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Presented by :
Amena khennoufa

Supervised by:
Dr. Madiha Maamir
Dr. Labiod Chouaib

Dr. CHERIF Hakima

Chairman

Dr. Madiha Maamir, Labiod Chouaib

Supervisor

Dr. KACEM Abdelmalek

Examiner

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Abstract

Power electronics systems play a fundamental role in modern energy conversion applications, particularly in industrial processes, renewable energy systems, and electric drive technologies. Among these systems, three-phase inverters are widely used due to their ability to convert direct current (DC) into alternating current (AC) with controllable voltage and frequency. The growing demand for efficient and reliable power conversion systems has increased the need for advanced control techniques capable of improving output waveform quality and overall system performance. In this context, this work focuses on the design, simulation, and experimental implementation of a three-phase inverter controlled using the Sinusoidal Pulse Width Modulation (SPWM) technique. The proposed system combines digital control and power electronic conversion to ensure stable operation and high-quality output waveforms. Simulation studies were carried out to validate the control strategy and evaluate system behavior under different operating conditions. Subsequently, a hardware prototype was developed and experimentally tested to verify the practical feasibility of the proposed approach. The obtained results demonstrate the effectiveness of the implemented control strategy in generating balanced three-phase output signals and achieving satisfactory performance. Furthermore, the study highlights the importance of appropriate control techniques in improving waveform quality, reducing harmonic distortion, and enhancing the reliability of power conversion systems. Keywords: Three-Phase Inverter, Power Electronics, SPWM, Digital Control, MATLAB/Simulink, Harmonic Distortion, Energy Conversion.

Key words: Three-Phase Inverter, Power Electronics, Sinusoidal Pulse Width Modulation (SPWM), Digital Control, MATLAB/Simulink, Total Harmonic Distortion (THD), Energy Conversion.

Résumé

Les systèmes d'électronique de puissance jouent un rôle essentiel dans les applications modernes de conversion d'énergie, notamment dans les domaines industriels, les systèmes d'énergie renouvelable et les entraînements électriques. Parmi ces systèmes, l'onduleur triphasé occupe une place importante puisqu'il permet la conversion du courant continu (DC) en courant alternatif (AC) avec une tension et une fréquence contrôlables selon les besoins de l'application. Ce travail porte sur l'étude, la conception, la simulation et la réalisation d'un onduleur triphasé utilisant la technique de modulation de largeur d'impulsion sinusoïdale (SPWM), reconnue pour sa capacité à améliorer la qualité des formes d'onde de sortie tout en réduisant les distorsions harmoniques. Une étude théorique du système a d'abord été réalisée, suivie d'une phase de simulation sous MATLAB/Simulink afin d'analyser le comportement du système et de valider la stratégie de commande proposée. Par la suite, un prototype expérimental a été développé et testé dans des conditions réelles de fonctionnement afin d'évaluer ses performances et de vérifier les résultats obtenus. Les résultats expérimentaux ont montré que le système proposé est capable de générer des signaux triphasés équilibrés et stables, tout en améliorant la qualité des formes d'onde et en garantissant un fonctionnement fiable et efficace. Mots-clés : Onduleur triphasé, Électronique de puissance, SPWM, Commande numérique, MATLAB/Simulink, Distorsion harmonique, Conversion d'éner

المخلص

تلعب أنظمة إلكترونيات القدرة دورًا أساسيًا في تطبيقات تحويل الطاقة الحديثة، خاصة في المجالات الصناعية وأنظمة الطاقة المتجددة وأنظمة قيادة المحركات الكهربائية. ويُعد العاكس ثلاثي الأطوار أحد أهم هذه الأنظمة، حيث يتيح تحويل الطاقة الكهربائية من التيار المستمر (DC) إلى التيار المتردد (AC) مع إمكانية التحكم في الجهد والتردد وفق متطلبات التطبيق. يهدف هذا العمل إلى دراسة وتصميم ومحاكاة وإنجاز عاكس ثلاثي الأطوار يعتمد على تقنية التضمين بعرض النبضة الجيبية (SPWM)، والتي تُعتبر من أكثر تقنيات التحكم استخدامًا لما توفره من جودة عالية لموجات الخرج وتقليل للتشوهات التوافقية. وقد تم إجراء دراسة نظرية للنظام، تلتها مرحلة المحاكاة باستعمال برنامج MATLAB/Simulink لتحليل سلوك النظام والتحقق من فعالية استراتيجية التحكم المقترحة. بعد ذلك، تم تنفيذ نموذج عملي واختباره في ظروف تشغيل حقيقية من أجل تقييم أداء النظام والتحقق من النتائج المحصل عليها. أظهرت النتائج أن النظام المقترح قادر على توليد إشارات خرج ثلاثية الأطوار متوازنة ومستقرة، مع تحسين جودة الموجة الكهربائية وضمان تشغيل موثوق وفعال. الكلمات المفتاحية: العاكس ثلاثي الأطوار، إلكترونيات القدرة، SPWM، التحكم الرقمي، MATLAB/Simulink، التشوه التوافقي، تحويل الطاقة.

الكلمات المفتاحية: العاكس ثلاثي الأطوار، إلكترونيات القدرة، التضمين بعرض النبضة الجيبية (SPWM)، التحكم الرقمي، MATLAB/Simulink، التشوه التوافقي الكلي (THD)، تحويل الطاقة

الإهداء

إلى من منحاني الحياة والأمل...

إلى من كانا سبباً في كل خطوة نجاح خطوتها...إلى والديّ العزيزين، أهدي هذا العمل المتواضع إليكما، تقديرًا لكل ما قدمتماه من حب وعطاء وتضحيات لا تُقَدَّر بثمن. لقد كنتما السند والدعم في كل مراحل حياتي، وكان دعاؤكما وتشجيعكما النور الذي أنار طريقي نحو هذا الإنجاز

.أسأل الله أن يحفظكما ويديم عليكما الصحة والعافية، وأن أكون دائماً مصدر فخر واعتزاز لكما

.إلى إخوتي وأخواتي الأعزاء،

أهديكم هذا العمل بكل حب وامتنان، شكرًا لمساندتكم الدائمة ووقوفكم إلى جانبي في مختلف مراحل حياتي. كنتم خير سند وعون، وكنتم دائماً مصدر قوة وأمل يدفعني إلى مواصلة الطريق مهما كانت الصعوبات. أدام الله محبتنا وجمعنا دائماً على الخير والنجاح، وجعل هذا الإنجاز فرحة نتقاسمها جميعاً .

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أتقدم إليكما بخالص الشكر والتقدير والامتنان على ما قدمتماه لي من توجيه علمي ومتابعة مستمرة ونصائح قيمة طوال فترة إعداد هذه المذكرة. لقد كان لدعمكما وتشجيعكما أثر كبير في تجاوز الصعوبات وإنجاز هذا العمل على أحسن وجه. جزاكم الله خير الجزاء، وبارك في علمكما وجهودكما، وجعل ما قدمتماه في ميزان حسناتكما .

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شكر خاص

أتقدم بخالص الشكر والتقدير والامتنان إلى أستاذيَّ المشرفين، الدكتورة مديحة معامير والدكتور الشيخ لبيض شعيب،

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كما أتوجه بشكر خاص إلى الأنسة مروة يومبيعي، تقديرًا لمساندتها القيمة ومساعدتها لي طوال مشوار إعداد هذه المذكرة. لقد كان لدعمها وتشجيعها أثر إيجابي كبير في مواصلة العمل وتجاوز مختلف التحديات، فجزاها الله عني خير الجزاء .

ولا يفوتني أن أتقدم بجزيل الشكر والعرفان إلى جميع أساتذتي الكرام الذين أشرفوا على تكويني العلمي طوال سنوات الدراسة الجامعية، والذين لم يدخروا جهدًا في نقل العلم والمعرفة وتوجيهنا نحو طريق النجاح. فكان لهم الفضل،

بعد الله سبحانه وتعالى، في بناء رصيدي العلمي الذي مكّني من الوصول إلى هذه المرحلة .
أسأل الله أن يجزي الجميع خير الجزاء، وأن يبارك في علمهم

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ولا يفوتني أن أتوجه بجزيل الشكر والعرفان إلى جميع **أساتذتي الكرام** الذين أشرفوا على تكويني العلمي طوال سنوات الدراسة الجامعية، والذين كان لهم الفضل، بعد الله سبحانه وتعالى،

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List of abbreviations

Abbreviation	Full Name
AC	Alternating Current
ADC	Analog-to-Digital Converter
AMC	Amplifier Module Current
DC	Direct Current
DSP	Digital Signal Processor
EMI	Electromagnetic Interference
HO	High Side Output
IGBT	Insulated Gate Bipolar Transistor
LO	Low Side Output
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
SPWM	Sinusoidal Pulse Width Modulation
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
VSI	Voltage Source Inverter
V/f	Voltage per Frequency Control
UPS	Uninterruptible Power Supply
dq	Direct and Quadrature Axes
IGBTs	Insulated Gate Bipolar Transistors
%	Percentage
Ω	Ohm
V	Volt
k H z	Kilohertz
η	Efficiency (as a decimal or percentage)

General Introduction

General Introduction:

Power electronic conversion plays a pivotal role in modern electrical engineering, where numerous practical systems demand reliable transformation between various forms of electrical energy. Among the key conversion stages stands the three-phase inverter, which converts direct current (**DC**) to alternating current (**AC**) tailored for industrial loads and motor drive applications. The inverter's output quality directly influences waveform distortion, system stability, efficiency, and precision in voltage and frequency control. This project seeks to design and implement an effective controller for a three-phase inverter employing an embedded strategy. The proposed system relies on Pulse Width Modulation (**PWM**) to produce precise switching instructions for the six electronic switches in the inverter bridge.

The control stage centers on the TMS320F28379D digital signal controller, while the power stage is driven via appropriate gate driver and isolation circuits such as the IR2104 and HCPL2530. Voltage and current sensors are integrated to monitor the inverter's electrical behavior and evaluate output quality. Modeling and simulation are conducted using MATLAB/Simulink, whereas practical validation depends on laboratory equipment like oscilloscopes and multimeters. The anticipated goals include achieving a quasi-sinusoidal three-phase output with minimized distortion, controllable voltage and frequency, and stable performance during operation.

In line with the academic standards of prior master's projects, this dissertation is structured into three main chapters.

Chapter 1 presents the theoretical foundations of three-phase inverters and power electronics.

Chapter 2 focuses on the modeling and simulation of PWM-controlled three-phase inverters using MATLAB/Simulink. It discusses PWM generation techniques, simulation procedures, and the analysis of the obtained waveforms and inverter performance.

Chapter 3 is dedicated to the design and practical implementation of the proposed three-phase inverter controller. It presents the TMS320F28379D-based control platform, hardware realization, experimental setup, testing procedures, and analysis of the obtained results.

Chapitre I :
Fundamentals of Three-
Phase Inverters and Power
Electronics

I.1. Introduction

Nowadays, power electronics has become an essential field in electrical engineering due to its wide use in energy conversion and control applications. The continuous development of semiconductor devices and digital control techniques has significantly improved the performance and efficiency of power electronic systems. These systems are found in many industrial applications such as motor drives, renewable energy systems, electric vehicles, and power supplies.

Among the different power converters, the three-phase inverter is one of the most important devices. Its main function is to convert a DC voltage source into a three-phase AC voltage with controllable amplitude and frequency. For this reason, three-phase inverters are widely used in variable-speed drives for AC motors, uninterruptible power supplies (UPS), and many industrial processes that require reliable and efficient energy conversion.

To obtain good performance from the inverter, appropriate control methods must be used. Pulse Width Modulation (PWM) is one of the most common techniques because it allows the generation of output voltages close to sinusoidal waveforms while reducing harmonic distortion. In addition, mathematical tools such as Clarke and Park (dq) transformations are frequently used to simplify the analysis and control of three-phase systems.

The purpose of this chapter is to present the basic concepts related to power electronics and three-phase inverters. It introduces the main power semiconductor devices, the operating principle of the three-phase inverter, and the most commonly used modulation techniques. These theoretical notions constitute the foundation for the design and implementation of the inverter control system presented in the following chapters.

I.2 Power electronic converters and their role

Power electronic converters are considered among the most essential components in modern electrical engineering, as they enable the efficient conversion of electrical energy between different forms using solid-state semiconductor devices such as MOSFETs, IGBTs, and thyristors. [1]

I.2.1 AC-DC converters

AC-DC converters, commonly known as rectifiers, are used to convert alternating current (AC) into direct current (DC) through semiconductor devices such as diodes or controlled switches [53]. These converters are widely used in applications requiring a DC power supply, including electronic equipment, battery chargers, and industrial power systems. They provide a stable and reliable DC voltage while ensuring efficient energy conversion [2] [25].

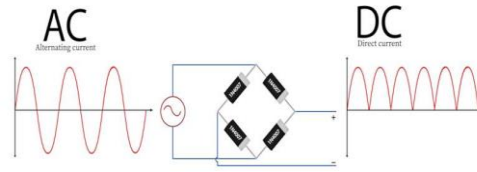


Figure I.1 : AC-DC converters

I.2.2 DC-DC converters

They are used to change the level of direct current voltage, either by stepping it down (Buck) or stepping it up (Boost), through the use of electronic switching techniques.

These converters are considered important in modern electronic systems,

as they allow the provision of appropriate voltage for various components, and they are also widely used in renewable energy systems such as photovoltaic systems [2]

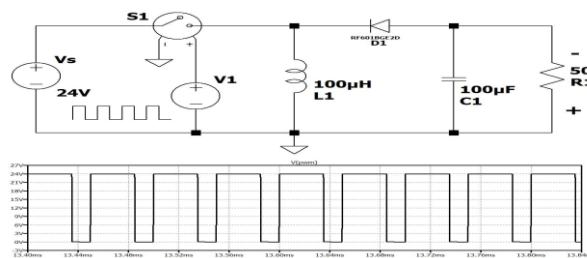


Figure I.2 : DC-DC converters

I.2.3 DC-AC converters

DC-AC converters, commonly known as inverters, convert direct current (DC) into alternating current (AC). They are widely used in industrial applications such as electric motor drives, uninterruptible power supplies (UPS), and photovoltaic energy systems [54]. To improve the quality of the output voltage waveform, inverters often employ advanced control techniques such as Pulse Width Modulation (PWM). These techniques help reduce harmonic distortion, improve efficiency, and provide better control of the output voltage and frequency [3].

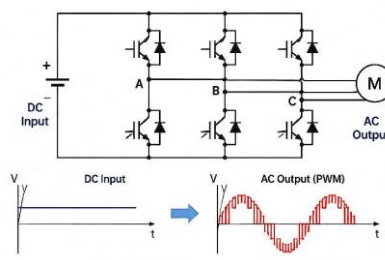


Figure I.3 : DC-AC converters

I.3 Single phase inverter

I.3.1 Definition of a Single-Phase Inverter

A single-phase inverter is a power electronic converter that converts direct current (DC) into single-phase alternating current (AC). It is commonly used in residential applications, uninterruptible power supplies (UPS), and low-power motor drive systems[41]. The inverter generates an AC voltage from a DC source by controlling semiconductor switches according to a specific switching sequence [1].

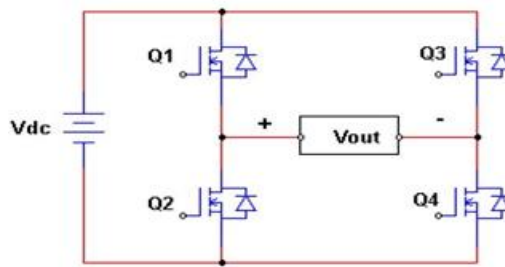


Figure 1.4: Single -Phase waveform

I.3.2 Operating Principle of a Single-Phase Inverter

The operating principle of a single-phase inverter is based on the periodic switching of power semiconductor devices to alternate the polarity of the voltage applied to the load [55]. By controlling the switching states, the inverter produces an alternating output voltage from a constant DC input source. Advanced control methods such as Pulse Width Modulation (PWM) are often used to improve the quality of the generated waveform and reduce harmonic distortion [2].

I.3.3 Output Waveform of a Single-Phase Inverter

The output waveform of a single-phase inverter may be square, quasi-square, or sinusoidal depending on the switching technique employed. In modern applications, PWM techniques are commonly used to generate an output waveform that closely approximates a sinusoidal signal, resulting in improved power quality and reduced harmonic content [2].

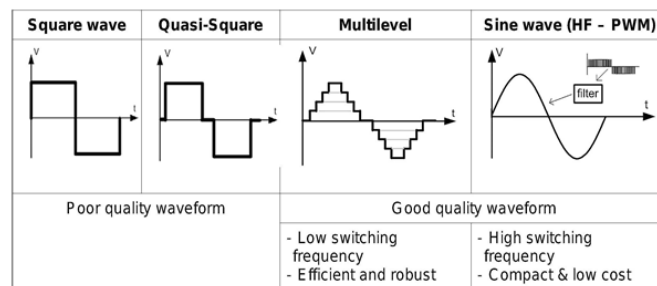


Figure 1.5: Output Voltage Waveforms of a Single-Phase Inverter Using Different Switching Techniques

I.4.Three-phase inverter

I.4.1.Definition of Three-phase inverter

A three-phase inverter is an electronic device that converts direct current (DC) into three-phase alternating current (AC) with controllable voltage and frequency.

It consists of a six-switch bridge (6 switches) arranged in three legs (bridge legs) [1]. This system relies on Pulse Width Modulation (PWM) to generate precise switching signals for the electronic switches, ensuring proper coordination and synchronization between the generated pulses.

