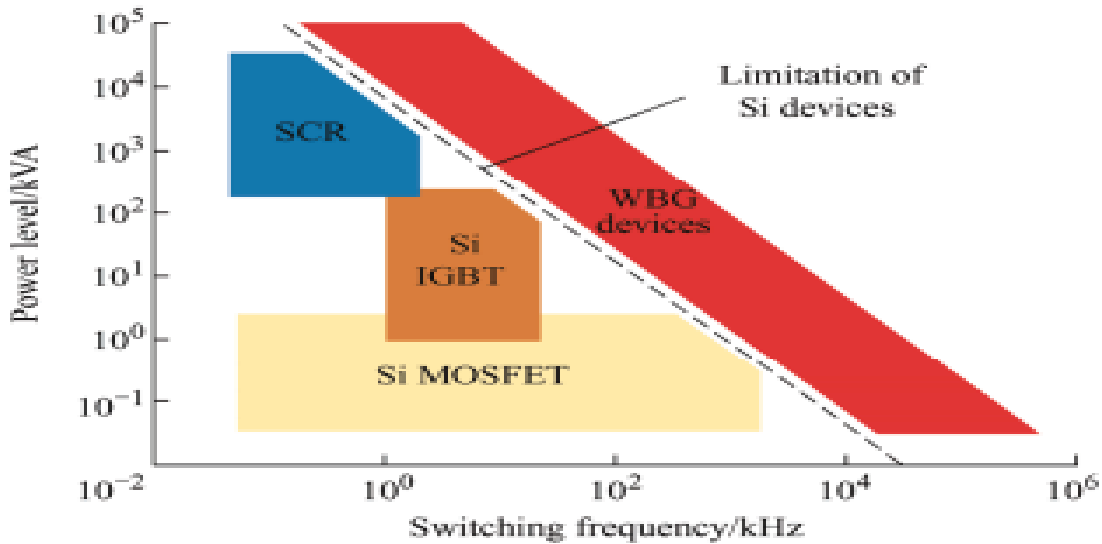


Figure 2. 3:Operating limits of commonly used semiconductor power devices[28].

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

Many researchers can be employed for achieving the specific objectives of this research. The solar power inverter is needed where AC power is required in order to supply AC appliances especial in rural areas. During this research of designing high efficiency solar power inverter, some steps was performed using selected site visit, Documentation, mathematic modelling and the simulation.

3.2. Documentation

The present research involved documentation related to the literature Review, desk review was used to explore different researcher's outcome and have an overview the research gap. In addition, the documentation visited the different technology related to our power electronic switches especial the mostly used in inverter design. Zhiling Liao and Chenchen Cao works on "Single-Phase Common-Ground-Type Transformer less PV Grid-Connected Inverters" Five power switches, one capacitor, and one filter were used in this research to achieve their goals but researcher fail the following point: completely eliminating leakage current; using few, inexpensive devices; achieving high efficiency and low loss; and being able to realize reactive power when the system is connected to the grid. [10]

Nurul Farhana, Abdul Hamid et al, worked on "Design and simulation of single phase inverter using SPWM unipolar technique" Switches have been made using Insulated Gate Bipolar Transistor (BJT), The researchers emphasize on using old technology that characterized by high power losses

Sun et al reported "an improved model of medium voltage SIC-MOSFET with wide temperature range operation" The on-state resistor, internal gate resistor, temperature dependent sources, and a few capacitors were among the main characteristics that were determined and evaluated in detail in this study. The experiment results show that the suggested model demonstrates great accuracy throughout a broad temperature range. The researchers after find many inverters failed when traditional Switches were applied and the research show is these switches are used my time inverters are failed. So by combining all these information, the result show that the design on NYIRABIRORI Primary Schools inverter failed due to the use of old traditional switches.so when SIC MOSFET is applied on their inverter topology, the system will be efficiently, less expensive and life time improved.

3.3. Site Visit

To have the specific concept for the inverter to be employed, a Primary school was selected as case study. This primary located in TUMBA Sector, RULINDO, RWANDA. The Coordinate of NYIRABIRORI Primary school is the following: Latitude: -2.2893982. Longitude: 29.9304418 known as TUMBA in RULINDO district, Northern Province. Figure 3.1. illustrates the locations of NYIRABIRORI Primary school on the geographical map.



Figure 3. 1:Geographical location of NYIRABIRORI Primary school[8]

The total load at NYIRABIRORI Primary Schools was determined by examining each appliance's power consumption and working frequency during the site visit. AC load appliances with their operating voltage, current consumption, and rated power were also taken into consideration. Each device has a fixed power consumption that can be found on its nameplate information, and it is important to gather this information for all the devices that will be used.

3.4. NYIRABIRORI Primary School AC Load profile

The NYIRABIRORI Primary School provides a variety of services that depend on energy, including: printing paper, utilizing computers to record lessons, scanning documents, and nighttime lighting. When the inverter used to supply their loads with electricity fails to power their AC equipment due to high power losses that result inverter inefficiency. Table3-1 presents NYIRABIRORI Primary School AC Loads appliances with their Operating Voltage, Current Consumption, the rated power, and its working frequency.

Table 3. 1:AC load Appliances of NYIRABIRORI Primary School

<i>Load Description</i>	<i>Quantities</i>	<i>Power (watt)</i>	<i>Voltage and Frequency (Hz)</i>	<i>Operating Current (A)</i>	<i>Total Power (kW)</i>	
Electric Lamp	40	60	220V/50 Hz	6A	2400	
Radio	1	80	220V/50 Hz	2A	80	
RED TV	1	250	220V/50 Hz	2A	250	
Printer	2	75	220V/50 Hz	2A	150	
Scanner	3	70	220V/50 Hz	2A	210	
Projector	3	90	220V/50 Hz	2A	270	
			220V/50 Hz	15A	Total Power	3.3kW

The total Power Consumption at NYIRABIRORI Primary School when considering if all AC appliances are connected to the system at the same time is **3.3 kW**, with total current consumption equivalent to **15A** at a system voltage of **220V** with Operating frequency of **50 Hz**

3.4. Mathematical Modelling

To achieve the specific objective of efficiency of the inverter based on inverter design, a mathematical model was designed. This mathematical Modal was based on the general specific proposed topology which have three parts: PV System, Boost Converter, Inverter but the inverter is a single phase based on the SIC-MOSFET. During the design, some formulas are needed for getting the final results.

In this project, Boost Converter is modeled before being used. The size of inductor and capacitor is determined in order to find exact value to meet the system need. The output voltage of boost converter need to meet inverter requirement based on SIC MOSFET, then the size of LC Filter is modeled to find the system parameters to meet the loads.

During mathematical modeling, some parameters are required for making equations for calculation. The relationship of parameters makes formulas to calculate system power losses, system efficiency and total harmonics distortion of the system.

Figure 3-1 illustrates the proposed designed solar power inverter components where The electricity is coming from PV Panels pass through booster converter to be regulated then after it continue through the SIC MOSFET Configuration in order to be converted from dc to ac signal but in this time, the SIC MOSFET switch, their driver is provided by pulse width modulation (PWM) with PID controller and LC filter to remove harmonics content and then the system be connected to the distribution network as loads.

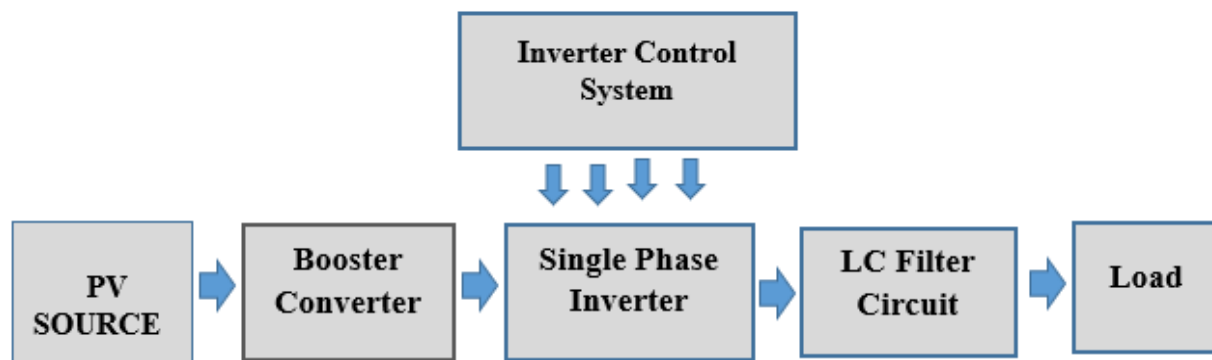


Figure 3. 2: Model of Inverter design in MATLAB/Simulink

3.5. Simulation Tools

This step designed to validate the mathematical Modal, the simulation used, where the MATLAB /Simulink version 2017 were used, making input data sets for simulations and running thousands of simulations concurrently are both possible with MATLAB. The data can then be analyzed and visualized in MATLAB. You may design and execute digital control for motors, power converters, and power inverter and battery systems with the aid of MATLAB /Simulink for Power Electronics Control Design. Additional in MATLAB /Simulink, the simulation center has to take the consideration the power electronics as nonlinear, problem therefore in the simulation same specific solvers were selected. During the simulation same collected data from the site visit and data from catalogue were exploited.

3.6. Project Flow Chart

This work has been carried out by using different techniques but the final results will be based on various performed calculation based on inverter step, for simulation of designed inverter MATLAB/Simulink Software involved based on calculated on each step.

Fig 3.3 describes the thesis flowchart.

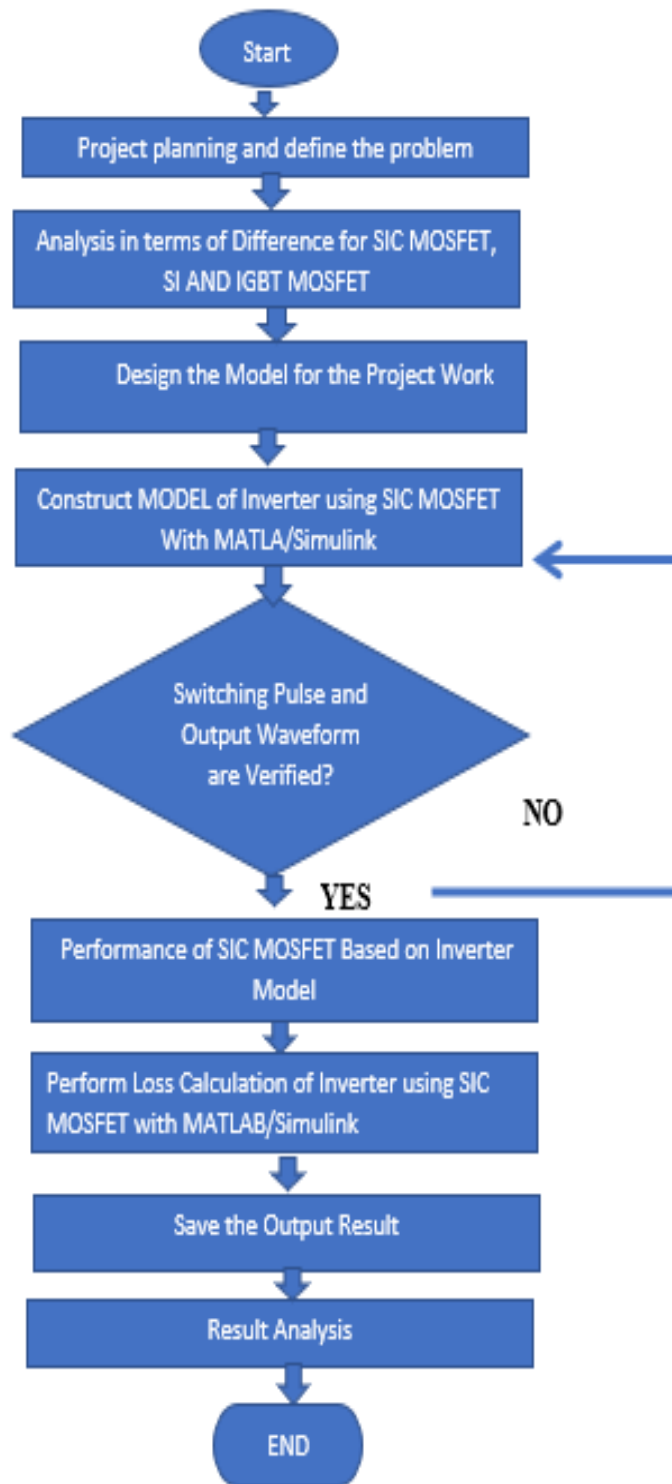


Figure 3. 3:Project Flowchart

CHAPTER 4: MODELLING OF SINGLE-PHASE INVERTER ON BASED ON SIC-MOSFET USE

4.1. Introduction

In this section the Inverter modal must be based on a Topology, that Topology can be a single phase or three-phase, however during this research focused on a single-phase solar power inverter topology configuration based on SIC MOSFET model, Boost Converter model based SIC MOSFET, LC Filter circuit for harmonics distortion reduction and resistive loads circuit.

4.2. Proposed Topologies

The proposed topologies used consists of the following parts: PV array, MPPT, Boost Converter, single-phase H-Bridge inverter power, LC Filter circuit and load resistance.

P-N- junction semiconductors are used in PV arrays to convert solar energy into electrical energy, the Boost Converter raises the voltage from the PV array's low input voltage to the high output voltage that enters the inverter, LC filter circuit reduction of harmonics content inverter and load circuit for power consumption. Fig 4-1 show the Block diagram research proposed topology.

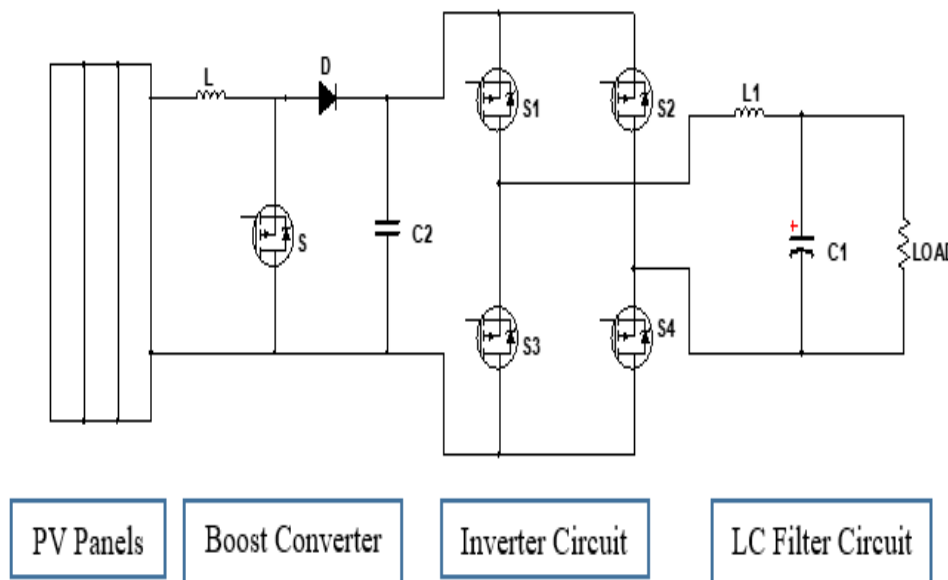


Figure 4. 1:Block Diagram Research Proposed Topology

4.5. Modelling of Boost Converter

The output power from the PV array is very low, a step-up converter is required before sending the PV output voltage to the inverter and MPPT controller for the DC-DC converter in order to extract the maximum power from the PV array. The design of booster converter is required to find the inductor value and capacitor value minimizing the ripples and rising the Power from PV Module.

The inductor's susceptibility to resisting changes in current delivered is the key to managing the boost converter. The boost converter functions as shown below. Inductor retains the energy till switch S is closed. The direction of current flow is clockwise. The inductor's left side is polarized as +ve. Current decreases while switch S is open. And the inductor fights against the shift in current entering it. Polarity will be reversed because of this. i.e. In this case, the left side of the inductor is negative. Inductor, diode, and high frequency switch are the boost converter's primary components (Here it is MOSFET). This sort of converter's duty cycle-based control method regulates voltage changes in accordance with requirements.

A diode (D1), a SIC-MOSFET switch (S1), an inductor (L1), and a capacitor (C1) make up a DC-DC converter (C3). When the switch is closed, current flows through the diode and is stored in the capacitor as direct current, resulting in V_{dc} , Figure 4-5 present the circuit analysis for Boost Converter system.

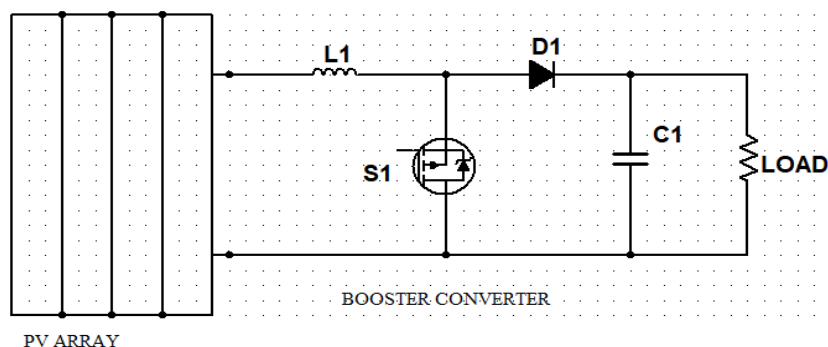


Figure 4. 2:Electrical Circuit of Boost Converter [32]

The electric circuit of Fig.4.5 depicts the boost converter model circuit. Equation (4,1) connects the output voltage and input voltage:

$$D=1- (V_{in}/V_o) \quad (4,1)$$

To ensure the boost converter operation, two main steps are respected such as: Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). The Continuous Conduction Mode (CCM), deals with the inductor storing the energy when S1 Open state. The discontinuous conduction mode is when the S1 is Closed circuit then energy stored in inductor discharged through the Capacitor and the

Capacitor discharged through the load. So here the minimum inductor must be selected. Fig 4.6 shows inductor during continuous conduction mode (CCM) and discontinuous conduction mode (DCM).