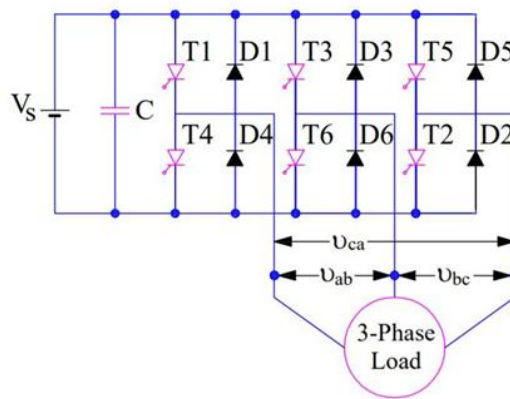


Figure 1.5: Three-phase inverter

I.4.2 Operating Principle of a Single-Phase Inverter

The operating principle of a three-phase inverter is based on generating three alternating voltage waveforms that are sinusoidal in nature and phase-shifted by 120° with respect to each other. These waveforms are produced by a controlled switching of semiconductor devices (such as MOSFETs or IGBTs) arranged in a bridge configuration[55]. By properly controlling the switching sequence, the inverter converts a DC input voltage into a balanced three-phase AC output suitable for driving AC loads [42]. In practical implementations, the output voltage is not a perfect sinusoid. Instead, pulse-width modulation (PWM) techniques are commonly used to synthesize quasi-sinusoidal waveforms. These PWM signals vary the duty cycle of the switching devices in order to approximate the desired sinusoidal reference signals. As a result, the harmonic content is significantly reduced, and the output waveform closely resembles an ideal sinusoidal signal, improving power quality and system efficiency. This principle is widely used in motor drive systems and grid-connected power converters [1], [2].

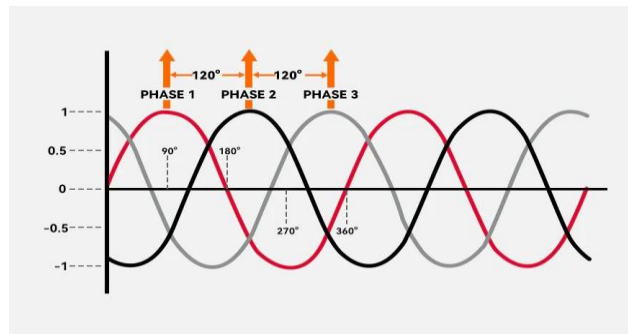


Figure I.6: Three-phase sinusoidal waveforms (120° phase shift)

I.4.3. Output Waveform of three-phase inverters

Three-phase converters generate three waveforms that are phase-shifted with respect to each other (typically in the range of 380–400 V), enabling the delivery of high and balanced power in industrial applications [4].

In other words, a balanced output is produced using three phases shifted by 120° , allowing for high power delivery. This configuration is widely used in electric motor drives, photovoltaic systems, and various industrial applications [43]

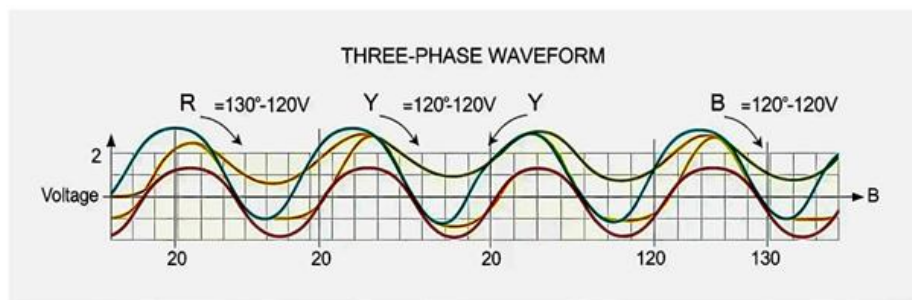


Figure I.7: Three-Phase waveform

I.5. Power semiconductor switches

Power semiconductor switches are controllable devices such as IGBTs, MOSFETs, and thyristors that rapidly switch between the ON and OFF states in converters, enabling the conversion of direct current (DC) into alternating current (AC) with minimal losses.[5]

These switches are based on semiconductor materials such as silicon and are characterized by their

ability to withstand high voltages and currents[56]. in addition to their high switching speed, which plays an important role in improving system performance and reducing losses.

I.5.1 MOSFET

Fast switching capability (in the megahertz range) and low on-state resistance make it ideal for high-frequency applications operating below 250–1200 V. [6]

These characteristics also contribute to reducing switching losses and significantly improving system efficiency, especially in modern electronic circuits that require fast response and precise control[32]..

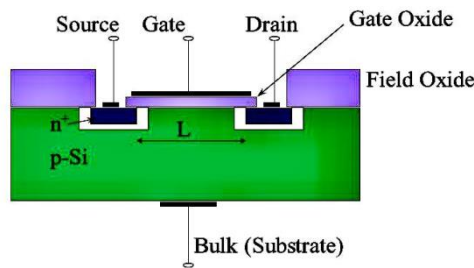


Figure I.7: A diagram illustrating the structure of MOSFETs

I.5.2 IGBT

Insulated Gate Bipolar Transistors (IGBTs) combine the gate control characteristics of MOSFETs with the conduction behavior of bipolar transistors. They are capable of withstanding very high voltages (up to 6.5 kV) and high currents (in the kiloampere range) at medium switching frequencies (1–20 kHz), making them ideal for three-phase power converters and motor drive applications due to their low conduction losses [7].

This cross-sectional view illustrates the structure of a P-N-P type IGBT, which integrates a MOSFET input stage with a bipolar output stage to achieve high power efficiency.

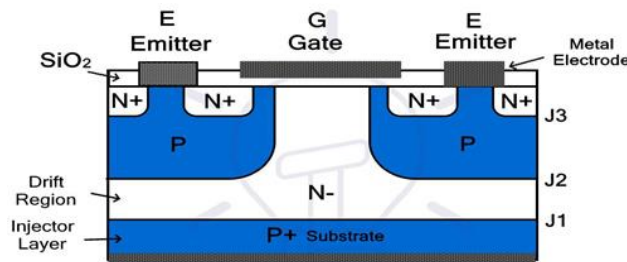


Figure I.8: A diagram illustrating the structure of

I.5.3 Switching characteristics

Power semiconductor switches exhibit a dynamic behavior during state transitions, which is characterized by key timing parameters that determine the losses and the maximum operating frequency. [8]

I.5.3.1 Main parameters:

Turn-on time(t_{on}) Total time from gate signal application to full conduction = delay time + rise time(t_r)

Turn-off time(t_{off}) Time from gate signal removal to blocking state = delay time + fall time(t_f)

Rise time (t_{on}) Voltage/current transition from 10-90% during turn-on

Fall time(t_{off}) Voltage/current transition from 90-10% during turn-off [8]

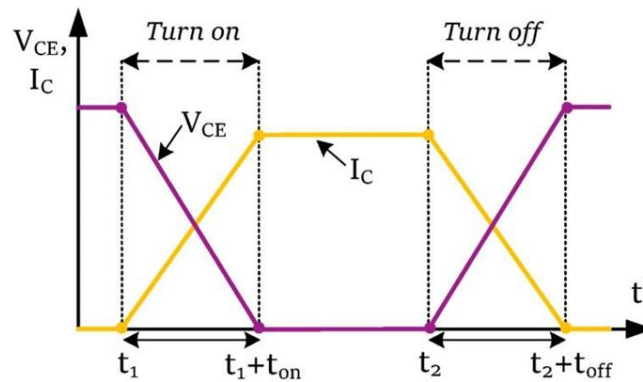


Figure I.9: Main parameters

I.6. Basic topology of a three-phase inverter

A standard three-phase inverter uses a full bridge with six switches connected to a DC source, producing a three-phase alternating current through PWM modulation with 120° phase shifts [9].

The inverter controls both the amplitude and the frequency of the output voltage, allowing more precise control of the speed and torque of electric motors. In addition, modulation techniques such as Pulse Width Modulation (PWM) are commonly used to obtain a waveform close to a sinusoidal signal and to reduce harmonic distortion [47].

Thanks to these characteristics, three-phase inverters play an important role in industrial applications, electric vehicles, and renewable energy systems such as photovoltaic power plants and wind energy systems[57].

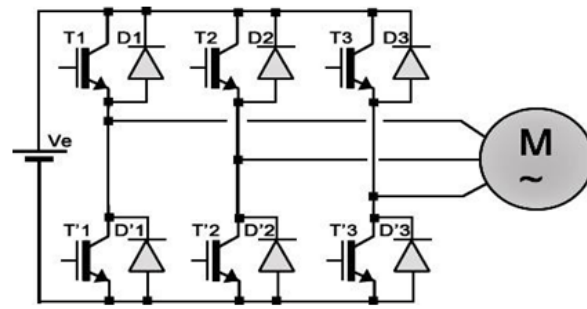


Figure I.10: Basic topology of a three-phase inverter

I.6.1 DC source

The DC source provides the energy required to operate the inverter. It is typically obtained from batteries, rectifiers, or photovoltaic systems.

A DC-link capacitor is commonly connected across the DC source to stabilize the voltage and reduce ripples, ensuring a stable DC input [48].

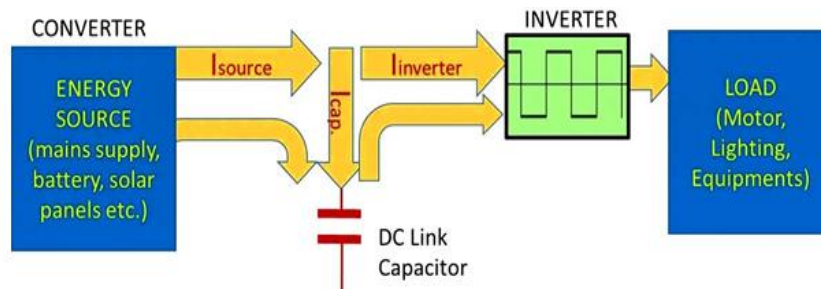


Figure I.11: DC source

I.6.2 Six-switch bridge

The inverter consists of six power semiconductor switches arranged in three legs. Each leg represents one phase (A, B, C) and contains two switches: an upper switch and a lower switch.

These switches operate in a complementary manner to prevent short circuits. By controlling their switching sequence, the inverter generates a three-phase alternating current.

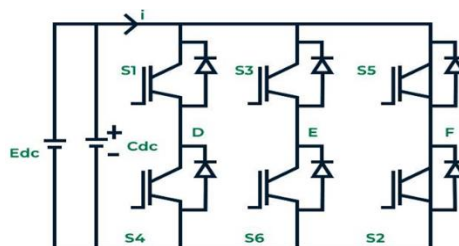


Figure I.12: Six-switch bridge

I.5.3 Output line and phase voltages

The three-phase inverter generates three output voltages: V_a , V_b , and V_c —these are phase voltages offset by 120° from each other.

Two voltage types:

Phase voltage: Measured from each phase to neutral point

Line voltage: Measured between two phases ($V_{ab} = V_a - V_b$)

These voltages power three-phase loads like electric motors. In 180° conduction mode, each leg produces $+V_{dc}/2$ or $-V_{dc}/2$ pole voltages, while PWM filtering creates quasi-sinusoidal line voltages [10]

No.	Aspect	Line Voltage	Phase Voltage
1	Definition	Voltage measured between two line conductors.	Voltage measured between a line conductor and neutral.
2	Symbol	V_{lin}	V_{ph}
3	Star Connection (Y)	$V_{lin} \times \sqrt{3} \times V_{ph}$	$V_{ph} = \frac{V_{lin}}{\sqrt{3}}$
4	Delta Connection (Δ)	Equal to phase voltage.	Equal to line voltage.
5	Common Value (Example)	400 V	230 V
6	Measurement	Between two lines.	Between line and neutral.
7	Explanation	Represents the voltage difference between any two phases	Represents the voltage of a single phase with respect to neutral.

Table I.1: Comparison Between Line Voltage and Phase Voltage

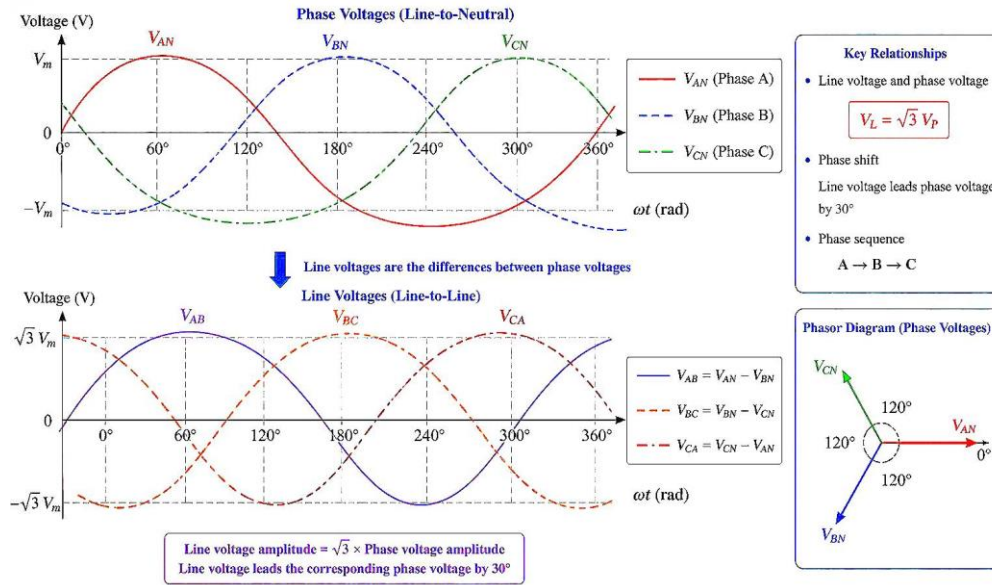


Figure I.13: Output line and phase voltages

I.7. Inverter Output Waveform Quality and Harmonic Analysis

I.7.1. Output waveform quality

The quality of the inverter output waveform is a key factor that affects the overall performance, efficiency, and reliability of electrical power systems. In ideal conditions, the inverter should generate a pure sinusoidal output; however, due to the switching nature of power electronic devices, the actual waveform

contains [44], harmonic components that deviate from the fundamental frequency. A high-quality inverter output is typically characterized by low Total Harmonic Distortion (THD), stable voltage magnitude, and minimal ripple content. Excessive harmonic distortion can lead to additional power losses, heating in electrical machines, acoustic noise, and electromagnetic interference (EMI). Therefore, advanced modulation techniques such as Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM) are widely used to improve waveform quality and reduce harmonic content. In addition, LC and LCL filters are commonly implemented at the inverter output to further smooth the waveform and achieve a near-sinusoidal AC signal suitable for grid and sensitive loads [45], [46]

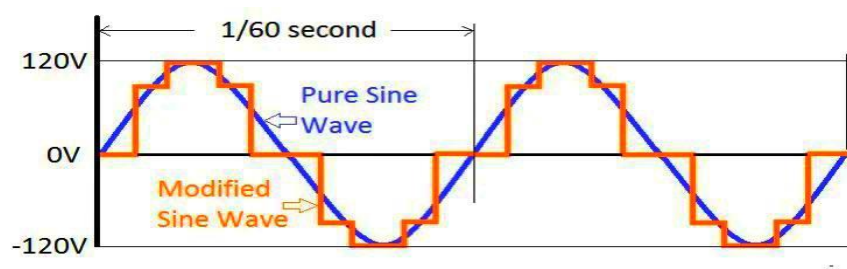


Figure I.14: Output waveform quality

I.7.2. Sinusoidal waveform concept

The output of an ideal inverter should match the pure sinusoidal waveform of the electrical grid (50/60 Hz). In practice, a stepped approximation is generated using PWM switching, which is then filtered to the fundamental frequency by the load inductance [9]

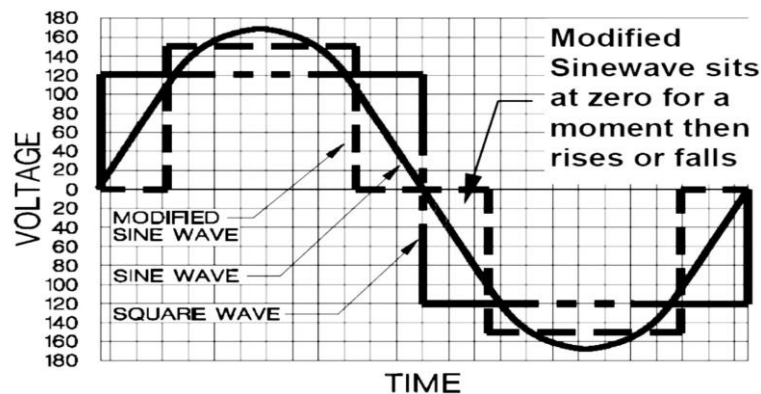


Figure I.15: Sinusoidal waveform concept

I.7.3 Harmonics

Harmonics are unwanted frequency components that appear alongside the fundamental frequency (50/60Hz) in the inverter waveform.

Root cause: The rapid switching of MOSFETs/IGBTs creates a stepped waveform instead of pure sine,

generating odd harmonics (3rd, 5th, 7th...).

Problems they cause:

Motors: torque pulsations and overheating

Transformers: saturation and buzzing

Sensitive equipment: interference and damage [11]

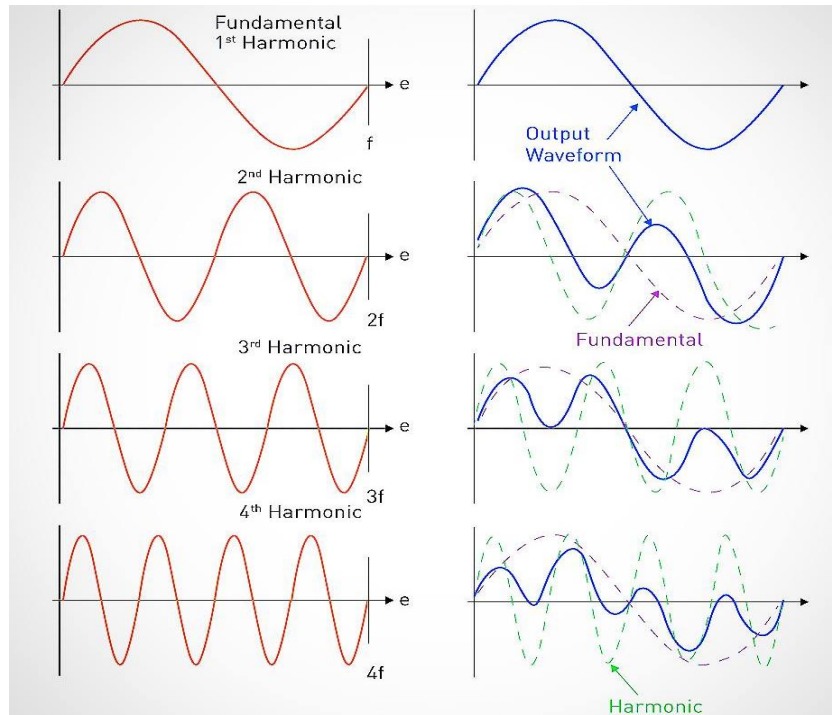


Figure I.16: Effect of Harmonics on a Sinusoidal Waveform

I.7.4.Total Harmonic Distortion (THD)

component:

$$\text{THD} = \sqrt{(V_3^2 + V_5^2 + V_7^2 + \dots)} / V_1 \times 100\%$$

Lower THD = cleaner sine wave closer to ideal grid power.

Typical targets:

Grid-tied inverters: <5% THD (IEEE-519 standard)

Standalone systems: < **THD** measures waveform distortion by calculating the ratio of all harmonic power to the fundamental 10% acceptable

Square wave: 48% THD (unusable for motors)

Pure sine: <3% excellent quality [12]

It reduces motor heating, transformer saturation, and network resonance, and improves the overall efficiency of the system.

The SVPWM technique achieves a total harmonic distortion (THD) of approximately 15% compared to 31% for the basic SPWM technique, while maximizing the utilization of the DC bus [12]

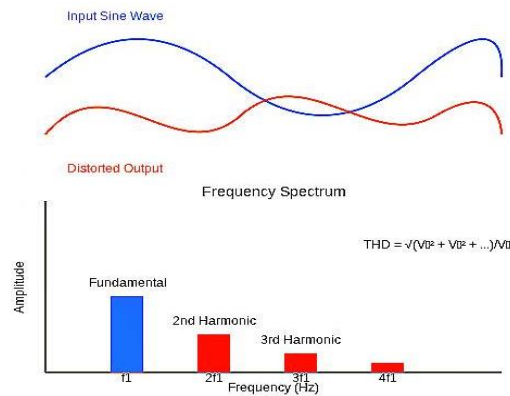


Figure I.17: Total Harmonic Distortion (THD)

I.7.5. Influence of switching strategy on waveform quality

The switching strategy significantly affects the quality of the inverter output waveform.

Techniques such as Pulse Width Modulation (PWM) are used to control the switching of power devices, with the aim of producing a waveform that approximates a sinusoidal signal.

An appropriate switching strategy reduces harmonic distortion, improves waveform quality, and enhances the overall performance of the system.

Benefits: Lower harmonics = less motor heating, better grid compliance, higher efficiency. SVPWM standard for industrial three-phase inverters due to superior performance.[9]

I.8. Industrial uses of inverter systems

Inverter systems are widely used in industrial applications due to their ability to convert DC power into AC power. They play a key role in improving power quality, facilitating operation, and enhancing overall system performance [49].

In addition, these systems enable precise control of voltage and frequency, allowing the operation of electrical loads, particularly electric motors, to be adapted according to application requirements. This contributes to reducing energy consumption and minimizing mechanical stress [50].

Furthermore, inverters support the integration of renewable energy sources such as photovoltaic systems and wind energy by converting the generated power into a form compatible with the electrical grid. They are also used in uninterruptible power supply (UPS) systems to ensure continuous power delivery in critical [52] situations.

Thanks to these characteristics, inverter systems have become essential components in modern industrial systems, contributing to improved operational quality, enhanced reliability, and optimal energy utilization.

I.8.1 Motor drives

Inverters are used to adjust the frequency and amplitude of the AC supply provided to motors, enabling precise control of motor speed and torque according to load requirements. This technique is applied in various industrial systems, such as conveyors, pumps, fans, and HVAC systems, where it helps reduce energy consumption and eliminate vibrations and mechanical shocks during startup. [12].



Figure I.18: Motor drives

I.8.2 Renewable energy systems

Inverters play a crucial role in renewable energy systems, particularly in photovoltaic farms and wind energy systems, where they convert the DC power generated by solar panels or generators into AC power compatible with the electrical grid or local loads. [13]

In addition, inverters perform Maximum Power Point Tracking (MPPT) to maximize energy extraction and improve overall system efficiency. They also contribute to voltage and frequency stabilization within the power grid. [14]



Figure I.19: Renewable energy systems

I.8.3 Uninterruptible power applications

Uninterruptible Power Supply (UPS) systems use inverters to provide backup power during electrical power outages, ensuring the continuous operation of sensitive loads and protecting equipment that may be damaged by sudden power interruptions[15].



Figure I.19: Uninterruptible power applications

I.9. Conclusion

Three-phase inverters are fundamental components in power electronics systems. They are based on a six-switch bridge topology using MOSFET or IGBT transistors, and are controlled by Pulse Width Modulation (PWM) techniques such as SPWM or SVPWM, enabling efficient DC–AC power conversion. Advanced modulation methods, particularly SVPWM, significantly reduce Total Harmonic Distortion (THD), often to values below 5%, while improving DC bus utilization. With the integration of renewable energy systems and the emergence of advanced semiconductor technologies such as Silicon Carbide (SiC) and Gallium Nitride (GaN), inverter systems are expected to achieve higher switching frequencies, improved output quality, and lower power losses, making them essential for future energy systems.

Chapter II:
Modeling and Simulation of
PWM-Controlled Three-Phase
Inverters

II.1 Introduction

Control of electrical inverters is a fundamental element in industrial computing and modern electromechanical systems, as it enables the conversion of direct current (DC) into alternating current (AC), where both frequency and amplitude can be efficiently adjusted. This allows the adaptation of the supplied voltage and frequency to variable loads such as electric motors and solar energy systems. The importance of this control also lies in its ability to respond to different operating requirements with quality and flexibility, especially in applications that require stable dynamic performance.

These advanced inverter control techniques aim to improve energy conversion efficiency, reduce losses, and minimize harmonic distortion, which may negatively affect the quality of the electrical signal and the performance of connected devices. They also seek to ensure system stability under various operating conditions, whether during sudden load changes or in complex operating environments. Therefore, inverter control systems are considered a key component in the design and development of modern electrical systems, due to their crucial role in enhancing reliability and improving overall system performance.

In this chapter, the control techniques employed in three-phase inverters are presented, with a particular focus on various PWM methods and their role in enhancing the quality of the output waveform.

II.2 Principle of Pulse Width Modulation (PWM)

PWM is based on comparing a reference signal (usually sinusoidal) with a carrier signal (usually triangular). When the reference signal is greater than the carrier signal, the electronic switch is turned ON; otherwise, it is turned OFF. In this way, the average output voltage can be controlled without changing the main supply voltage.

PWM signals are characterized by their high capability for precise voltage and frequency control, making them highly suitable for electric motor control applications [18].

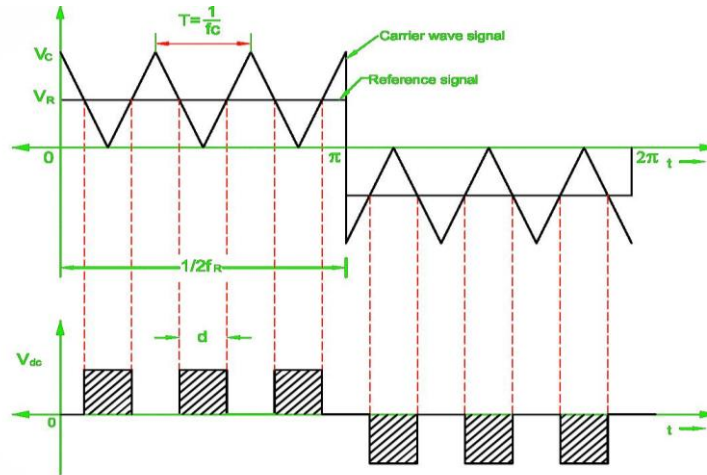


Figure II 1: Principle of Pulse Width Modulation (PWM)

II.3 Types of PWM used in inverter control

Pulse Width Modulation (PWM) techniques are considered fundamental methods that enable precise and efficient control of voltage and current by adjusting the width of pulses according to a defined reference signal[16][17].. These techniques play an important role in improving inverter performance, reducing harmonic distortions, and enhancing the quality of power conversion. Accordingly, several types of PWM techniques exist, differing in their generation principle, comparison method, and performance level. This section presents the main PWM types and analyzes their characteristics before discussing them in detail in the following subsections [19].

II.3.1 Basic PWM

This is the simplest method, which is based on fixed-frequency pulses while only varying the pulse width. It is commonly used in simple applications; however, it produces relatively high harmonic distortion [20].

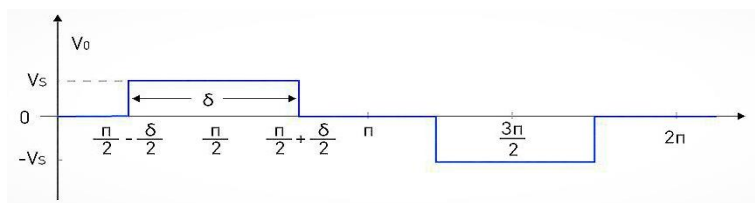


Figure II. 2: Basic PWM

II.3.2 Space Vector Pulse Width Modulation PWM (SPWM)

In Sinusoidal Pulse Width Modulation (SPWM), the pulse width is not constant; instead, it varies according to

a sinusoidal reference waveform. This variation is achieved by comparing a low-frequency sinusoidal signal with a high-frequency triangular carrier wave, which generates pulses whose duty cycle follows the shape of the sine wave. This technique significantly reduces harmonic content in the output voltage, making it suitable for AC loads and three-phase inverter systems.

The control method is based on two main signals: a sinusoidal reference waveform with defined amplitude and fundamental frequency, and a triangular carrier waveform with constant amplitude and high switching frequency. The intersection between these two signals determines the switching states of the inverter. In some applications, a DC offset can be added to improve the modulation range and to avoid overmodulation conditions.

SPWM is widely used in power electronic converters due to its simplicity and effectiveness in producing quasi-sinusoidal output waveforms while reducing total harmonic distortion (THD)[22].

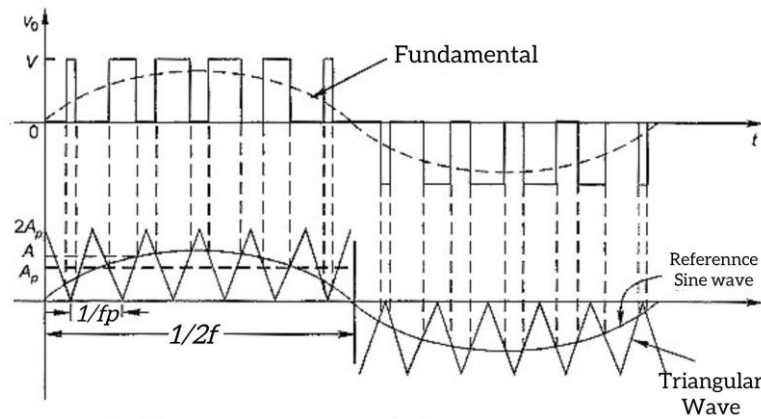


Figure II. 3: Comparison Between Sinusoidal Reference and Triangular Carrier Signals

II.3.3. Space Vector Pulse Width Modulation (SVPWM)

Space Vector Pulse Width Modulation (SVPWM) is an advanced modulation technique used in three-phase inverter systems to generate AC voltages from a DC source. It is based on representing the three-phase output voltages as a single rotating vector in a two-dimensional stationary reference frame (α - β plane), which simplifies inverter control and improves voltage synthesis.

In a two-level inverter, eight switching states are available: six active vectors and two zero vectors. These vectors form a hexagonal space vector diagram. During each switching period, the desired reference voltage is obtained by combining the nearest active vectors and zero vectors for specific time intervals.

SVPWM is widely used in motor drives and power conversion systems because it provides precise switching control [18] [19] and efficient voltage generation

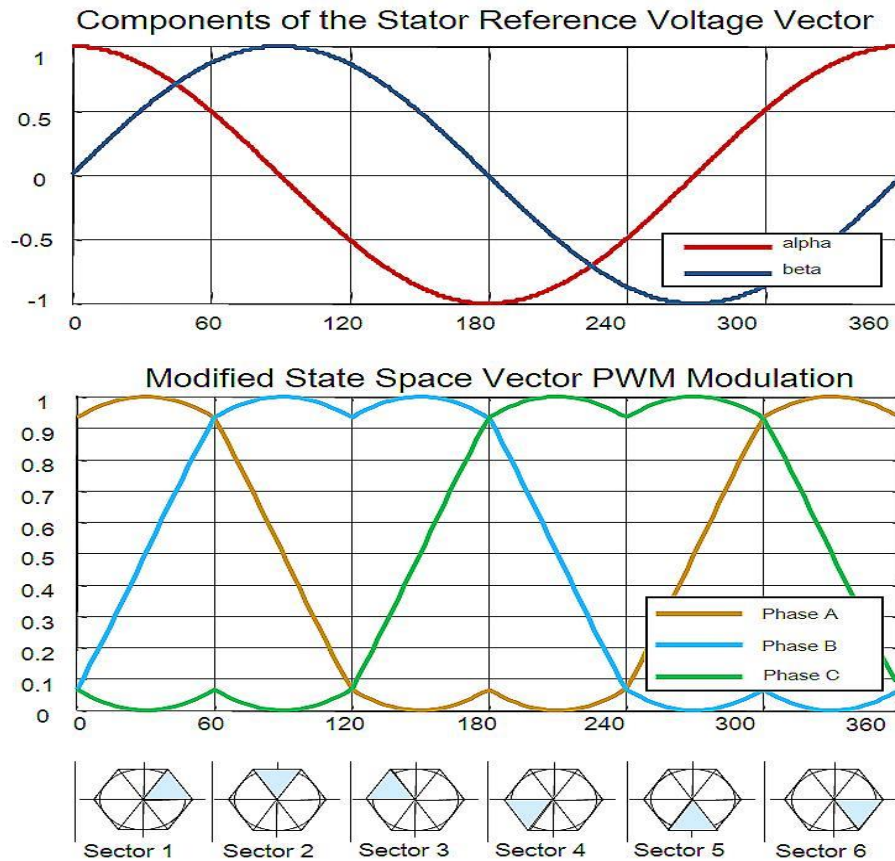


Figure II. 4: Space Vector Hexagon and Sector Identification in SVPWM

II.3.4 Comparison of switching strategies

Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM) are widely used switching techniques in three-phase inverter systems, both aimed at producing sinusoidal output voltages and currents while reducing harmonic distortion. In SPWM, the control strategy is based on comparing a sinusoidal reference signal with a high-frequency triangular carrier wave, where each phase is modulated independently. This results in a fundamental output voltage that is limited by the utilization of the DC-link voltage. This limitation occurs because the modulation is centered around a fixed midpoint of the DC bus voltage, as explained in standard power electronics theory[18].

In contrast, SVPWM treats the three-phase system as a unified vector space and generates switching states by synthesizing reference voltage vectors within the inverter switching hexagon. This approach provides better utilization of the DC-link voltage compared to SPWM by introducing an optimized switching sequence and a controlled common-mode voltage component, which increases the achievable output voltage level [22].

However, this common-mode voltage can introduce electromagnetic interference (EMI) issues, which require careful consideration in practical inverter design, as discussed in advanced drive systems literature[20].

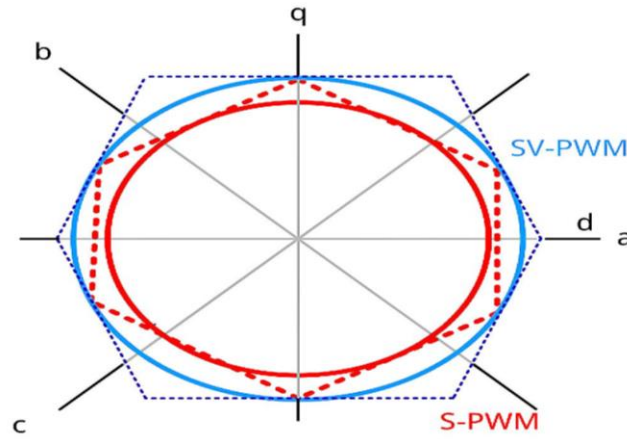


Figure II. 5: Comparison of switching strategies

II.4 System Modeling and Simulation

Three-phase inverter modeling is carried out using several techniques, including MATLAB/Simulink, in order to simulate the inverter's performance before real hardware implementation. This environment is considered one of the essential tools in the design of power electronics and control systems. It enables the construction of an accurate model of the three-phase power converter and its integration with control strategies such as PWM and V/f control, allowing the system behavior to be tested under different operating conditions without the need for a physical circuit.