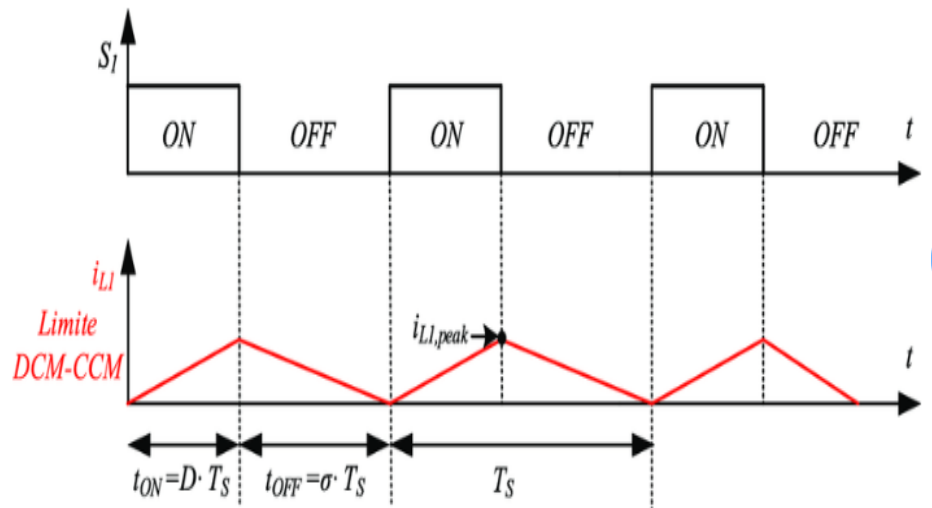


Figure 4. 3: inductor during continuous and discontinuous conduction mode (CCM, (DCM)

The design of Booster converter is required for increase the voltage level given to inverter and continues giving voltage. In case of DC-DC boost converter, Average output voltage is always higher than the input voltage.

To achieve to the goals some parameters have to be careful such as: selecting proper inductor depending on the level of desired output power to the system. Proper inductor is selected by using the equation (1,2) by considering the voltage ripple (ΔV) as 1% and the ripple current (ΔI) as 5% at maximum input voltage.

$$L(H) = \frac{V_{in}(V_{out}-V_{in})}{\Delta V * f_s * V_{out}} \quad (4,2)$$

Where, V_{in} : is the input voltage from PV array, V_{out} : Output voltage of booster converter, Δv : voltage ripple from the inductor.

The capacitor is also another very important parameters during Booster Converter design, when the chopper ON, the energy stored in inductor (L) charging the capacitor (C). when the Chopper OFF, the energy stored in Capacitor is discharged through the loads. As the Capacitor is very important the proper selection of the capacitor value add an advantages during booster converter design. The proper Capacitor selected is calculated from the variation in output voltage or ripple voltage, it is given from equation (4,3) by considering the voltage ripple (ΔV) as 1%.

$$C(H) = \frac{I_O(V_{out}-V_{in})}{\Delta V * f_s * V_{out}} \quad (4,3)$$

Where, I_O : Output current for booster converter, V_{in} : is the input voltage from PV array, V_{out} : Output voltage of booster converter, ΔI : Current ripple for the inductor and f_s : switching frequency for SIC-MOSFET.

4.6. Modelling of Inverter based on SIC-MOSFET

The single-phase power inverter for the S1, S2, S3, and S4 are the, consisted by four traditional switches that were characterized by high power losses that was the main challenges of NYIRABIRORI primary School inverter to be fail. Figure 4.2 present a single-phase power inverter circuit used based on SIC-MOSFET four switches S1, S2, S3, and S4 to be used on NYIRABIRORI primary School based on their superior Characteristics.

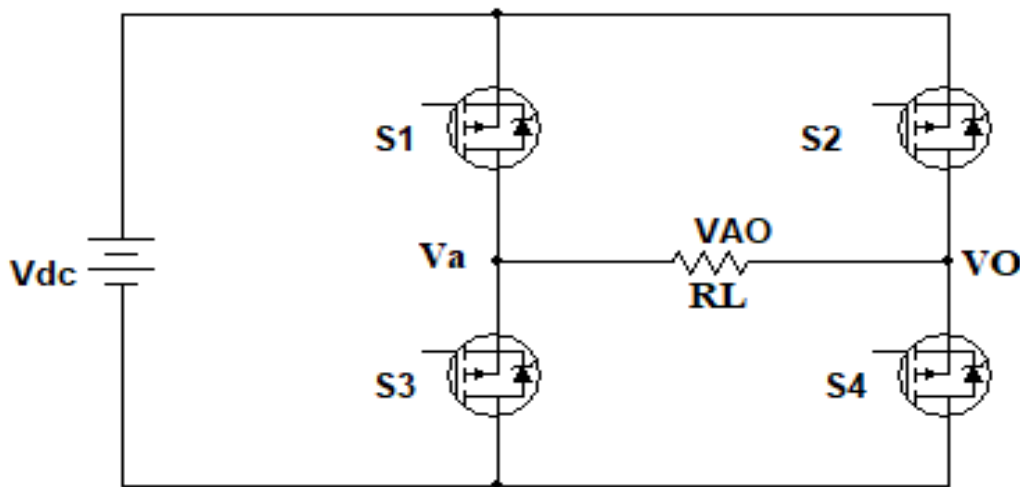


Figure 4. 4: Inverter based on SIC- MOSFET

Table 4.1 are display the switching state a single-phase power inverter circuit used based on SIC-MOSFET. S1, S2, S3, and S4 are the four switches. First, switches S1 and S4 are switched ON and remained ON for a half-period, while switches S2 and S3 are shut OFF, resulting in an output voltage across the load that is equal to V_{dc} . Second, the switches S1 and S4 are switched OFF when S2 and S3 are turned ON. And V_{dc} is the same as the output voltage.

Table 4. 1: Inverter switching state based on SIC MOSFET

S1	S2	S3	S4	V_a	V_o	V_{ao}
ON	OFF	OFF	ON	$V_{dc}/2$	$-V_{dc}/2$	$V_{dc}/2$
OFF	ON	ON	OFF	$-V_{dc}/2$	$V_{dc}/2$	$-V_{dc}/2$
ON	OFF	ON	OFF		$V_{dc}/2$	0
OFF	ON	OFF	ON	$-V_{dc}/2$	$-V_{dc}/2$	0

4.6.1. Power Losses in Inverter based on SIC-MOSFET

The power losses in SIC MOSFET are typically separated into two categories: static loss and dynamic loss. Conduction loss (On state power losses) and cut-off loss are included in the static loss, whereas turn-ON and turn OFF loss are included in the dynamic loss. The switching loss and conduction loss are the two most important losses that must be computed in the SIC MOSFET. However, because the leakage current of a SIC device is so small, the cut-off loss is disregarded. Conduction loss (P_c), turn-on loss ($P_{sw(on)}$), and turn-off loss ($P_{sw(off)}$) transition waveforms of SIC - MOSFET are shown in Figure 4.5.

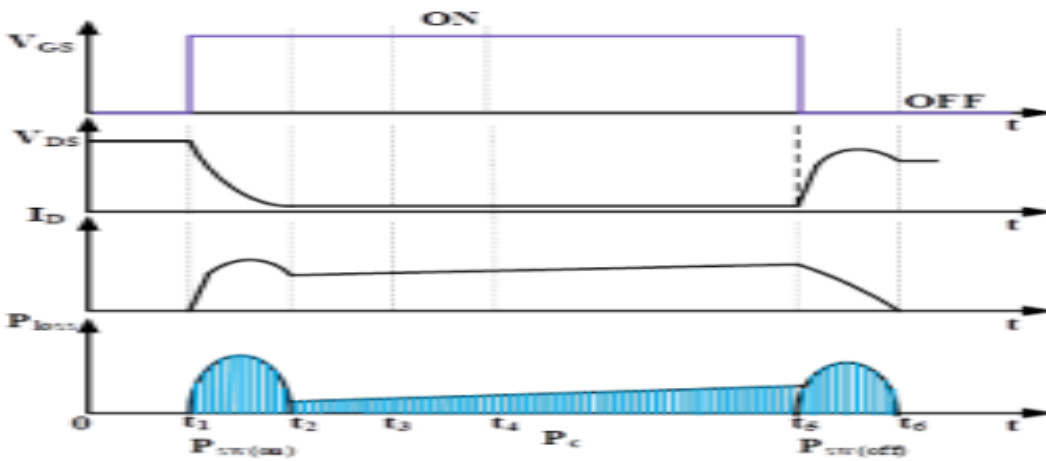


Figure 4. 5: Power Losses Transition Waveforms of SIC-MOSFET

4.6.2. Conduction Power Loss

When the switch is ON, the SIC MOSFET's resistance properties cause conduction loss. The MOSFET emits heat when the current passes through the dynamic on-resistance $R_{DS(on)}$. The conduction loss is also influenced by the physical size. This is due to the fact that increasing physical size will reduce $R_{DS(on)}$, which in turn will reduce loss.

4.6.3. Expression Mathematically Conduction Loss of the SIC MOSFET

The conduction losses in SIC MOSFET switches is find using equation (4,4) the resistance at the gate of SIC MOSFET is very lows that result the faster switching and less losses during the conduction

$$P_C(MOSFET) = \int_{t_2}^{t_1} I^2_{rms} * R_{DS(ON)} dt \quad (4,4)$$

Where, P_C : Power Conduction losses in SIC MOSFET during interval t_1 to t_2 , RMS; Roots Mean Square, $R_{DS(ON)}$: Resistance from drain to source.