Using Simulink power electronics tools, it is possible to analyze the output voltage and current waveforms of the inverter and study the effect of switching actions on signal quality. The platform also allows the measurement of Total Harmonic Distortion (THD), which is used to evaluate the quality of the output waveform and its closeness to an ideal sinusoidal signal—an important aspect in electric motor applications. In addition, the simulation provides the ability to study the dynamic response of the system under load or frequency variations, which helps in optimizing the control design before practical implementation and reduces both errors and development costs [21].

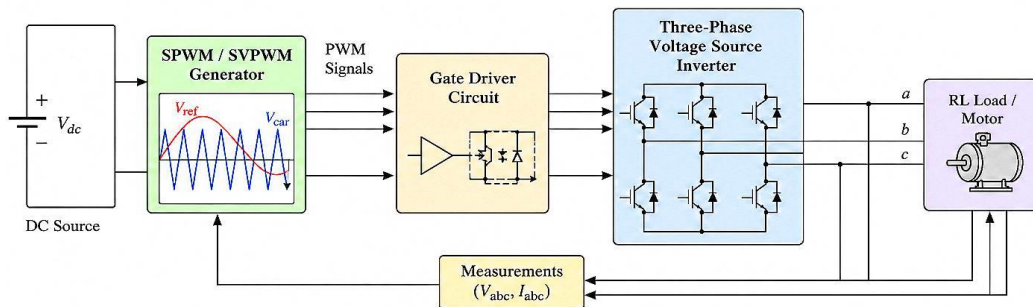


Figure II. 6: MATLAB/Simulink Model of the Proposed Three-Phase Inverter.

II.4.1. Modeling a three-phase inverter

The power supply circuit of a three-phase inverter is designed to convert direct current (DC) into alternating current (AC) in order to supply three-phase loads or feed the electrical grid. The inverter structure is typically composed of three legs, each containing two power switches controlled in a complementary manner to prevent a short circuit in the DC link[35][32].

In each inverter leg, there is an upper switch and a lower switch. When one switch is turned on, the other is turned off. This complementary switching strategy ensures safe inverter operation and prevents the direct short-circuit condition that could damage power electronic components[38] [40].

Figure II.1 illustrates the electrical diagram of a three-phase inverter connected to a three-phase load. The output voltages and currents depend directly on the switching states of the power devices

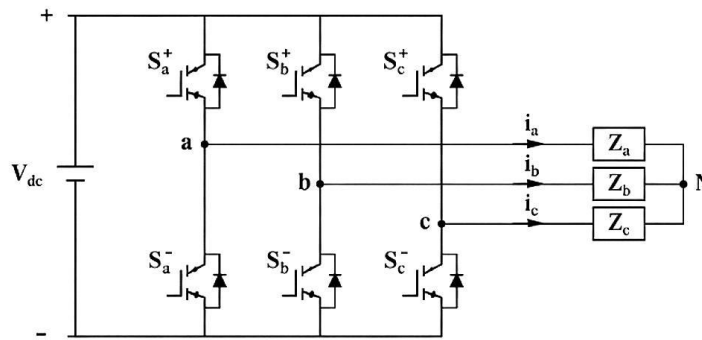


Figure II.7: Circuit d'un onduleur connecte au réseau.

$$S_a, S_b, S_c \in \{0,1\}$$

The three-phase inverter is powered by a DC voltage source.

The switching state of the power switches S_x , with

$x = 1, \dots, 6$, can be represented by the switching signals S_a , S_b , and S_c , defined as follows:

$$S_a = \begin{cases} 0 & \text{if the upper switch of leg A is closed} \\ 1 & \text{if the lower switch of leg A is closed} \end{cases} \quad (2.1)$$

$$S_b = \begin{cases} 0 & \text{if the upper switch of leg B is closed} \\ 1 & \text{if the lower switch of leg B is closed} \end{cases} \quad (2.2)$$

$$S_c = \begin{cases} 0 & \text{if the upper switch of leg C is closed} \\ 1 & \text{if the lower switch of leg C is closed} \end{cases} \quad (2.3)$$

The output voltages of the inverter legs with respect to the negative terminal of the DC source are expressed as:

$$V_{a0} = S_a V_{dc} \quad (2.4)$$

$$V_{b0} = S_b V_{dc} \quad (2.5)$$

$$V_{c0} = S_c V_{dc} \quad (2.6)$$

The neutral point voltage is given by:

$$V_{c0} = \frac{V_{a0} + V_{b0} + V_{c0}}{3} \quad (2.7)$$

The phase voltages are then defined as:

$$V_{an} = V_{a0} - V_{n0} \quad (2.8)$$

$$V_{bn} = V_{b0} - V_{n0} \quad (2.9)$$

$$V_{cn} = V_{c0} - V_{n0} \quad (2.10)$$

After substitution, the phase voltages become:

$$V_{an} = \frac{V_{dc}}{3} (2S_a - S_b - S_c) \quad (2.11)$$

$$V_{bn} = \frac{V_{dc}}{3} (2S_b - S_a - S_c) \quad (2.12)$$

$$V_{cn} = \frac{V_{dc}}{3} (2S_c - S_a - S_b) \quad (2.13)$$

To simplify the analysis and control of the inverter, the Clarke transformation is applied to convert the three-phase quantities (abc) into the stationary reference frame ($\alpha\beta$):

$$V_\alpha = \frac{2}{3} \left(V_{an} - \frac{1}{2} V_{bn} - \frac{1}{2} V_{cn} \right) \quad (2.14)$$

$$V_\beta = \frac{2}{3} \left(\frac{\sqrt{3}}{2} V_{bn} - V_{cn} \right) \quad (2.15)$$

The voltage vector in the ($\alpha\beta$) plane is expressed by:

$$\vec{V}_s = V_\alpha + jV_\beta \quad (2.16)$$

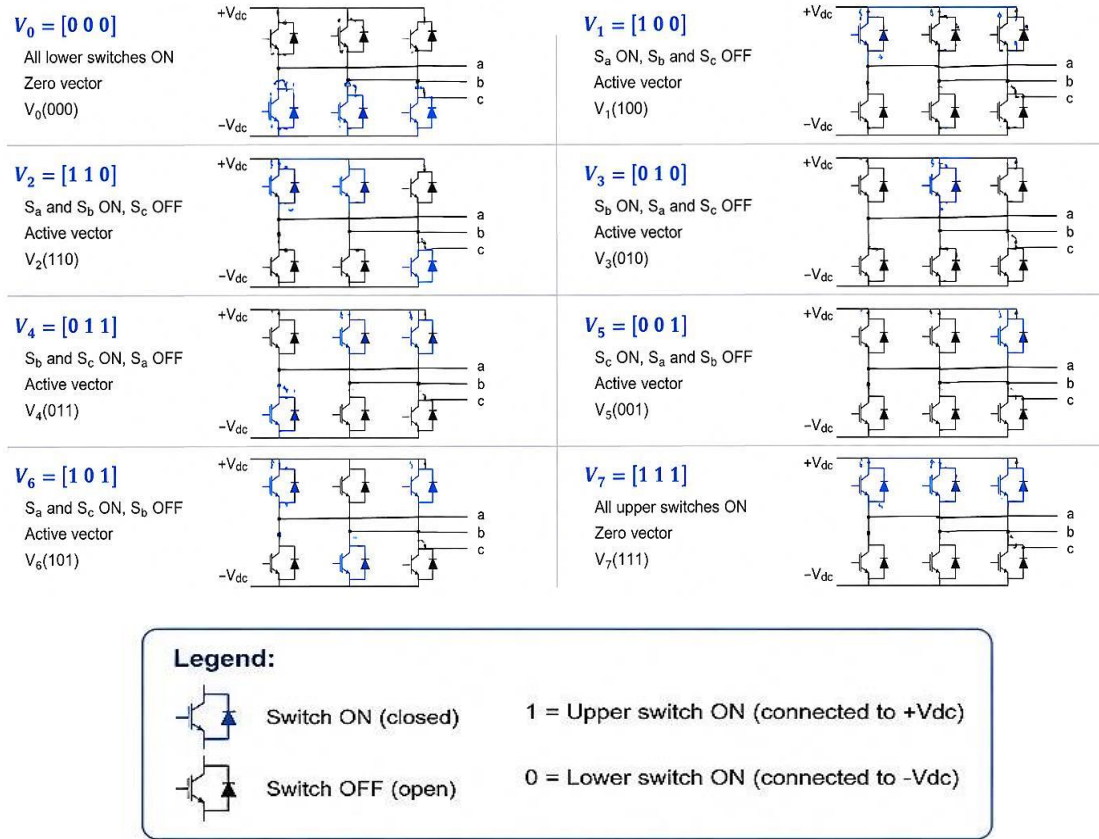


Figure II.8: Commutations possibles de l'onduleur triphasé à deux niveaux.

The preceding **figure** illustrates the different voltage vector states in a two-level, three-phase inverter, showing the possible switching modes of the electronic switches (S_a , S_b , S_c), which in turn determine the resulting simple and combined voltages at the inverter output. This analysis is based on studying all possible logic combinations of the switches, allowing for the identification of the effective and zero voltage vectors used in various control strategies such as PWM and SVPWM. The following table shows the relationship between the logic switching modes of each leg of the inverter and the corresponding values of the phase and line voltages, which forms the basis for understanding the inverter's behavior and improving the output signal quality

Vecteur tension	Fonctions logiques			Tensions simples			Tensions composees		
	S1	S2	S2	Vas	Vbs	Vcs	Usab	Usbc	Usca
V0	0	0	0	0	0	0	0	0	0
V5	0	0	1	$-E/3$	$-E/3$	$2.E/3$	0	$-E$	E
V3	0	1	0	$-E/3$	$2.E/3$	$-E/3$	$-E$	E	0
V4	0	1	1	$-2.E/3$	$E/3$	$E/3$	$-E$	0	E
V1	1	0	0	$2.E/3$	$-E/3$	$-E/3$	E	0	$-E$
V6	1	0	1	$E/3$	$-2.E/3$	$E/3$	E	$-E$	0
V2	1	1	0	$E/3$	$E/3$	$-2.E/3$	0	E	$-E$
V7	1	1	1	0	0	0	0	0	0

Table II.1: Switching States, Phase Voltages, and Line-to-Line Voltages of the Three-Phase Inverter

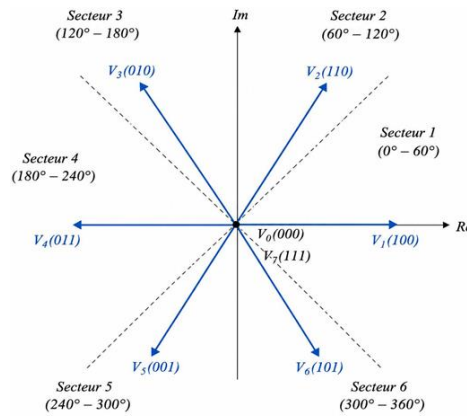


Figure II.9:Representation of Voltage Vectors in the Complex Plane

II.4.2 Modeling in MATLAB/Simulink

In this subsection, the complete system is modeled using MATLAB/Simulink, where each component of the inverter is represented to reflect its real behavior.

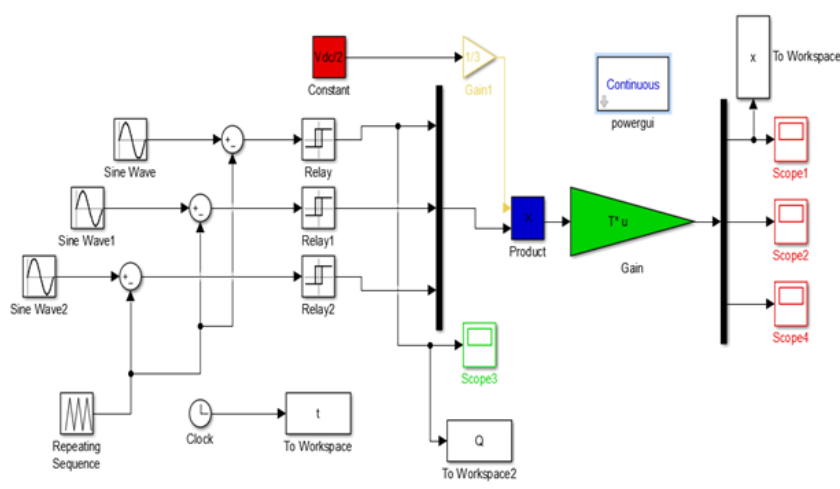


Figure II.10: Modeling in MATLAB/Simulink

II.4.1. programming MATLAB/Simulink

Clc

clear all

T=[2 -1 -1; -1 2 -1; -1 -1 2];

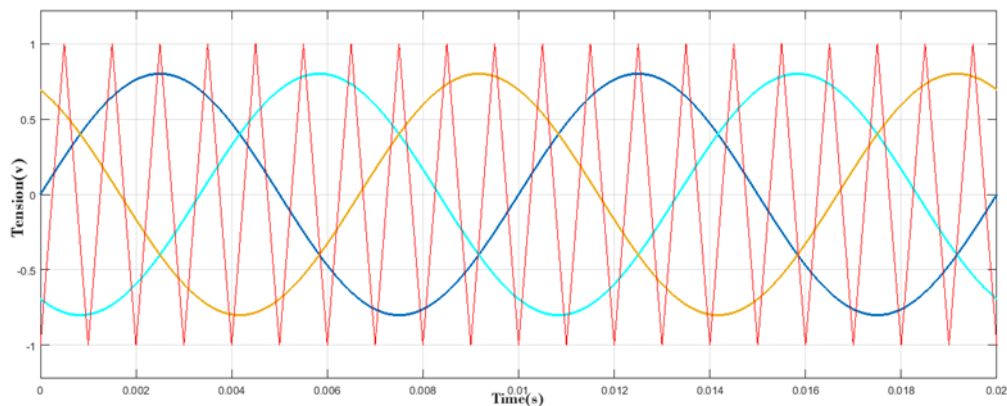
fref=100;

fp=1000;

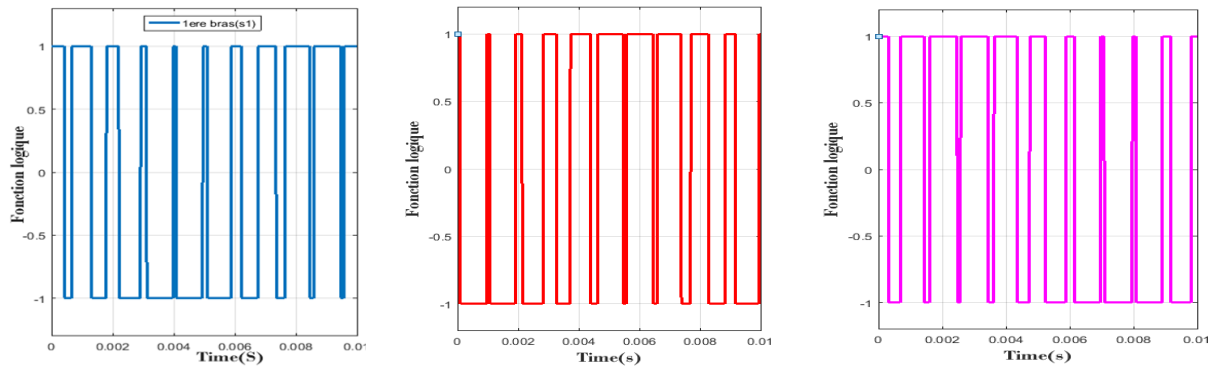
Vdc=465;

II.4.3. Simulation Results

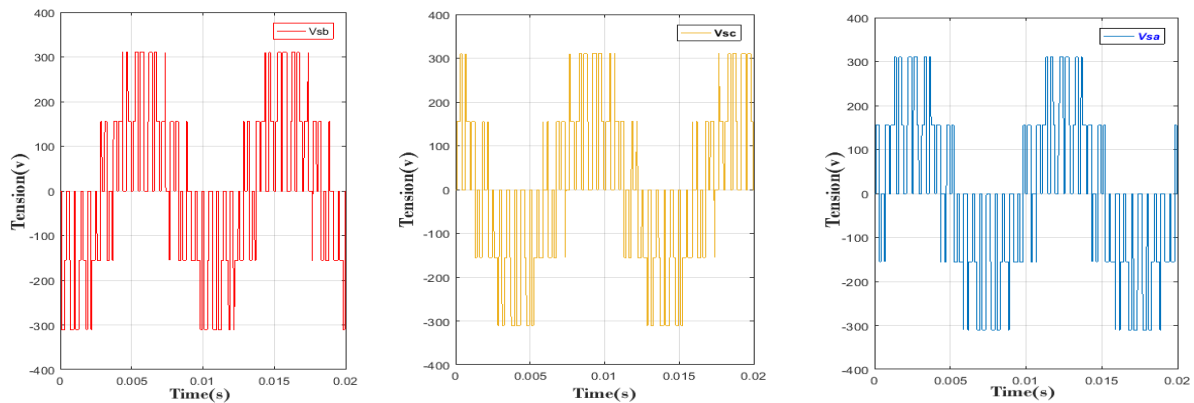
After modeling and programming the three-phase inverter in Simulink using MATLAB, the following results were obtained.



FigureII.11: Porteuse et signaux de référence



FigureII.12:The output voltages of ondulcun



FigureII.13: Sign the interruption command from the MLI technology

II.4.4. Simulation Analysis

Triangular Carrier Signal and Sinusoidal Reference Signals (Figure III.1)

This figure illustrates the comparison between a high-frequency triangular carrier signal and three sinusoidal reference signals phase-shifted by 120° . This comparison represents the operating principle of Sinusoidal Pulse Width Modulation (SPWM). When the reference signal exceeds the carrier signal, the corresponding switch is turned ON; otherwise, it is turned OFF. It can be observed that the three reference signals are balanced and synchronized, which ensures stable control of the three-phase inverter. In addition, the high switching frequency of the carrier signal improves the quality of the output waveform and reduces harmonic distortion.

Generated PWM Signals for the Three Phases (Figure III.2)

This figure represents the PWM gate signals generated after comparing the sinusoidal reference signals with the triangular carrier signal. The pulse widths vary continuously according to the instantaneous amplitude of the sinusoidal reference signals, which is the main characteristic of the Sinusoidal Pulse

Width Modulation (SPWM) technique.

The pulses are distributed symmetrically and regularly across the three phases, ensuring safe operation of the power devices. This control strategy provides effective regulation of the inverter output voltage while reducing harmonic distortion.

Three-Phase Inverter Output Voltages (Figure III.3)

This figure illustrates the output voltages generated by the three-phase inverter using the SPWM control technique. The generated waveforms contain multiple voltage levels resulting from the switching operations of the inverter switches.

The output voltages generally follow a sinusoidal waveform, which confirms the correct operation of the applied modulation method. Although some harmonics caused by the switching process are still present, the signal quality has been significantly improved due to the use of the SPWM technique.

In addition, the three output voltages are balanced and phase-shifted by 120° , which confirms the proper operation of the three-phase system

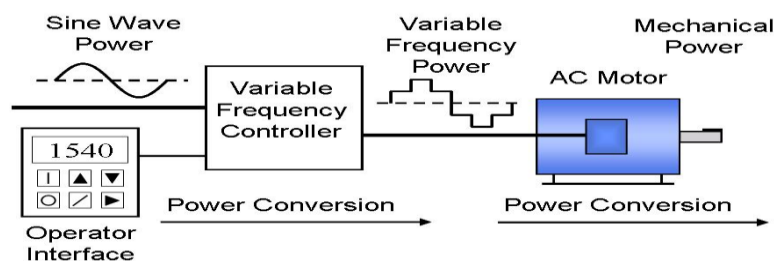
II.5. Frequency and voltage control in inverter systems

Frequency and voltage control are considered essential for achieving stable and highly efficient performance in inverter systems, especially in three-phase AC motor applications and modern power systems. This control aims to obtain a quasi-sinusoidal output while enabling precise and flexible regulation of motor speed and torque. It is typically achieved using power electronics techniques such as Pulse Width Modulation (PWM) and Voltage/Frequency (V/f) control, which help maintain a constant magnetic flux inside the motor, reduce harmonic distortion, and improve the overall system efficiency [19][18].

II.5.1 Frequency adjustment

The output frequency in inverters is fixed by adjusting the frequency of the PWM reference signal or through a digital command from a microcontroller. This allows the speed of motors to be varied or the frequency to be adapted according to grid or load requirements.

Modern control systems are designed to ensure precise synchronization with the grid (in the case of renewable energy injection) and to avoid frequency drift, which could lead to disturbances or loss of stability. [20][16]



FigureII.13: Frequency adjustment

II.5.2 Voltage amplitude adjustment

The amplitude of the output voltage in a three-phase inverter is commonly controlled using Pulse Width Modulation (PWM) techniques by adjusting either the modulation index or the DC-link voltage. In sinusoidal PWM (SPWM), the fundamental component of the output voltage is directly proportional to the amplitude of the sinusoidal reference signal. Therefore, varying the reference voltage enables efficient regulation of the inverter output without modifying the switching frequency. This method is widely employed in AC motor drives, renewable energy conversion systems, and uninterruptible power supply (UPS) applications due to its smooth voltage regulation capability and improved dynamic performance [24][23]. In practical power electronic systems, voltage regulation is essential to maintain stable operation under varying load conditions[39]. Closed-loop control strategies are commonly implemented to compensate for voltage drops and external disturbances, ensuring a constant output voltage and reducing harmonic distortion. Proper adjustment of the voltage amplitude also improves inverter efficiency and protects semiconductor switches from excessive electrical stress. [24][25].

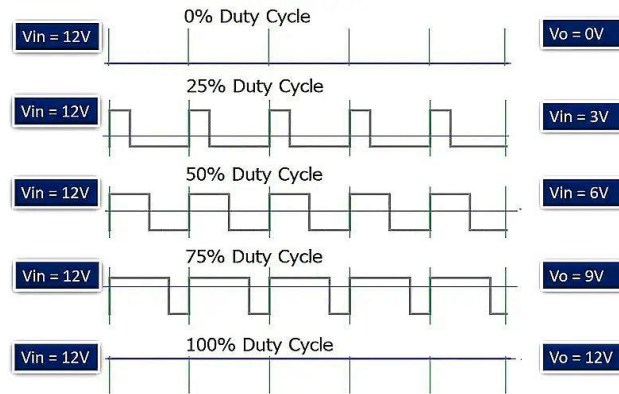


Figure II.4: Variation of Output Voltage Amplitude with Modulation Control

II.5.3 Modulation index

The modulation index is defined as the ratio between the amplitude of the sinusoidal reference signal and the amplitude of the triangular carrier signal used in PWM generation. It is an important parameter that determines both the amplitude of the fundamental output voltage component and the operating region of the inverter[37]. Mathematically, the modulation index is expressed as:

$$m_a = V_{\text{ref}} / V_{\text{carrier}}$$

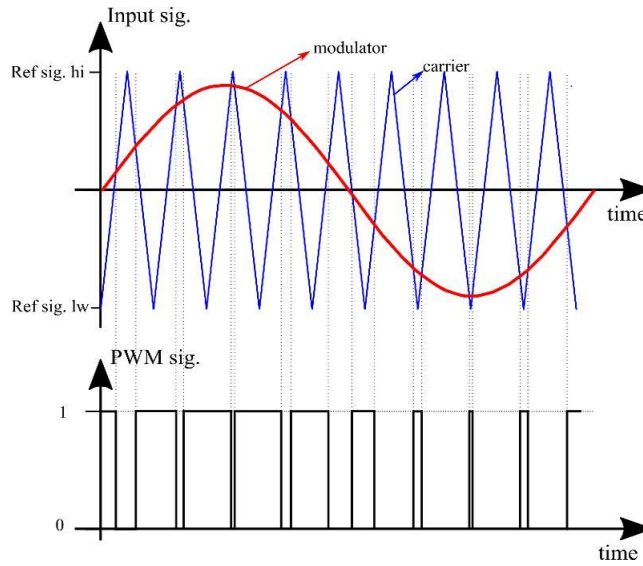


Figure II.15: Sinusoidal Reference and Carrier Signals for Modulation Index Determination

where V_{ref} is the amplitude of the reference signal and $V_{carrier}$ is the amplitude of the carrier signal. [24][23] In the linear modulation region, increasing the modulation index improves the utilization of the DC bus voltage and enhances the fundamental output voltage component while maintaining low harmonic distortion. However, when the modulation index exceeds the linear operating range, the inverter enters the overmodulation region, leading to waveform distortion and an increase in Total Harmonic Distortion (THD) [36]. Consequently, selecting an appropriate modulation index is essential to achieve a balance between voltage utilization, switching losses, harmonic performance, and safe operation of power semiconductor devices. [24][25]

II.6 Conclusion

In conclusion, inverter control based on PWM techniques and microcontroller implementation represents a modern and efficient solution for electromechanical and industrial systems. It provides a good compromise between performance, flexibility, and ease of implementation. Moreover, the integration of isolated gate driver circuits, accurate measurement and feedback systems, as well as advanced protection mechanisms, plays a crucial role in ensuring high efficiency, system reliability, and safe operation under various working conditions

Chapter III:
Design and Practical
Implementation of the
Proposed Three-Phase
Inverter Controller

III.1. Introduction

The design and implementation of three-phase inverter systems represent an important research area in modern power electronics because of their wide use in renewable energy conversion, industrial motor drives, and uninterruptible power supply applications. A conventional inverter system generally consists of a power conversion stage based on semiconductor switches, a control stage responsible for generating PWM switching pulses, and a sensing stage used for voltage and current feedback measurements to improve system regulation and protection. In embedded control applications, microcontrollers such as Arduino are frequently employed due to their simplicity, low cost, and flexibility in generating switching strategies for inverter operation. Before hardware realization, simulation tools such as MATLAB/Simulink are commonly used to study the dynamic behavior of the inverter and evaluate the performance of the selected control technique under different operating conditions. Simulation analysis helps reduce implementation errors and allows optimization of parameters such as switching frequency, modulation index, and dead time. After the simulation phase, an experimental prototype is usually developed in order to validate the theoretical and simulated results through practical measurements and real-time testing. Experimental verification remains an essential step in power electronics research because it confirms the feasibility of the proposed controller and ensures stable inverter operation under practical conditions. The integration of simulation and experimental testing therefore provides a reliable methodology for evaluating inverter performance and improving overall system efficiency and robustness.

III.2 General Architecture of the System

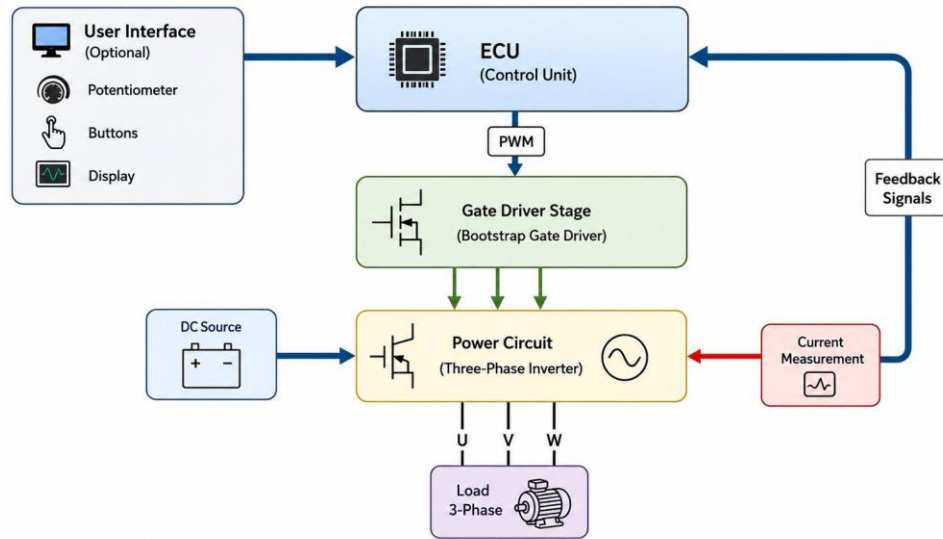


Figure III 1: I.Workflow of the Proposed Project.

This diagram represents the general architecture of the system. The electronic control unit (ECU) generates pulse-width modulation (PWM) signals based on user inputs (potentiometer, buttons, or display). These signals are sent to the gate driver stage (bootstrap driver), which ensures proper switching of the power semiconductor devices. The power circuit, supplied by a DC source, converts the input into a three-phase AC output delivered to the load. The current measurement unit provides feedback signals to the control unit, enabling system regulation and protection.

III.3 Design of the Proposed System

III.3.1. Driver and interface stage

The Driver and Interface Stage was designed using the IR2104, HCPL2530, and B0515 components to ensure safe and efficient operation of the inverter system.

The IR2104 is used as a gate driver to control the MOSFET power switches by generating the required gate signals for fast and proper switching of both the high-side and low-side switches in the inverter bridge.

The HCPL2530 optocoupler provides electrical isolation between the control circuit and the power circuit, protecting the microcontroller from high voltages and electrical noise generated during the switching process.

In addition, the B0515 isolated DC-DC converter supplies isolated power to the driver stage, improving system stability and ensuring safe operation of the control and driving circuits.

This design helps improve switching performance, reduce electrical interference, and increase the reliability and safety of the inverter system during operation.

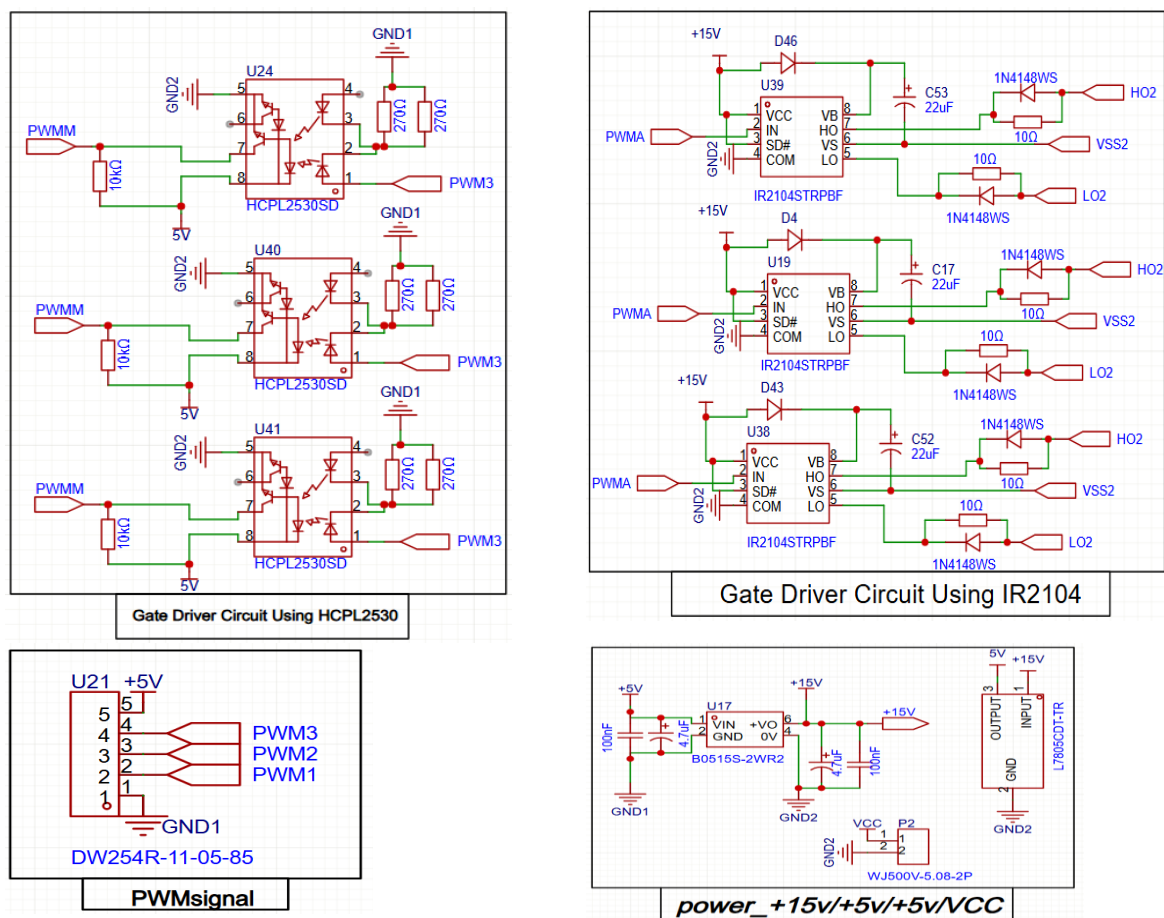


Figure III.2: Schematic Diagram of the Gate Driver Circuit.

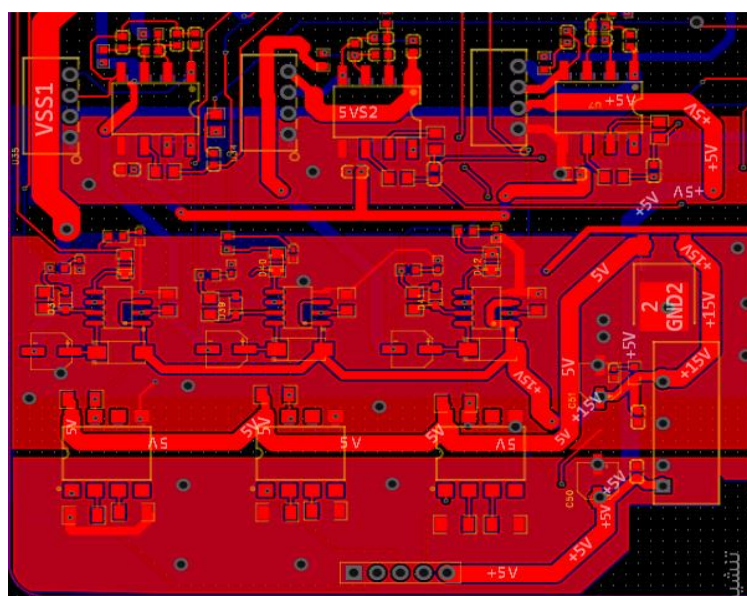


Figure III.3: Fabricated PCB of the Gate Driver Circuit.

III.3.2. Gate Driver Circuit Based on the IR2104

The IR2104 is a high-voltage, high-speed gate driver designed for driving power MOSFETs and IGBTs in half-bridge configurations. It integrates both high-side and low-side output channels, enabling efficient control of switching devices in inverter applications.

The device is based on high-voltage integrated circuit (HVIC) technology combined with latch-immune CMOS design, which ensures robust and reliable operation. It is compatible with standard CMOS and LSTTL logic levels, allowing easy interfacing with microcontrollers operating at low voltages (down to 3.3 V).

The IR2104 features a high-current output stage that minimizes cross-conduction during switching transitions. Its floating high-side channel can drive N-channel MOSFETs or IGBTs operating at voltages ranging from 10 V up to 600 V, making it well suited for power electronics and inverter systems [26].



Figure III.4: Gate Driver Circuit Based on the IR2104 IC.