The presence of frequency affects the system when SIC-MOSFET are used, this result an impact on conduction loss, frequency can be used to multiply conduction loss in equation (4.4) and equation become (4.5).

$$P_C(MOSFET) = f_{sw} \int_{t_2}^{t_1} I^2_{rms} * R_{DS(ON)} dt \quad (4,5)$$

Where, I_{rms} is the root mean square (RMS) value for the SIC MOSFET conduction current, and f_{sw} is the switching frequency.

For the side of their dynamic on resistance ($R_{on(Diode)}$), the conduction loss of a SIC power Schottky diode $P_C(diode)$ as it is very important parameter during SIC-MOSFET conduction.so the presence SIC power Schottky diode $P_C(diode)$ with dynamic on resistance ($R_{on(Diode)}$) make the power conduction in diode $P_C(Diode)$ as it is presented in equation (4,6)

$$P_C(Diode) = f_{sw} \int_{t_2}^{t_1} I^2_{rms} * R_{DS ON(DIODE)} dt \quad (4,6)$$

Where, I_{rms} is the root mean square (RMS) value for the SIC MOSFET conduction current, and f_{sw} is the switching frequency, ON-resistance $R_{DS(on)}$ and $R_{on(Diode)}$ are required to determine the conduction losses for SIC MOSFET and SIC Diode.

4.6.4. Switching Energies Loss on Sic MOSFET

The energy losses in Sic-Mosfet represented by the switching loss of SiC semiconductor devices, which is categorized as a dynamic loss. When the switch on a SiC device is turned on and off, switching loss occurs (switching transient). These losses are influenced by the switch's voltage, current, and switching frequency. Presents a novel series hybrid switching technique for reducing switching energy loss in SiC devices. Presents a novel series hybrid switching technique for reducing switching energy loss in SiC devices.

The Turn-on and Turn-off switching energies for the SiC MOSFET switching energies, the summarized equation (4,7) shows power switch for SiC MOSFET switching energies.

$$P_{SW(MOSFET)} = E_{ON(MOSFET)} + E_{OFF(MOSFET)} \quad (4,7)$$

Where, the terms Eoff (MOSFET) and Eon (MOSFET) refer to the turn-on and turn-off energies of SiC MOSFET, respectively.

The equations (4,8) and (4,9) show power switch for SiC MOSFET switching energy when the device is Turn-ON and OFF, respectively. The Turn-on and Turn-off switching energies for the SiC MOSFET switching energies are summarized as follows.

$$E_{ON(Mosfet)} = f_{sw} \int_{t_2}^{t_1} V_{DS(ON)} * I_{D(ON)} dt \quad (4,8)$$

$$E_{OFF(Mosfet)} = f_{sw} \int_{t_2}^{t_1} V_{DS(OFF)} * I_{D(OFF)} dt \quad (4,9)$$

The following is a representation of the mathematical formula used to determine the overall switching losses of the SiC MOSFET, equation (4,8) and (4,9) can then be modified to read the overall switching losses of the SiC MOSFET as shown in equation (4,10).

$$P_{SW(MOSFET)} = f_{sw} (\int_{t_1}^{t_2} V_{DS(ON)} * I_{D(ON)} dt + \int_{t_2}^{t_1} V_{DS(OFF)} * I_{D(OFF)} dt) \quad (4,10)$$

Where, SiC MOSFET ID (on) and ID (off) signify the currents flowing through the device during the turn-on and turn-off stages, respectively, VDS (ON) and VDS (OFF): denote the drain-source voltages applied to the device during the turn-on and turn-off stages, respectively.

Based previous above discussion on SiC MOSFET Power losses, the overall MOSFET s power loss model can be estimated in equation (4,11) and (4,12), respectively.

$$P_{Loss(MOSFET)} = P_c (MOSFET) + P_{SW(MOSFET)} \quad (4,11)$$

$$P_{LOSS}(MOSFET) = f_{sw} \int_{t_2}^{t_1} I^2_{rms} * R_{DS(ON)} dt + f_{sw} \int_{t_1}^{t_2} V_{DS(ON)} * I_{D(ON)} dt + \int_{t_5}^{t_6} V_{DS(OFF)} * I_{D(OFF)} dt \quad (4,12)$$

The switching energy of the SiC diodes used in a power converter are typically ignored when calculating power loss. This is due to the SiC diode switching energy being significantly lower than SiC MOSFET switching energies; as a result, it is disregarded in the following total loss model of a SiC power Schottky diode.

$$P_{Loss(Diode)} = P_c(Diode) + P_{SW(Diode)} \text{ where Or } P_{SW ON} = \frac{E_{on}}{t_{on}},$$

$$P_{Loss(Diode)} = f_{sw} \int_{t_2}^{t_5} I_{rms} * R_{ON(Diode)} dt \quad (4,13)$$

By considering the voltage drops across SiC MOSFETs, SiC Diodes, and the load current function during a conduction period as presented in equation (4,13) there is a voltage drop across drain to source terminals (V_{DS}) for SIC-MOSFET that result the current (I_D) passing though the loads as it is represent on equation (4,14), (4,15) and (4,16).

$$P_{cond. loss- SIC -MOSFET} = \frac{1}{t_{on}} \int_0^{t_{on}} I_D(t) * V_{DS}(t) * D dt \quad (4,14)$$

$$P_{cond. loss SIC -MOSFET} = \frac{1}{t_{on}} I_d * V_{DS} * D * t_{on} \quad (4,15)$$

$$P_{cond. loss SIC -MOSFET} = IDS * V_{DS}(sat) * D \quad (4,16)$$

Where, I_D : drain current passing though Sic Mosfet, V_{DS} :denote the drain-source voltages applied to the device during the turn-on and I_{DS} : denote the drain-source voltages applied to the device during the turn-ON.

4.6.4. Power Switching ON Losses in Diodes

The voltage drop across drain to source terminals (V_{DS}) for SIC-MOSFET that result the current (I_D) passing though the loads also the diodes has the varieties of power losses due to the Turn – off Switching Losses of Power Diode Requires which are in Three Things : Reverse Recovery Charge (Q_{rr}), Blocking Voltage (v_r) and Switching Frequency (f_{SW}) in diode. Equation (4,17) illustrate the Power losses (P-off) for SIC power diode

$$P_{SW-OFF} = Q_{rr} * v_r * f_{SW} \quad (4,17)$$

Where, Q_{rr} : Reverse Recovery Charge when diode is off, V_r : Blocking Voltage is applied high voltage, f_{sw} : Switching Frequency for diode. Based on The total inverter losses.

When considering the diode forward conduction characteristics, equation (4,18) Shows forward voltage when Sic Diode are used.

$$P_{\text{cond. loss diode}} = \frac{1}{t_{\text{on}}} \int_0^{t_{\text{on}}} I_F(t) * V_F(t) * D dt \quad (4,18)$$

Total Inverter Losses = 4*(Total power conduction losses (SIC MOSFET and diode) + Total Power Switching Losses (SIC MOSFET and diode))

4.7. Efficiency

Based on the various mathematical equation based on SIC-MOSFET, the total power loss input voltage as well as the output power for the system are used to determine the inverter's efficiency. The inverter's efficiency is determined using the following expression as in equation (4,19).

$$\text{Efficiency} = \frac{P_{OUT}}{P_{OUT} + \sum P_{LOSSES}} \quad (4,19)$$

Where, P_{OUT} : Power output of the system, $\sum P_{LOSSES}$: the total summation of power losses within the system

4.7. Modelling of LC Filter

This Design modal of an LC filter based on the single-phase inverter is required in order to find the minimum value of inductor and capacitor to reduce the high frequency distortion of output voltage and control the switching current. Fig 4-5 show LC Filter diagram.

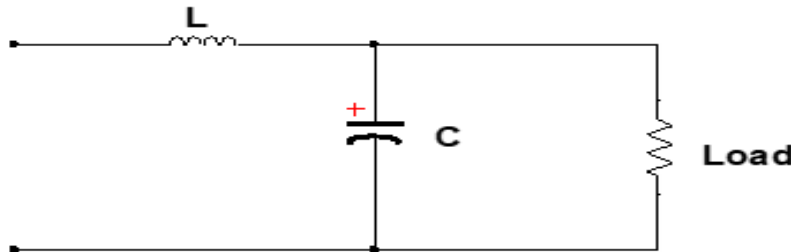


Figure 4.6:LC Filter Circuit

The inductor and capacitor are the very important parameters to considered while deal with filter. The proper selection of by considering the ripple current (ΔI) as 20% at maximum input voltage. The equation (4,20) and (4,20) represent proper selection of inductor by considering the ripple voltage

$$\text{Inductor } (L) = \frac{V_{dc}}{4 * \Delta I_{ppmax} * f_{sw}} \quad (4,20)$$

$$\Delta I_{ppmax} = 20\% * I_0 * \sqrt{2} \quad (4,21)$$

The proper Capacitor selected is calculated from the variation in inductor value, the capacitor selection it is given from equation (4,21) by considering the switching frequency.

$$\text{Capacitor } C = \left(\frac{10}{2 * \pi * f_{sw}}\right)^2 * \frac{1}{L} \quad (4,21)$$

Where, f_{sw} : switching frequency of the inverter, L: denotes as inductor

4.8. Voltage Harmonic Distortion of Inverter

Total harmonic distortion (THD) is a measure of harmonic pollution in the power system and it is observed that variations in both DC voltages and switching angles of inverter affect the THD of inverter output voltage. Equation (4,22) and (4,23) represent THD of inverter output for voltage and Current, respectively.

$$(THD_V = \frac{\sqrt{V^2 - V_1^2}}{V_1}) \quad (4,22)$$

$$(THD_I = \frac{\sqrt{I^2 - I_1^2}}{I_1}) \quad (4,23)$$

4.9. Modelling of Inverter Controller

The design of the inverter controller is to turn on and off the power electronic switches in the inverter specifically SIC MOSFET as used. The inductor current of the filter acts as an inner loop parameter while the output voltage is the outer loop parameter. Fig 4.7 shows Outer voltage and inner current feedback loop control.