Gate Drive Power Calculation

The gate-drive power is calculated by:

$$P_g = Q_g \times V_{GS} \times f_{sw}$$

Where:

- $Q_g = 66\text{nC}$
- $V_{GS} = 12\text{V}$
- $f_{sw} = 10\text{kHz}$

Substituting the values:

$$P_g = 66 \times 10^{-9} \times 12 \times 10^4$$

$$P_g = 7.92\text{mW}$$

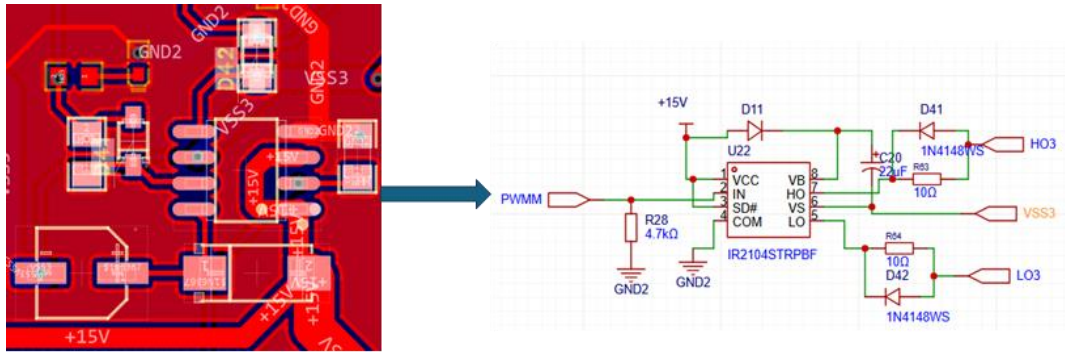


Figure III.5: Schematic and Printed Circuit Board (PCB) Design of the IR2104 Gate Driver Stage.

III.3.3. HCPL-2530 Optocoupler Circuit

The HCPL2530 is a high-speed dual-channel optocoupler that integrates a light-emitting diode (LED) with a phototransistor detector, providing complete electrical isolation between the input and output. This component is primarily used for signal isolation in electronic systems, particularly in power electronics applications.

The HCPL2530 features a high data transmission speed due to its optimized structure, which reduces the parasitic capacitance between the base and collector, enabling a bandwidth of several megahertz. It also exhibits high immunity to rapid voltage transients (Common Mode Transient Immunity), making it suitable for operation in electrically noisy environments.

This optocoupler supports TTL logic levels and provides an open-collector output. In addition, it ensures a high level of electrical isolation reaching several kilovolts, thereby enhancing system safety.

The HCPL2530 is used in various applications, including control signal isolation, digital system interfacing, and replacement of pulse transformers, as well as improving the performance of driver circuits in inverters and electric motor systems [27].



Figure III.6: HCPL-2530 Optocoupler Circuit.

According to the datasheet, the HCPL-3120 provides:

- Peak output current: 2 A
- Supply voltage range: 15 V to 30 V
- High noise immunity
- Fast switching performance

This device is used to amplify the control signal from the microcontroller and safely drive the MOSFET gate.

Input Resistor Calculation

The input side of the HCPL-3120 contains an internal LED. A current-limiting resistor must be used.

• The resistor value is calculated as:

$$R_{in} = V_{in} - V_f / I_f$$

Where:

- V_{in} : input voltage from the microcontroller
- V_f : forward voltage of the internal LED
- I_f : forward current

Assuming:

$$V_{in} = 5V$$

$$V_f = 1.4V$$

$$I_f = 15mA$$

Then:

$$R_{in} = 5 - 1.4 / 0.015$$

$$R_{in} = 240 \Omega$$

Power Consumption Calculation

The power consumed by the HCPL-3120 can be estimated by:

$$P = V \times I$$

Assuming:

$$V = 15V$$

$$I = 10mA$$

Then:

$$P = 15 \times 0.01$$

$$P = 150mW$$

This confirms that the driver operates within safe power limits

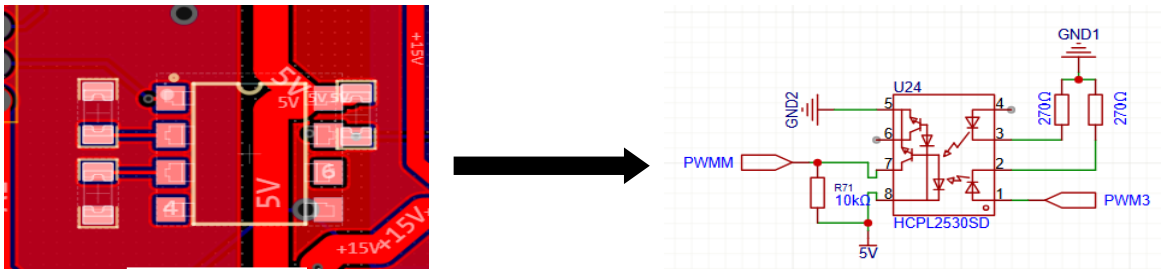


Figure III.7: Schematic Diagram and Printed Circuit Board (PCB) of the HCPL-2530-Based Isolation Stage.

III.3.4. B0515S DC–DC Converter for Gate Driver Power Supply Le module

B0515S-2WR2 is a 2 W isolated DC-DC converter with a 5 V nominal input and a 15 V output. It offers an efficiency of up to 86%, includes short-circuit protection, and provides low ripple and low noise performance. This module is commonly used in digital circuits, control circuits, and systems requiring an isolated power supply [28].



Figure III.8: B0515S DC–DC Converter for Gate Driver Power Supply.

$$P = V \times I$$

Where:

- P: Power (W)
- V: Voltage (V)
- I: Current (A)

For the B0515S-2WR2 module:

$$P_{out} = 15V \times 0.133A = 2W$$

The efficiency equation is:

$$\eta = P_{out} / P_{in} \times 100$$

Where: η

P_{out} : Output power

P_{in} : Input power

The module efficiency can reach:

%86

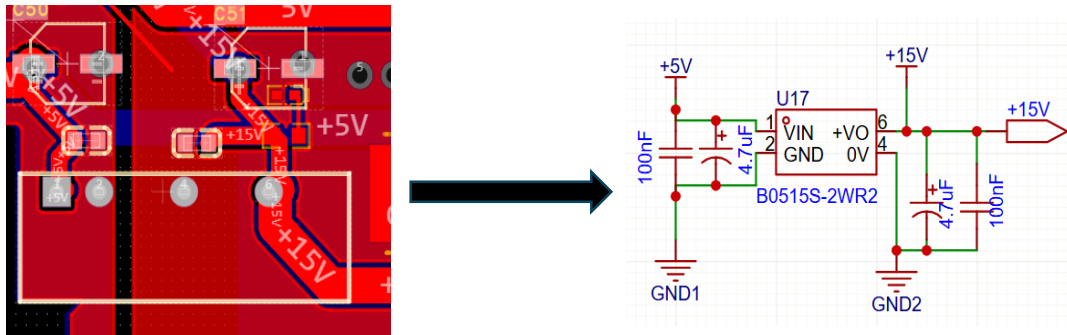


Figure III.9: Schematic and PCB Design of the B0515S Power Supply Module.

III.3.5. voltage regulators L7805CD2T

The L78 series consists of three-terminal positive voltage regulators available in several package types such as TO-220, TO-220FP, D²PAK, and DPAK, with different fixed output voltage values. These regulators are widely used in electronic applications to provide a stable and regulated DC voltage. They are equipped with internal protection features such as current limiting, thermal shutdown, and safe operating area protection, which improve reliability and protect the device from damage. With proper heat dissipation, the regulator can deliver an output current greater than 1 A. Furthermore, although the L78 series is mainly designed for fixed-voltage regulation, it can also be combined with external components to obtain adjustable voltage and current values [29].



Figure III.10: L7805CD2T Voltage Regulator Circuit.

• Voltage Drop Calculation

•

$$V_D = V_{in} - V_{out}$$

• If the input voltage is 12V and the regulator used is 7805:

$$V_D = 12 - 5 = 7V$$

• Approximate Efficiency Calculation

$$\eta = V_{out} / V_{in} \times 100$$

$$\eta = 5 / 12 \times 100$$

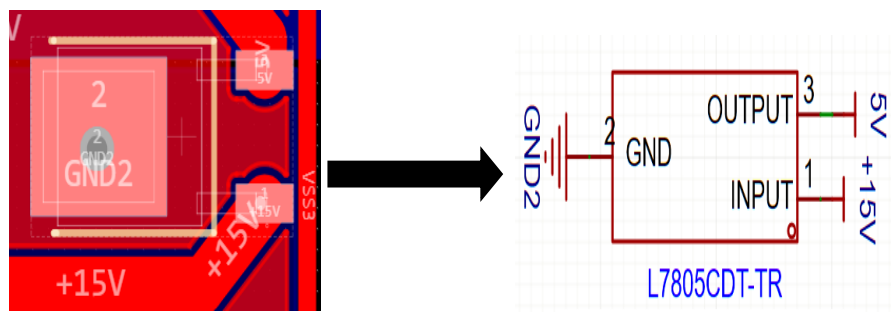


Figure III.11: Schematic and PCB Design of the 5 V Power Supply Based on the L7805CD2T.

III.4. Power stage design

III.4.1. DC source

A DC source is used to supply the inverter circuit with a stable direct current voltage required for proper operation.



Figure III.12: Power Supply Circuit.

In this project, the DC power supply is connected to the circuit through a WJ500V-5.08-2P terminal block connector, where the positive terminal is connected to VCC and the negative terminal is connected to GND. The DC source provides the necessary energy for the driver circuit and power components, ensuring stable and reliable inverter performance.



Figure III.13: WJ500V-5.08-2P Terminal Block Used for Power Connections.

Main Electrical Characteristics [30]

- Rated voltage:
 - 300 V according to UL standard
 - 400 V according to IEC standard
- Rated current:
 - 10 A to 20 A
- Wire range:
 - 22–12 AWG
- Contact resistance:
 - 20 m Ω
- Insulation resistance:
 - 500 M Ω at DC 500 V
- Withstanding voltage:
 - AC 1600 V for 1 minute

Mechanical Characteristics [30]

- Operating temperature range:
 - -40°C to +105°C
- Maximum soldering temperature:
 - +250°C for 5 seconds
- Tightening torque:
 - 0.4 N.m

- PA66 UL94V-0 flame-retardant plastic
- Screw material:
- Zinc-plated steel

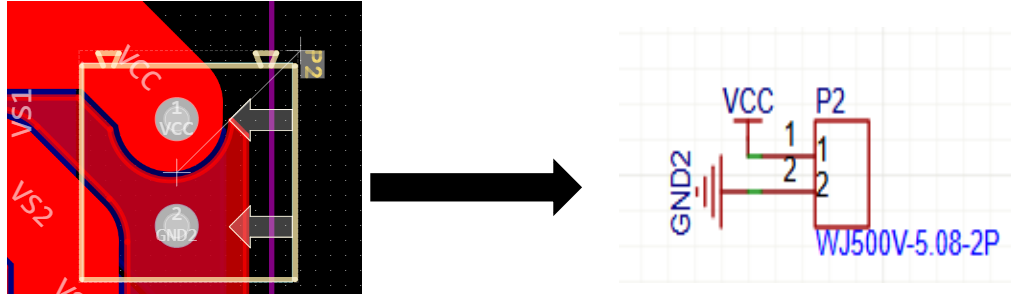


Figure III.14: Schematic Symbol and PCB Footprint of the WJ500V-5.08-2P Terminal Connector.

III.4.2. inverter bridg

A modern three-phase inverter was developed based on an advanced inverter bridge structure, using MOSFET power switches (IRZ44NS) due to their high switching speed and good power conversion efficiency. The printed circuit board (PCB) was also carefully designed to reduce electrical interference and power losses while ensuring proper current distribution within the inverter bridge.

To improve the switching performance of the MOSFETs, a Snubber Circuit was implemented to provide smoother turn-on and turn-off operations, reduce voltage spikes and switching oscillations, and protect the electronic switches from electrical stress, thereby increasing the reliability and overall

performance of the system during operation.

In addition, a current sensing resistor was integrated into the circuit to enable accurate current measurement and monitoring within the inverter system

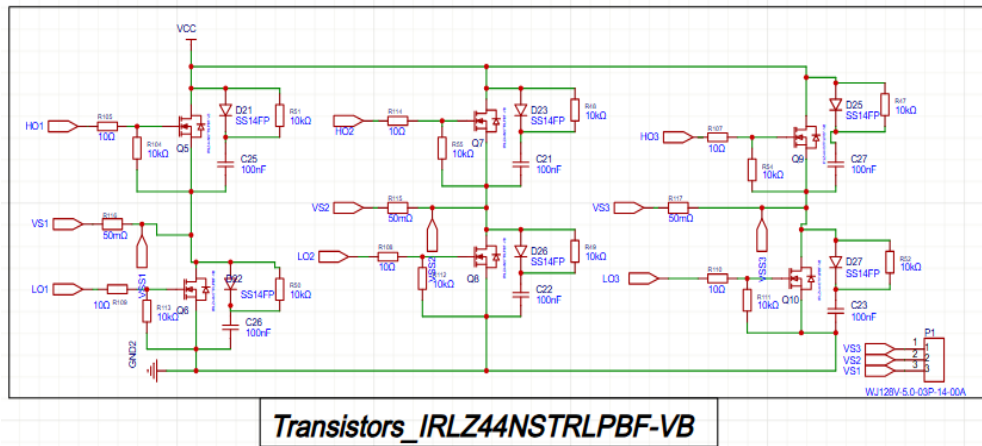


Figure III.15: Inverter bridge

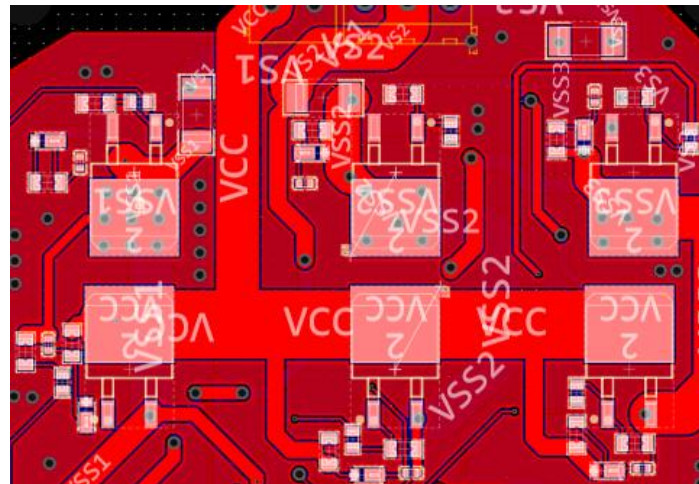


Figure III.16: Schematic and PCB Design of the Inverter bridge

III.4.3. MOSFET Power Switch(IRLZ44NS)

The **MOSFET** transistor used in this project is the **IRLZ44NSTRLPBF-VB**, an N-channel power MOSFET designed for high-speed switching applications and power conversion systems. This component was selected because of its low on-state resistance $R_{DS(on)}$, high current capability, and compatibility with low gate driving voltages, making it suitable for three-phase inverter applications.

The device supports a drain-source voltage of 60 V and a continuous drain current up to 75 A at 25° C. It also has a low on-resistance of approximately 11 mΩ at $V_{GS}=10V$, which reduces conduction losses and improves inverter efficiency.

In addition, the **MOSFET** exhibits fast switching characteristics, with low turn-on and turn-off delays, allowing efficient PWM operation at high switching frequencies. The maximum gate-source voltage is ± 20 V, while the operating junction temperature can reach 175°C, ensuring reliable operation under

demanding conditions.

The **IRLZ44NSTRLPBF-VB** is implemented in the inverter bridge as the main switching element responsible for converting the **DC** input voltage into a controlled three-phase **AC** output using **SPWM** control signals generated by the Arduino controller [31].



Figure III.17: MOSFET Power Switch(IRLZ44NS)

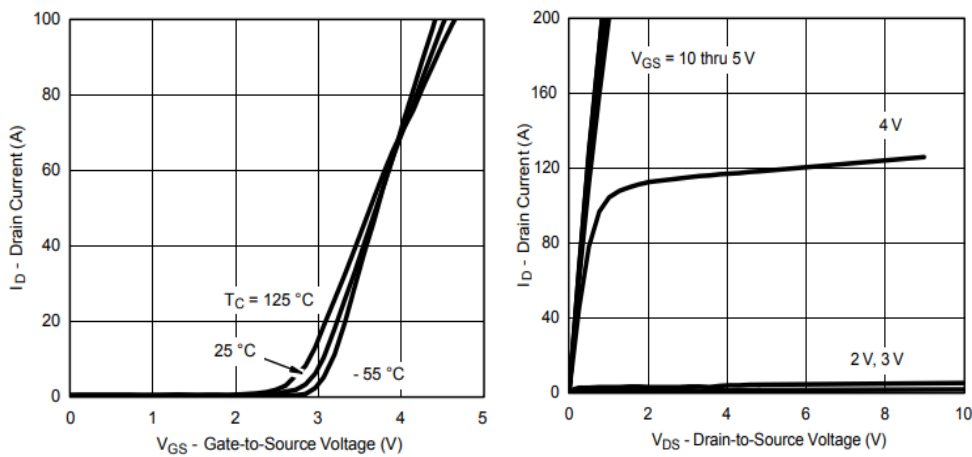


Figure III.18: Transfer and Output Characteristics of the IRLZ44NS MOSFET.

$$V_{DC} = V_D - V_S$$

Where:

- V_D : Drain voltage
- V_S : Source voltage

$$I_D = V_{DS} / R_{DS(on)}$$

Where:

- I_D : Drain current
- $R_{DS(on)}$: Internal operating resistance of the MOSFET

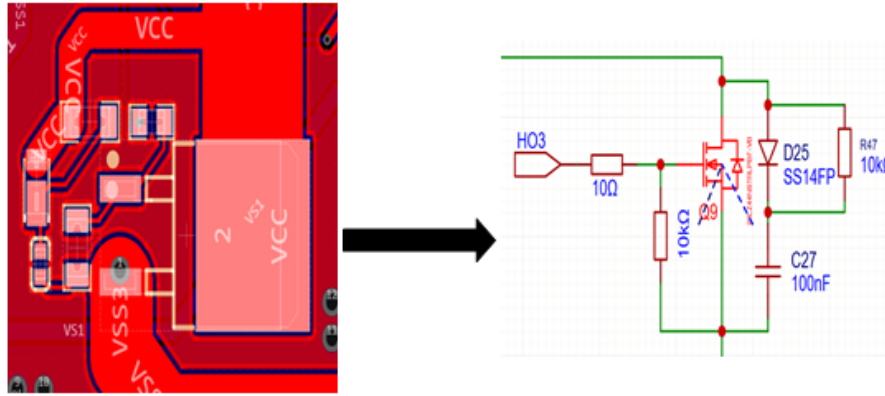


Figure III.19: Schematic and PCB Design of MOSFET Power Switch(IRLZ44NS)

III.4.4. Snubber Circuit

The Snubber Circuit is an important protection and damping circuit used with MOSFET power switches in inverter systems. Its main function is to reduce voltage spikes and switching oscillations caused by the rapid turn-on and turn-off of the MOSFET transistor. These sudden transients can create electrical stress and may damage semiconductor devices. Therefore, the snubber circuit is designed to absorb excess energy, reduce electromagnetic interference (EMI), and improve the smoothness of the switching process. As a result, it enhances the reliability, stability, and lifetime of the inverter system while ensuring safer and more efficient operation [25].

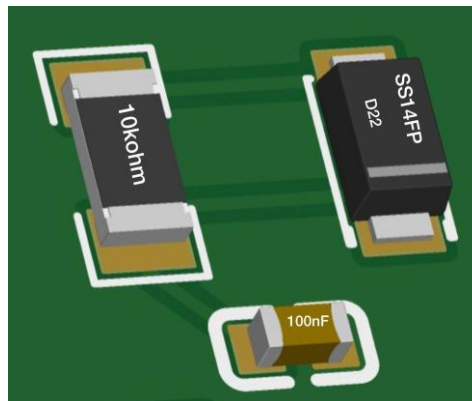


Figure III.20: Snubber Circuit

The implemented Snubber Circuit in this system consists of a 10 kΩ resistor, a 100 nF capacitor, and an SS14FP diode. These components work together to reduce voltage spikes and switching oscillations generated during the fast switching operation of the MOSFETs. The capacitor absorbs transient voltage peaks, while the resistor helps dissipate the stored energy and controls the damping process. In addition, the SS14FP diode provides a fast recovery path for reverse current protection, improving the stability of the circuit and protecting the electronic components from electrical stress and damage.

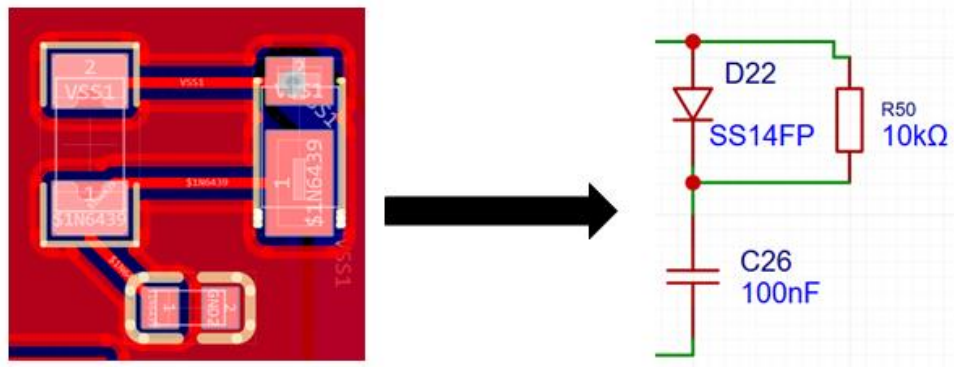


Figure III.21: Schematic and PCB Design of Snubber Circuit

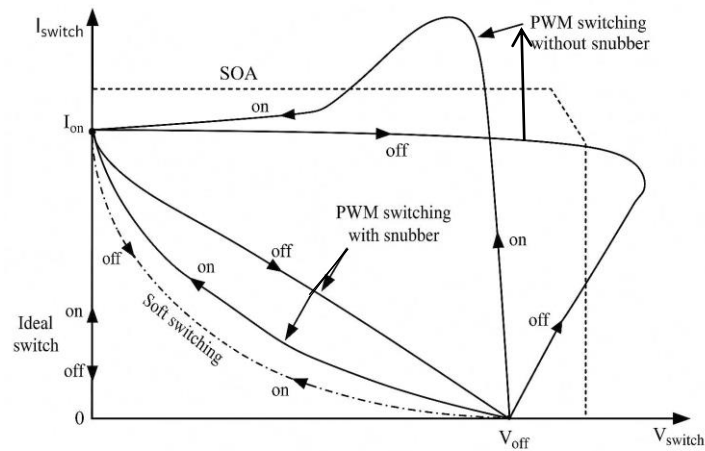


Figure III.22: Switching trajectories of a power semiconductor device during PWM

Figure Switching trajectories of a power semiconductor device during PWM operation with and without a snubber circuit. The snubber circuit reduces voltage and current stresses, limits switching losses, and improves the safe operating conditions of the switch[32].

III.5. Measurement system

III.5.1. current (AMC1200)

The AMC1200 is a precision isolation amplifier designed for current measurement applications. It provides galvanic isolation between the high-voltage power stage and the low-voltage control circuit through a silicon dioxide (SiO_2) barrier, ensuring high immunity against magnetic interference. The device offers an isolation capability of up to 4000 V_{peak}, which improves system safety and protects sensitive control circuits from high common-mode voltages.

The AMC1200 is mainly optimized for direct connection with shunt resistors, allowing accurate current sensing in power electronic systems such as motor drives and inverters. Its excellent precision contributes to better current control, reduced torque ripple, and improved overall system efficiency. In addition, the output

signal can be adapted automatically to either 3 V or 5 V low-side supply voltage, making it compatible with microcontrollers such as Arduino.

In the proposed system, the AMC1200 is used to measure the inverter output current through a 50 mΩ shunt resistor, while ensuring safe isolation between the measurement stage and the control stage.[34]



Figure III.23: current Measurement (AMC1200)

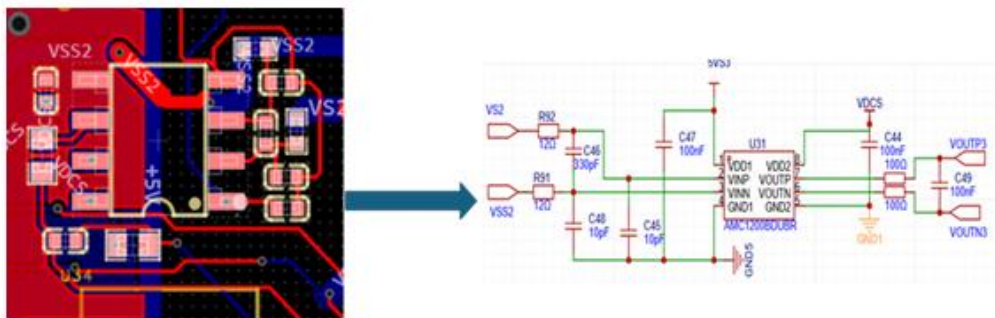


Figure III.24: Schematic and PCB Design of AMC1200

III.6.Final form of (3D)(pcb) design

III.6.1.Final form of (pcb) design

After numerous studies and analyses, an advanced and efficient three-phase inverter system was designed to meet the project requirements in terms of performance and stability. The circuit was designed using **EasyEDA** from both functional and structural aspects, with careful selection of electronic components to ensure system quality and reliable operation. The figure below illustrates the final **PCB** layout of the proposed system

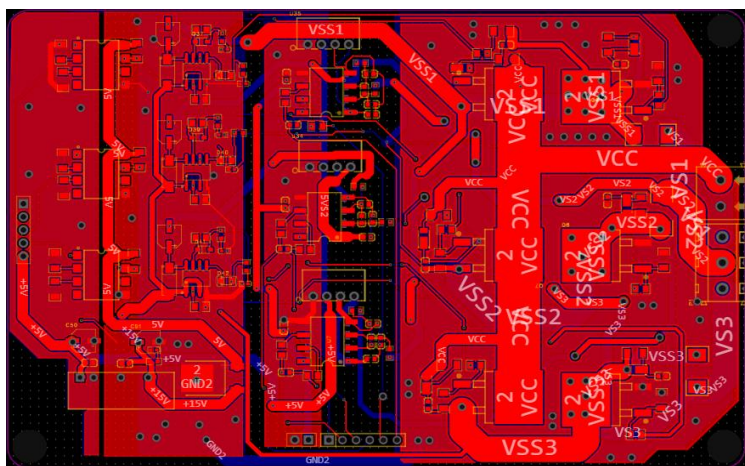


Figure III.25:Final form of (pcb) design

III.6.2.Final form of (3D) design

Figure II.25 shows the final 3D view of the designed three-phase inverter PCB. The model illustrates the placement of all electronic components and provides a realistic representation of the final hardware implementation. This verification step helps ensure proper component arrangement, electrical connectivity, and overall system integration before practical deployment.

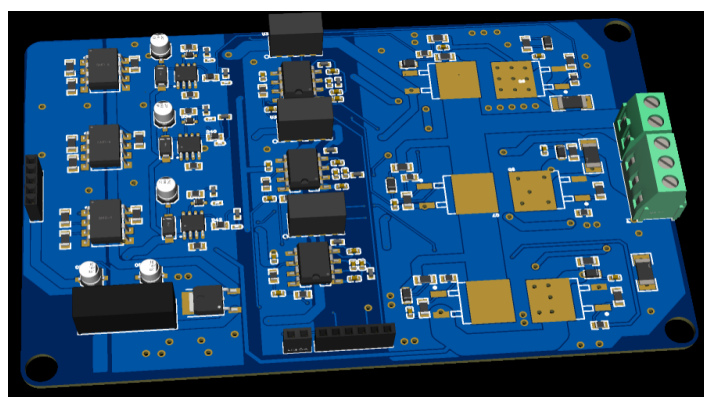


Figure III.26: Final form of (3D) design

III.6.3. Illustrates the final design of the three-phase inverter system developed

The figure illustrates the final design of the three-phase inverter system developed in this project. The designed prototype integrates power switches, driver circuits, and the control stage to ensure proper conversion of electrical energy from direct current (DC) to alternating current (AC) and to guarantee stable inverter operation.

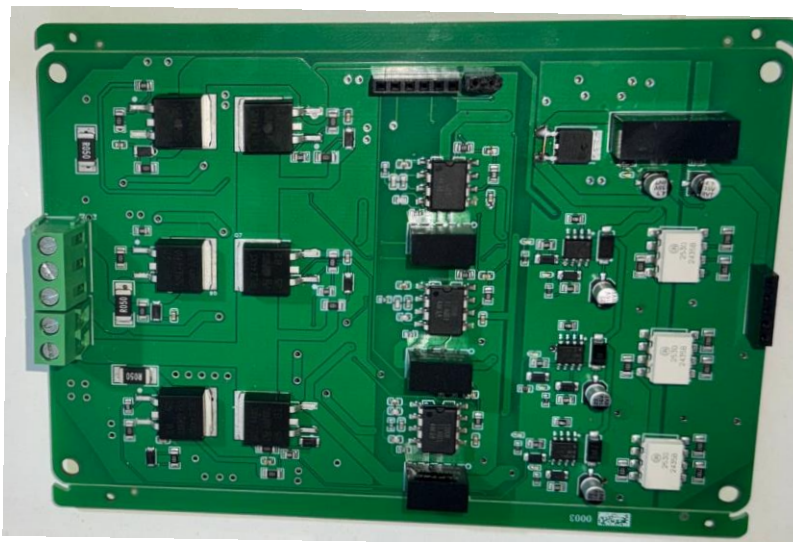


Figure III.26: illustrates the final design of the three-phase inverter system

III.6.3.Final PCB Layout and Pin Assignment of the Three-Phase Inverter

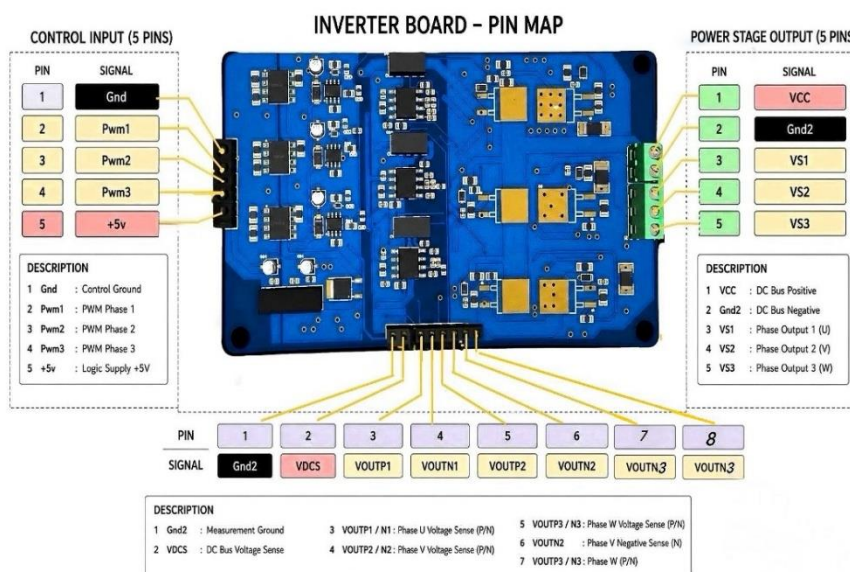


Figure III.27: Three-Phase Inverter Board Layout and Pin Configuration

Figure II.27 presents the final design of the proposed three-phase inverter board and its pin configuration. The board includes control input pins for the PWM signals and power supply, output terminals connected to the

inverter power stage, and measurement pins used for voltage sensing and system monitoring. This pin mapping facilitates the integration of the inverter with the control unit and ensures proper signal routing during operation and testing.

III.7. Control stage design

III.7.1. TMS320F28379D DSP Controller

The LAUNCHXL-F28379D development board, designed by Texas Instruments, is based on the TMS320F28379D microcontroller from the C2000™ family, which is optimized for real-time control applications. The board integrates high-performance processing capabilities, enhanced PWM modules, Analog-to-Digital Converters (ADCs), and multiple communication interfaces, making it suitable for digital power conversion and motor control applications. In this work, the LAUNCHXL-F28379D board was used to generate SPWM signals and implement the proposed inverter control algorithm with high accuracy and fast real-time response (Texas Instruments, 2024) [33].



Figure III.28: TMS320F28379D DSP Controller

III.7.2. Configuration of PWM Signal Output Pins in the LAUNCHXL-F28379D Controller

Figure III.26 illustrates the pin configuration of the LAUNCHXL-F28379D development board used in the proposed inverter control system. Specific PWM output pins were selected to generate the switching signals required for the operation of the three-phase inverter. These signals are generated by the microcontroller according to the SPWM control algorithm and transmitted to the driver stage to switch the power MOSFETs. The selected pins ensure precise timing, synchronization, and stable switching performance, which are essential for obtaining balanced three-phase output waveforms and reducing harmonic distortion

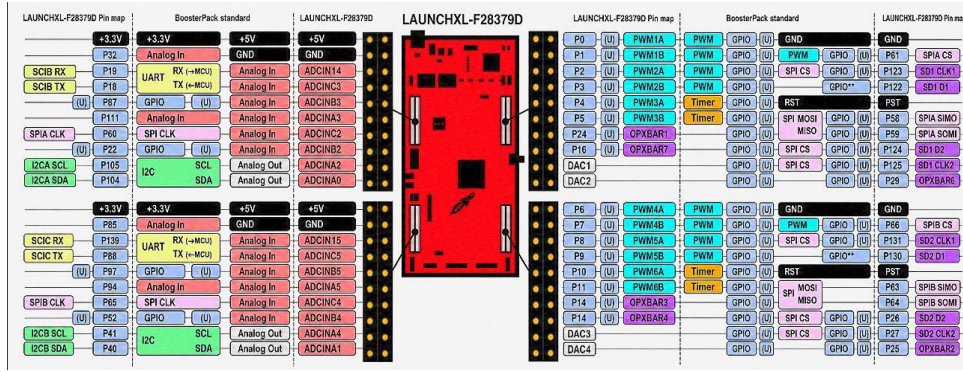


Figure III.29.: Programming the LAUNCHXL-F28379D card to generate an SPWM signal

The PWM signal output pins selected on the LAUNCHXL-F28379D board for inverter control are P0, P2, and P4. These pins were used to generate and transmit the PWM signals required for the control algorithm.