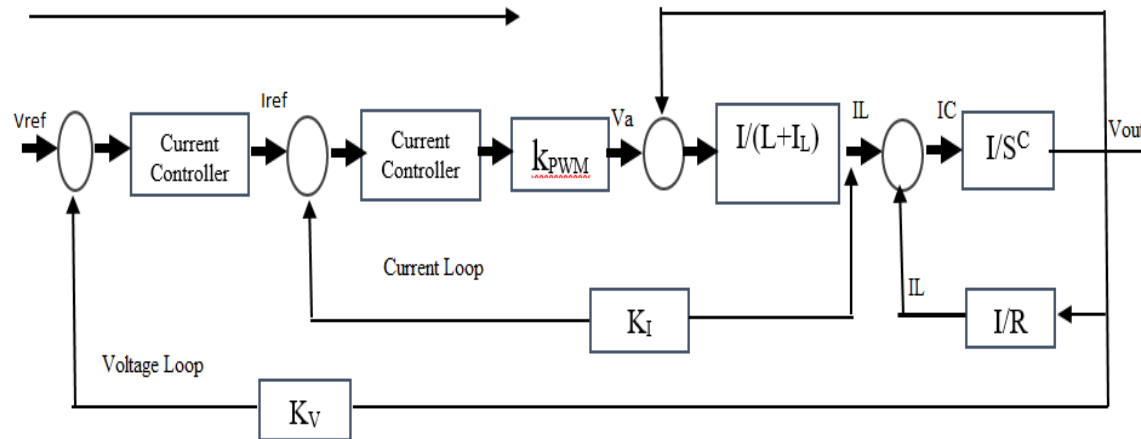


Figure 4. 7:Shows the Overall Current Mode Control Structure [26]

K_V and K_I , represent voltage and current sensors gain respectively where the variable K_{PWM} is the PWM gain, which is defined as: $\frac{V_{dc}}{V_{tri}}$

The controller for the loops can be either PI, Sliding mode, Fuzzy, Deadbeat etc. For this work, a conventional PI controller is used. I controllers are used as the voltage and current controllers.

The inverter controller is to turn on and off the power electronic switches in the inverter by using Voltage Control Loop and Current Control Loop. The equation (4,24) is representing PI controller transfer function.

$$K_p + \frac{K_i}{s} = K_p \frac{(s+k_i/K_p)}{s}, \text{ where } K_p = \frac{C}{T} \text{ and } K_i = \frac{L}{T} \quad (4,24)$$

CHAPTER 5: DESIGN AND SIMULATION OF SINGLE-PHASE INVERTER BASED ON SIC MOSFET

5.1. Introduction

This section focuses on design and simulation of single-phase solar power inverter for electrifying the primary school based on their power demand as discussed in above chapters and their load power consumption was discussed in tableau 2.1. To find a high efficiency solar power inverter, the information from Fig 4-2 have been used as well as the data sheet for SIC-MOSFET as it is in shown in figure 4.10.

The single-phase inverter circuit consist of 4 SIC MOSFET Switches with LC filter and load, PWM block, PID controller to generate driving signal. However, the inverter has some losses in MOSFET Switches and in diode. Therefore, this research presents calculations of those losses and Total Harmonic distortion (THD) as there is THD and small steady state error because of using PI controller. This research discusses the components used in designing and interpret the simulation results.

5.2. PV Module Technical Specifications

For this design, a Sunpower-SPR-445NJ-WHTD.PAN, Si-mono-crystalline PV module is used; the sub-array contains 675 parallel strings and 10 series-connected modules per string. Table 5.2 contains additional technical specifications for the selected modules. Sun Power SPR-445NJ WHTD.PAN technical specifications

Table 5. 1:Sun Power SPR-445NJ-WHTD.PAN Technical Specifications

Parameters	Abbreviations	Values	Units
Module open-circuit voltage	V_{sc}	250	Volts (V)
Temperature coefficient of V_{oc}	-	-0.29101	%/°C
MPP voltage	V_{mpp}	235	Volts (V)
Module short-circuits current	I_{sc}	6.21	Amps(A)
Temperature coefficient of I_{sc}	-	0.013301	%/°C
MPP current	I_{mpp}	5.8	Amps (A)
MPP Power	P_{mpp}	444.86	Watts(W)
Number of cells per module	128	-	-
Diode saturation current	I_0	1.35552e-11	Amps (A)
Light generated current	I_L	6.2167	Amps (A)
Number of sub-arrays	-	5	-

5.3. Design OF DC-DC Booster Converter

The design of DC-DC Booster converter is required for the purpose of stepping up the voltage and stabilizing the voltage supplied to the inverter due to the change of solar irradiance and ambient temperature. The parameters of the boost converter circuit are in Table 5.3.

Table 5.2:Boost Converter's Parameter

Parameter in S. I	Quantity
Input voltage, $V_{in}(V)$	250
Output Voltage, $V_o (V)$	400
Rate Power, $P_r (W)$	10e3
Switching Frequency (fs)	5e3
Resistive Load(Ω)	10
$L(H)= V_{in} (V_o-V_{in})/ (\Delta I*fs*V_o)$	125e-3
$C_o(F)=I_o (V_o-V_{in})/ (fs* \Delta V*V_o)$	400e-6
$D=1-(V_{in}/V_o)$	0.5

The ripple current and ripple voltage are set to 20% and 1%, respectively, to reduce voltage and current ripples at the boost converter's output. The boost converter's efficiency is assumed to be 98.5 percent.

5.5. Calculations of Inverter Power Losses

5.5.1. Power conduction loss on SiC MOSFET

The voltage drops across SiC MOSFETs, SiC Diodes, and the load current function during a conduction period as presented in equation (4,13) there is a voltage drop across drain to source terminals (V_{DS}) for SiC-MOSFET that result the current (I_D) passing though the loads as it is represent on equation (4,14), (4,15) and (4,16)

$P_{\text{cond. loss SiC-MOSFET}} = I_{DS} * V_{DS}(\text{sat}) * D$, By using the inverter that has a duty cycle of 0.5 and the data sheet of the specified SiC- MOSFET [6].

$$P_{\text{cond. loss SiC-MOSFET}} = I_{DS} * V_{DS}(\text{sat}) * D = 25 * 2 * 0.5 = 25w$$

5.5.2. Conduction Power Loss in Diode

The power switch for SiC MOSFET switching energy when the device is Turn-ON and OFF, respectively. The Turn-on and Turn-off switching energies for the SiC MOSFET switching energies were summarized. This is due to the SiC diode switching energy being significantly lower than SiC MOSFET switching

energies; as a result, it is disregarded in the following total loss model of a SiC power Schottky diode. by using the data sheet of the specified SIC- MOSFET [6],

$$P_{\text{cond. loss diode}} = \frac{1}{t_{\text{on}}} \int_0^{t_{\text{on}}} I_F(t) * V_F(t) * D dt$$

$P_{\text{cond. loss diode}} = I_F * V_F * D$; By using the inverter that has a duty cycle of 0.5 and the data sheet of the specified SIC- MOSFET [6]: $I_F = 25A$; $V_F = 3V$

$$P_{\text{cond. loss diode}} = 25 * 3 * 0.5 = 37.5w$$

Total power conduction loss = $P_{\text{cond. Loss SIC -MOSFET}} + P_{\text{cond. Loss - diode}} = 25W + 37.5W = 62.5W$

5.6. Switching Power Losses in SIC- MOSFET

5.6.1. Power Switching ON losses in the inverter based on SIC- MOSFET

The equations (4,8) and (4,9) show power switch for SiC MOSFET switching energy when the device is Turn-ON and OFF, respectively. The Turn-on and Turn-off switching energies for the SiC MOSFET switching energies were summarized and by using the data sheet of the specified SIC- MOSFET [6],

$$P_{\text{SW ON}} = \frac{E_{\text{on}}}{t_{\text{on}}},$$

$E_{\text{on}} = 4.3mj$; $E_{\text{off}} = 1.4mj$; Then the power switching on losses are:

$$Period(T) = \frac{1}{f} = \frac{1}{50} = 0.02s ; t_{\text{on}} = D * T = 0.5 * 0.02s = 0.01s$$

$$P_{\text{SW ON}} = \frac{4.3 * 10^{-3}}{0.01} = 0.43w ;$$

$$T_{\text{off}} = (1 - D) * T = (1 - 0.5) * 0.02 = 0.01s$$

$$P_{\text{SW Off}} = \frac{E_{\text{off}}}{t_{\text{off}}} = \frac{1.5mj}{0.01s} = 0.15w$$

5.6.2. Power Switching ON Losses in Diodes

The voltage drop across drain to source terminals (V_{DS}) for SIC-MOSFET that result the current (I_D) passing though the loads also the diodes has the varieties of power losses due to the Turn – off Switching Losses of Power Diode Requires which are in Three Things : Reverse Recover Charge (Q_{rr}), Blocking

Voltage (v_r) and Switching Frequency (f_{SW}) in diode. Equation (4,17) illustrate the Power losses (P-off) for SIC power diode, by using datasheet of given SIC MOSFET [5].

$$P_{SW-OFF} = Q_{rr} * v_r * f_{SW} ,$$

$$Q_{rr} = 4650nC \text{ at } T=125^{\circ}C; I_{rr} = 31A ; t_{rr} = 300ns \frac{dI}{dt} = 200 A/\mu s,$$

$$V_R = 400V ; f_{SW}=100kHz$$

$$P_{SW-OFF} = 4650 * 10^{-9}C * 400 * 100000HZ = 18.6W;$$

Turn on Losses are not only complicated but equally to small value.

Therefore,

Total Inverter Losses = 4*(Total power conduction losses (SIC MOSFET and diode) + Total Power Switching Losses (SIC MOSFET and diode))

$$\text{Total inverter power losses} = 4*(62.5W + 0.43W + 0.15W + 18.6) = 4*81.68W = 326.72W$$

5.7. Design of LC Filter

This Design modal of an LC filter based on the single-phase inverter is required in order to find the minimum value of inductor and capacitor required for filtering.

$$\text{Maximum Current Ripple } \Delta I_{ppmax} = 20\% * I_0 * \sqrt{2} = 0.2 * 15 * \sqrt{2} = 4.24A$$

$$\text{Inductor } L = \frac{V_{dc}}{4 * \Delta I_{ppmax} * f_{SW}} = \frac{400V}{4 * 4.24 * 100000} = 0.00236H = 2.36mH$$

$$\text{Capacitor } C = \left(\frac{10}{2 * \pi * f_{SW}} \right)^2 * \frac{1}{L} = \left(\frac{10}{2 * 3.14 * 100000} \right)^2 * \frac{1}{0.002357} = 0.000010757F = 10.757 * 10^{-6}F$$

5.8. Design of Inverter Controller

The design of the inverter controller is to turn on and off the power electronic switches in the inverter by using Voltage Control Loop and Current Control Loop as it is in equation (4,24)

5.8.1. Voltage Control Loop

$$\text{Control Time Constant } T = 200\mu s; \text{ Capacitor } C = 10.757\mu F; K_P = \frac{C}{T} = \frac{10.757\mu F}{200\mu s} = 0.053785$$

4.6.2. Current Control Loop

$$\text{Control Time Constant } T = 150\mu s; \text{ Inductor } L = 2.36mH ; K_P = \frac{L}{T} = \frac{0.00236H}{0.00015s} = 15.7$$

5.9. Efficiency of Inverter

Efficiency of inverter is the rate of output power divided by input power times 100%, the total power loss input voltage as well as the output power for the system are used to determine the inverter's efficiency as in equation (4,19).

$$P_{\text{Output}} = I_0 * V_0 = 220V * 15A = 3.3kW$$

Input power =output power + power losses

$$P_{\text{input}} = 3.3kW + 0.3267kW = 3.6267kW$$

$$\text{Efficiency} = \frac{3.3kW}{3.6267kW} * 100 = 98\%$$

6. Simulation Results

The Simulation of single solar phase inverter circuit using SILICON CARBIDE (1.2 kV SIC- MOSFET) NVHL080N120SC1 datasheet. The single-phase inverter circuit composed by Booster converter, inverter, LC filter and load, PWM block, PID controller to generate signal.

6.1. Boost Converter Simulation

To show the performance of the FSPV Module is simulation using

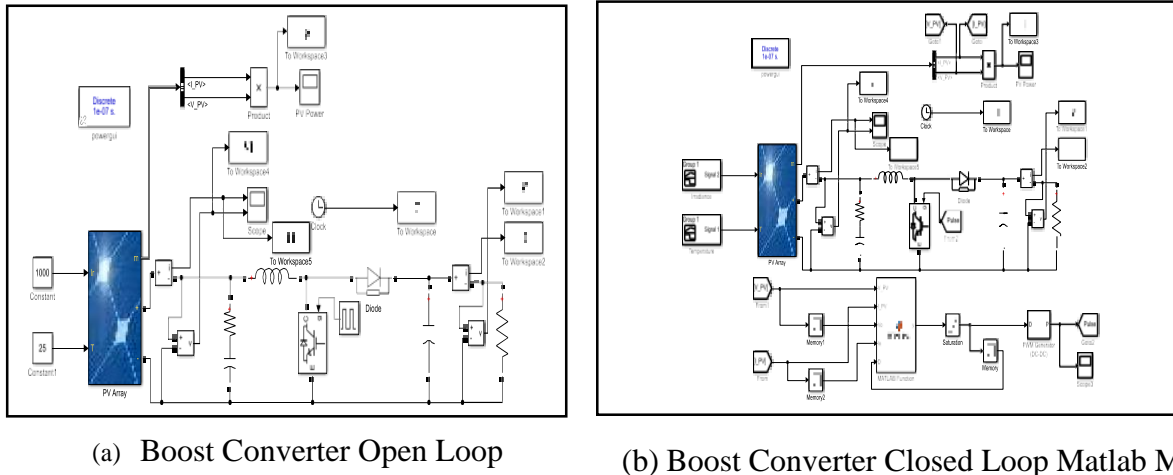
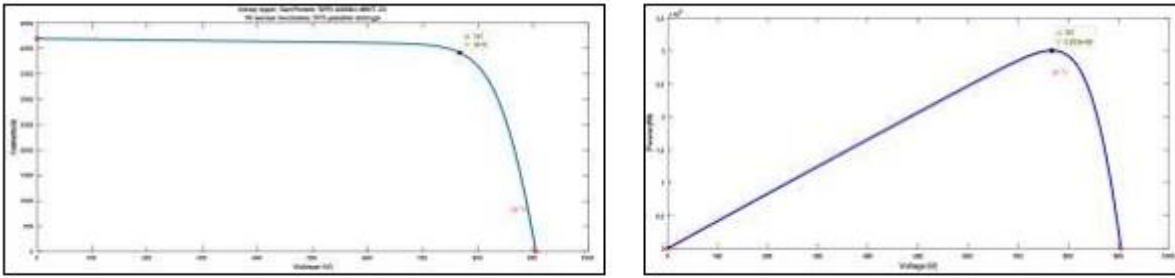


Figure 5. 1:Boost Converter open Loop and Closed Loop Matlab Models

The open loop boost converter simulation in Fig.5.1 (a) aims to depict the converter's steady state in the absence of feedback control. This provides a starting point for tuning control parameters for the boost converter with a closed loop system see Fig.5.1 (b). The MPPT control takes into account the PV array output voltage behavior shown in Fig.5.2. (a) and (b).

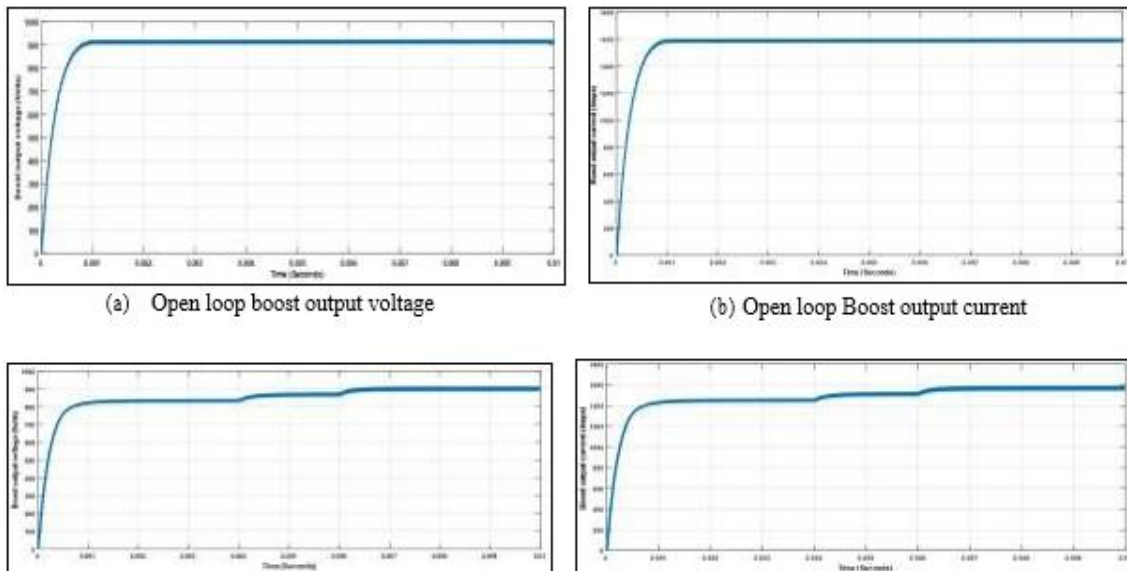
The maximum power can change depending on the irradiance value.



(a) Array Output Current vs Voltage

(b) Array Output Power vs Voltage

Figure 5. 2: Boost Open Loop and Closed Loop Simulation Results



(a) Open loop boost output voltage

(b) Open loop Boost output current

(c) Boost Closed Loop Output Voltage

(d) Boost Closed Loop Output Current

Figure 5. 3: Boost Open loop and closed loop simulation result.

The 10 series modules and 675 parallel strings of FSPV inputs the maximum peak voltage of 767 volts to the open loop boost converter as indicated in Fig.5.3 (a), and power of 10kW in (b). The open loop boost converter with 50% of duty cycle, its output voltage was found to be 400Volts, and the current of 18A as shown in Fig.5.3(a), and (b). While the closed loop boost converter voltage output voltage measured

is 400Volts as indicated in Fig.5.3 (d). MPPT control the voltage and current are maintained to the same values if any there is any change in FSPV operating parameters.

6.2. Inverter Simulation

The Simulation of single solar phase inverter circuit using SILICON CARBIDE (1.2 kV SIC-MOSFET) NVHL080N120SC1. The single-phase inverter circuit consist of 4 SIC MOSFET Switches with LC filter and load, PWM block, PID controller to generate signal.

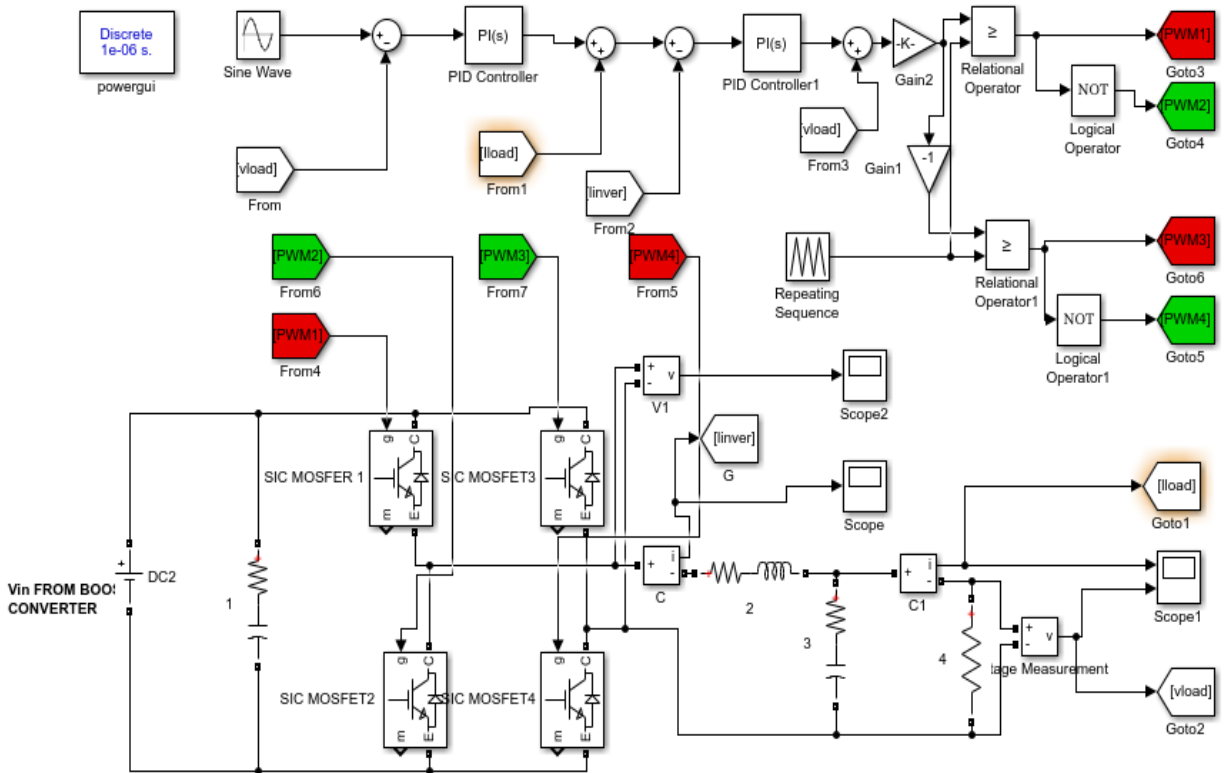


Figure 5.4:Shows Design of 4 SIC MOSFET Connected to LC Filter and Load Controlled by PID Controller

6.3. Output Voltage of Inverter before Adding LC Filter

This stage shows the various behaviors Output Voltage form of Inverter before Adding Filter and Voltage of Inverter Waveform shape before adding Filter. The signal found for the voltage side at the output of the inverter is sine wave in form of the square signal. This mean that it has too much harmonics, the same cases as the shape of the inverter output current as it is shown figure 5.5

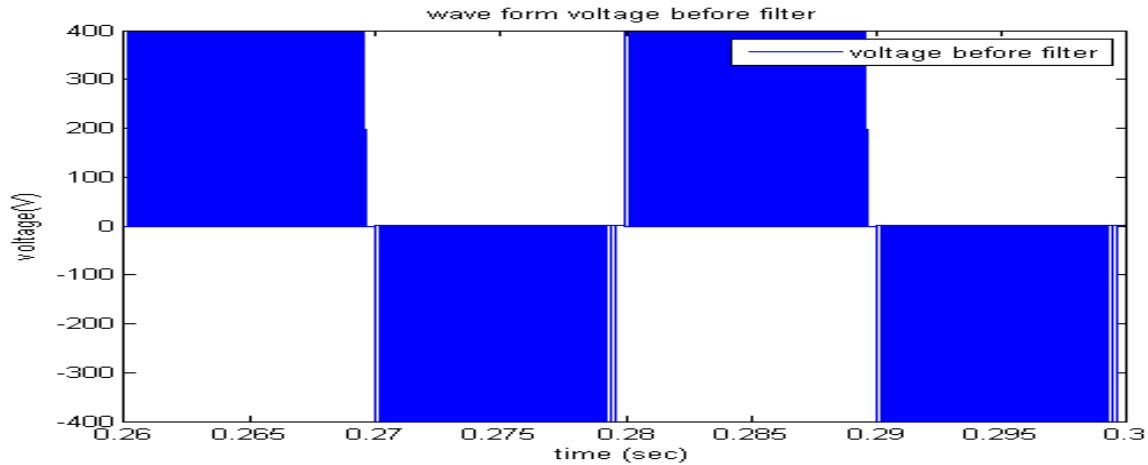


Figure 5. 5: Shape of Voltage and Current of Inverter Waveform before Adding Filter

Figure 2 shows the PWM square wave form of voltage of inverter with amplitude of voltage of 400V same as input DC voltage before adding LC filter. by visualizing well the signal found for the case of voltage wave form shape is sine wave in shape of the square signal. This means that the signal found content too much harmonics.

6.4. Output Current of Inverter Wave form before adding LC Filter

This stage also shows the various behaviors Output Current waveform of Inverter before Adding Filter and the value the current at the output of the Inverter and Waveform shape before adding Filter. This mean that it has too much harmonics, the same cases as the shape of the inverter output voltage waveform as it is shown figure 5.5

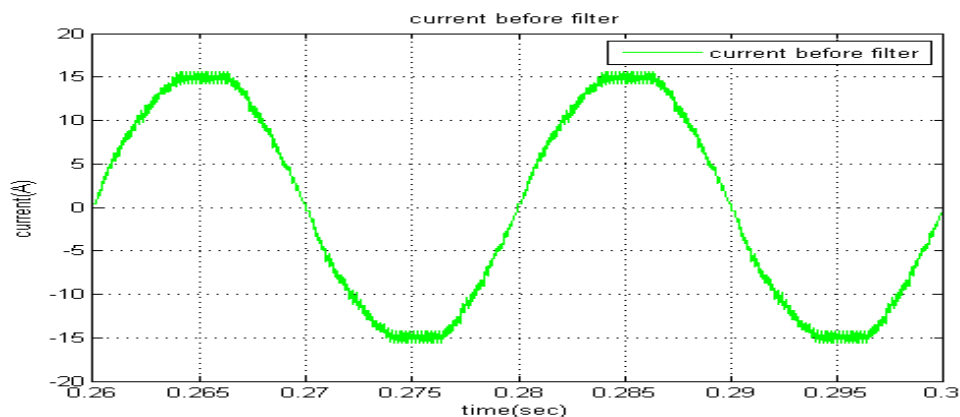


Figure 5. 6: Current of Inverter Wave Shape Before adding Filter

Figure 3 shows the current simulation PWM wave form that has high harmonic distortion because is measured before filtering, the amplitude of current coming around 15A as the same as the given. To reduce the ripple in induction current, inductance value must be increased. If the signal found is observed well, the shape of the output wave form for the Current is Sine wave shape with too much harmonics same as the shape of voltage waveform.

6.4. Output Wave form for Current and Voltage of Inverter after Adding LC Filter

This stage also shows the various behaviors Output for Voltage and Current waveform of Inverter after Adding LC Filter and the value the both voltage and current at the output of the Inverter where have been changed compared with the previous before adding filters as it is shown figure 5.6.

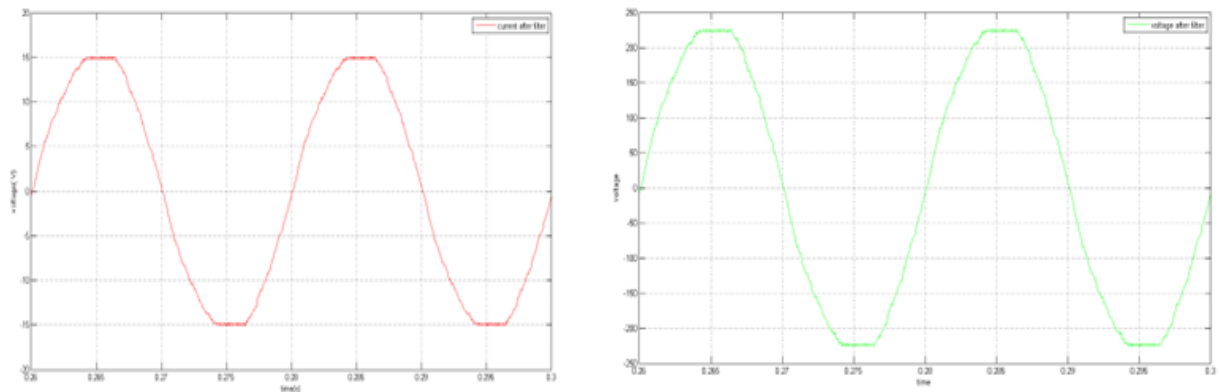


Figure 5. 7:Wave Shape of Output Current and Voltage of Inverter after Adding Filter.

Figure 5-7 shows the simulations results with current's amplitude and voltage's amplitude those are nearly 15A and 220V respectively which are the same as given value. When you look closer at voltage, you can see very small steady state error because of using PI controller in track sinusoidal quantities, to use it, always exist small error. 1st simulation is for current flowing in load and 2nd simulation is for voltage across load.

6.5. Signal when Modulation Index and Inductance Change Increasingly

This stage also shows PWM wave form the behaviors when the modulation index is changed, same as the when inductor value is changed, means the ripple (or harmonic distortion) in wave form of current and voltage is reduced by increasing inductance value as it is shown in the figure 5.8.

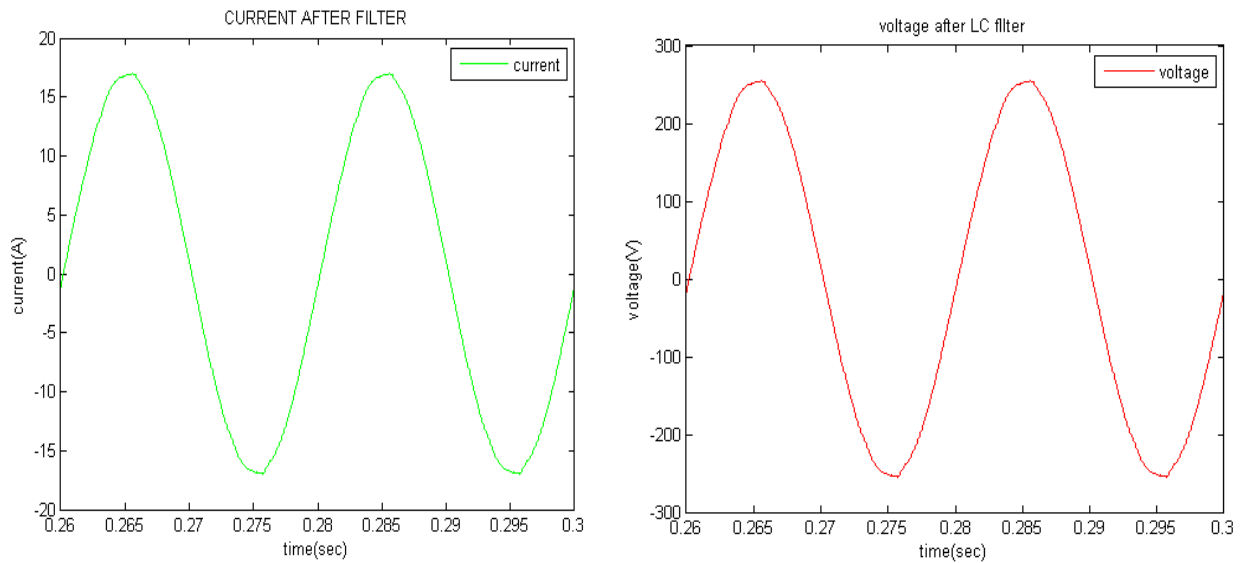


Figure 5. 8: I and V wave Form when Modulation index and Inductance are Changed

Figure 5-7 shows PWM wave form when the modulation index is changed, the amplitude of output current and voltage change. Above simulation shows amplitude of current and voltage are 17A and 250V respectively. Also, the ripple (or harmonic distortion) in wave form of current and voltage is reduced by increasing inductance value.

6.6. Calculation of Total Harmonic Distortion of Inverter

Total harmonic distortion (THD) is a measure of harmonic pollution in the power system for both THD for the voltage side and THD for the Voltage side. it is observed that variations in both DC voltages and switching angles of inverter affect the THD of inverter output voltage.

6.6.1. Voltage Total Harmonics Distortion

The total harmonics THD for voltage

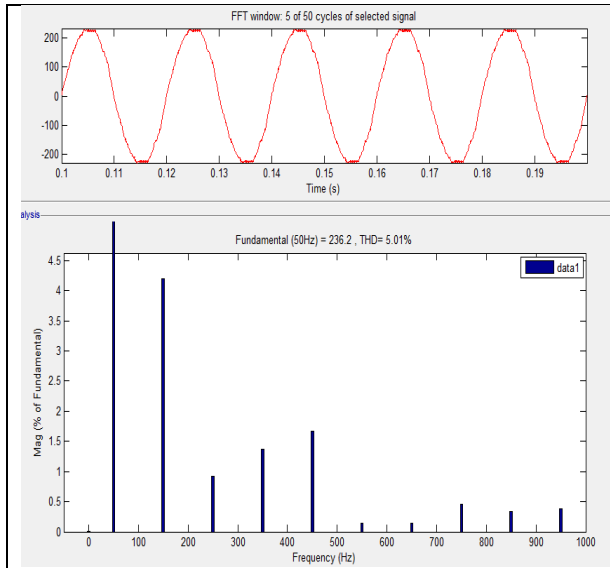


Fig 5.8 (a) Total Harmonics for Voltage

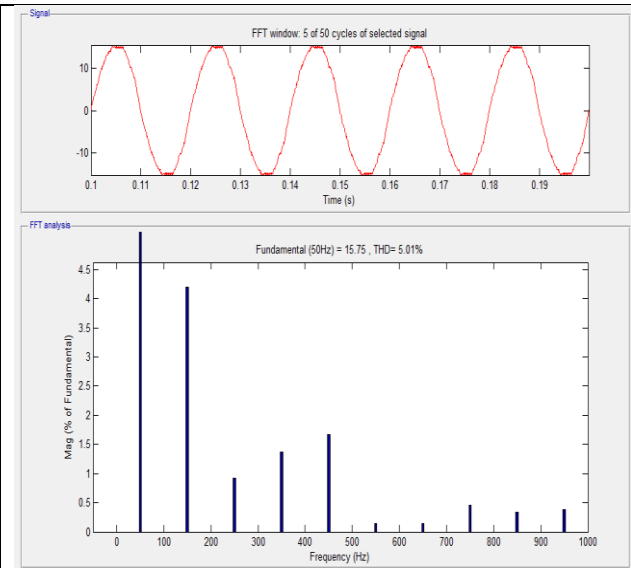


Fig 5.8 (b) Total Harmonics Distortion for Current

Figure 5.9: Total Harmonics Distortion for both the Voltage and Current.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This research presents a design of higher efficiency solar power inverter circuit based on SIC MOSFET. The single-phase inverter circuit consist of 4 SIC MOSFET with LC filter and load controlled by PI controller. The simulation shows that DC is changed into AC and the interpretation of simulations is in this research. When the modulation index change, the amplitude of output voltage and current change and to reduce ripple induction current, inductance value must be increased. Also in this research, THD is calculated that gives 5.01%, inverter power losses are calculated and the efficiency of inverter designed is 98% that shows the low power losses in inverter; there is no use of PLL because the inverter is single phase and to connect it to PLL, it gives complex diagram as it is not designed together with inverter. This works is limited only on MATLAB/SIMULINK simulation.

5.2. Contribution

Rwanda electrification plan is to be 100% for electric access for household, the power from the utility Grid is still low that is not able to supply whole country, by increasing the number of solar power plant with the new improved conversion technology based on SIC MOSFET, this will increase the number household with the access with electricity of the power plants due to the power losses reduction. As the designing inverter-based SI IGBT are the main challenges for the power losses, design of higher efficiency solar power inverter circuit based on SIC MOSFET is a good topology for increasing inverter efficiency and power losses reduction.

The design of high efficiency solar power inverter circuit based on SIC MOSFET is coming under start up projects

5.3. Future Work

The design of solar power inverter based on SIC MOSFET use has the multi-functionality for the power quality on the power system. However, the Power transfer from PV panels is passing directly to power converter and the to filter without MPPT controller for check the changes of solar irradiance and ambient temperature that should cause the failed of the system.

The following recommendations for future works are given at end of this work:

- ✓ The study on to maximize the power transfer from solar energy when MPPT is used.
- ✓ To reduce total harmonics distortion to 2.5% and power losses in inverter reduction to very low percentage
- ✓ To simulate the design based on hardware implementation for the solar power inverter project in the future.

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