III.7.3. Programming the LAUNCHXL-F28379D card to generate an SPWM signal

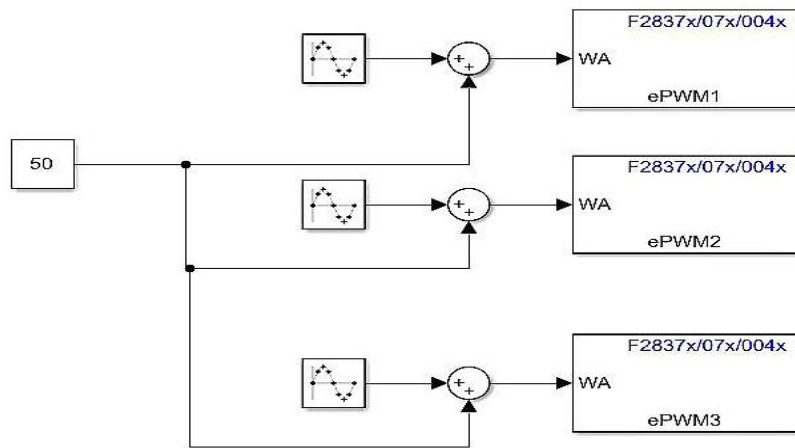


Figure III.30: MATLAB/Simulink Model Used for Programming the TMS320F28379D Control Board.

Figure III.27 illustrates the Simulink programming model used to generate SPWM signals for the LAUNCHXL-F28379D control board. The system is based on three sinusoidal reference signals shifted by 120° to produce the three-phase control signals required for inverter operation. A switching frequency of 50 Hz was selected as the fundamental output frequency.

Each sinusoidal signal is compared with a carrier signal through comparator blocks in order to generate PWM pulses. These pulses are then transmitted to the ePWM modules of the F2837xD microcontroller, namely ePWM1, ePWM2, and ePWM3. The generated PWM signals are used to control the switching states of the inverter power switches.

This programming structure ensures synchronization between the three phases and provides stable SPWM generation suitable for three-phase inverter control applications.

III.8. Experimental Setup

An experimental validation of the proposed three-phase inverter operation was carried out using a complete laboratory setup, as shown in **Figure III.28**. The experimental platform consists of a laptop used for Arduino programming and SPWM signal generation, a DC power supply to provide the input voltage, the designed inverter PCB board, an oscilloscope for waveform observation, digital multimeters for voltage and current measurements, and an AC motor used as the load.

The developed inverter was tested under real operating conditions in order to evaluate the performance of both the control and power stages. The oscilloscope measurements confirmed the correct generation and switching of the PWM signals, as well as the efficient operation of the gate driver circuit. In addition, the inverter was able to supply the motor with a stable AC output, demonstrating the effectiveness of the implemented SPWM control strategy.

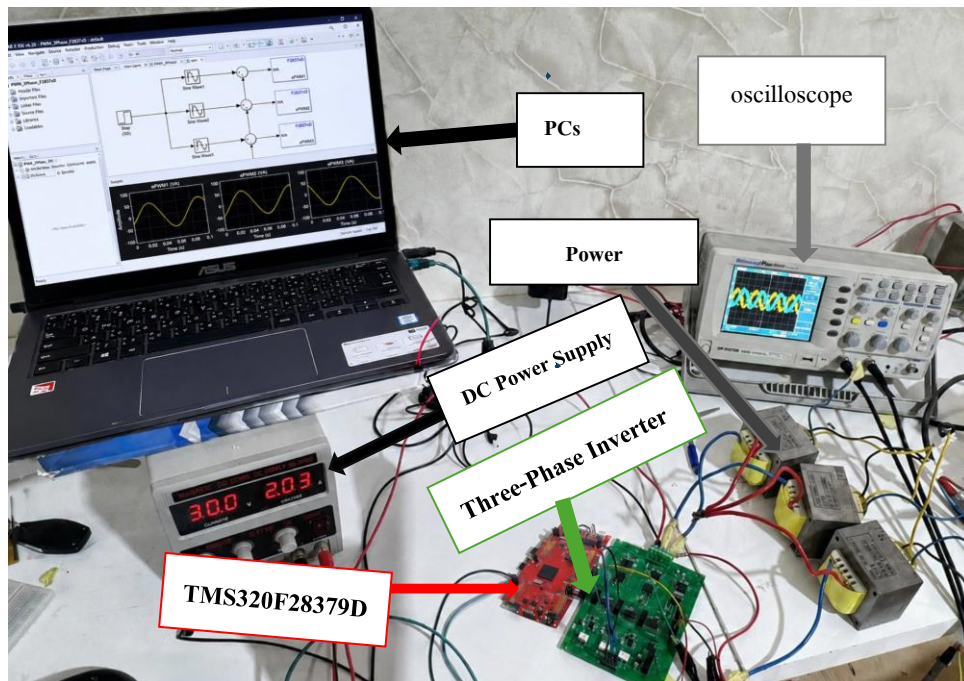


Figure III.31: Investigation expérimentale du système du concepteur

Tension DC (Vdc)	30V
Inductance (L)	10 mH
Résistance (R)	1.2 Ω
Fréquence de commutation (fc)	10 kHz
Load frequency (fl)	60 Hz

Tableau III.1 : Critères clés pour la configuration expérimentale

III.9. Experimental investigation of the conceptual system

III.9.1. PWM Signal

After the experimental investigation, the following results were obtained.

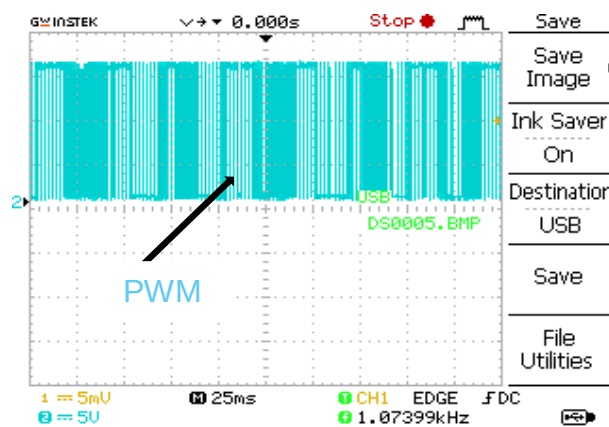


Figure III.32: PWM signals generated by the control system

Figure III.31 illustrates the PWM signals generated by the controller. It can be observed that the pulse width varies with time, which characterizes the SPWM control technique used in the three-phase inverter. This variation in pulse width helps generate an alternating voltage waveform close to a sinusoidal shape while reducing harmonic distortion and improving the quality of the output signal. In addition, the regularity of the pulses and the stability of the switching frequency confirm the successful programming and proper operation of the control circuit.

III.9.2. HO and LO Signals

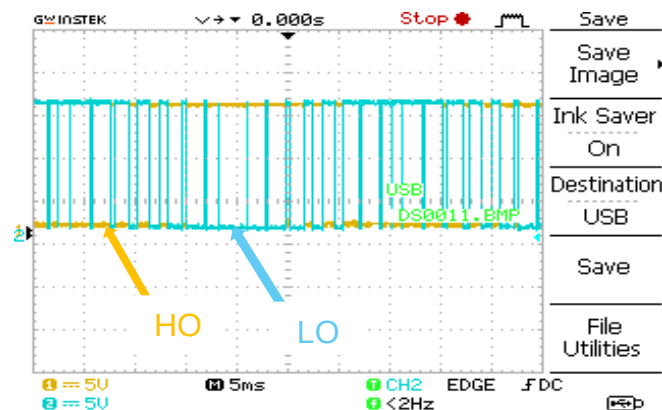


Figure III.33: Complementary HO and LO control signals of the gate driver

Figure III.32 shows the High Side (HO) and Low Side (LO) gate driver signals. It can be seen that the two signals are complementary and opposite to each other; when the HO signal is in the ON state (high level), the LO signal is in the OFF state (low level), and vice versa. This alternation is essential for the proper control of the IGBT switches inside the inverter and prevents both switches in the same inverter leg from conducting simultaneously. The obtained results also indicate that the gate driver signals are stable and operate regularly, confirming the effectiveness of the driver circuit in controlling the power switches. simultaneously. The obtained results also indicate that the gate driver signals are stable and operate regularly, confirming the effectiveness of the driver circuit in controlling the power switches.

III.9.3. Dead Time Signal

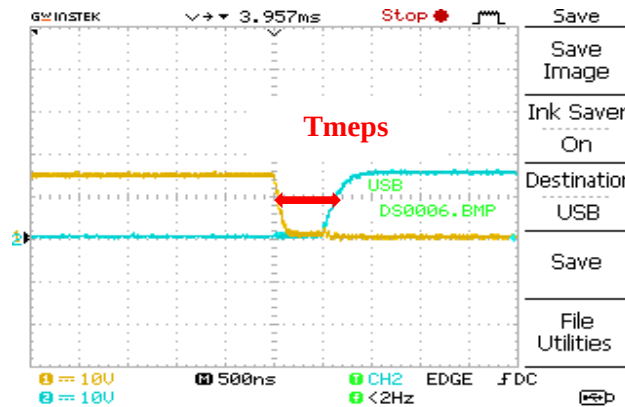


Figure III.34: Observation of the dead time between control signals

Figure III.30 illustrates the presence of the dead time between the complementary gate signals. This dead time represents a very short interval during which both control signals are turned OFF before activating the opposite switch. The importance of this interval lies in protecting the inverter against simultaneous conduction of the two switches in the same leg, which could lead to a short circuit across the DC bus. From the figure, a clear time gap can be observed between the two signals, indicating that the protection system operates efficiently and ensures the safe operation of the inverter.

III.10. Output Voltage and Current Waveforms

III.10.1. Output Current Waveforms

The output current was extracted and measured using an oscilloscope. This was achieved through the current sensing circuit integrated into the designed inverter using the AMC1200 isolation amplifier. This component provides electrical isolation between the power stage and the control stage while ensuring high measurement accuracy and improved system protection. The figure below illustrates the output current waveform

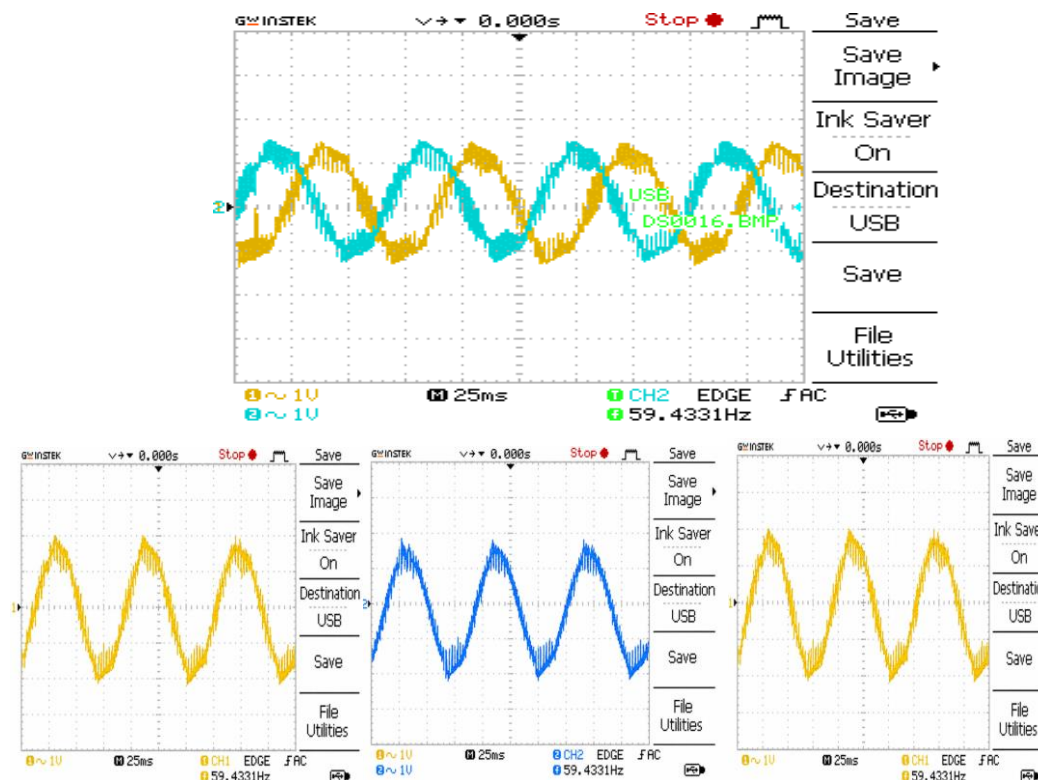
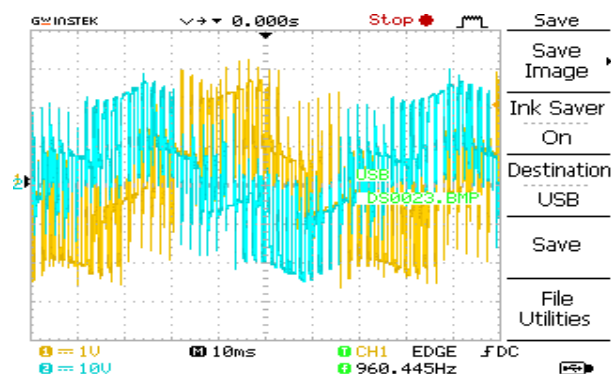


Figure III.35: Output Current Waveforms

III.10.2. Output Voltage (composite voltage) Waveforms

The obtained results illustrate the inverter outputs represented by the composite voltage of the system. These measurements make it possible to visualize the generated signals and analyze the inverter performance according to the applied control technique.

Moreover, the composite voltages allow the study of the waveform quality and the observation of the switching behavior inside the inverter



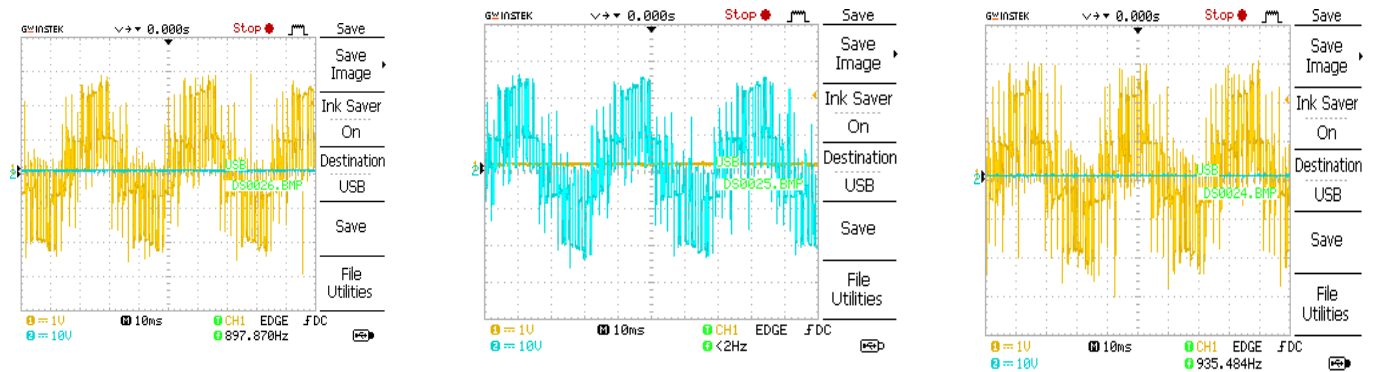
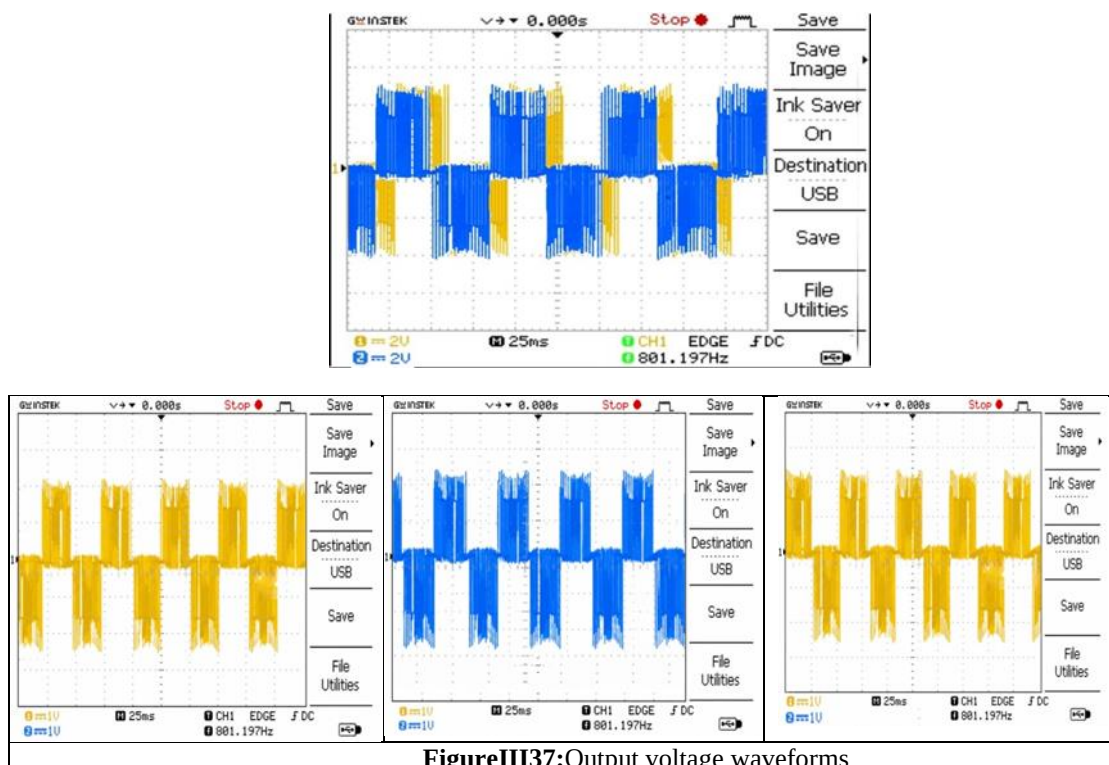


Figure III.36: Output Voltage Wavefo

III.10.3.Output Voltage (sampled voltage) Waveforms

The obtained results illustrate the inverter outputs represented by the sampled voltage of the system. These measurements make it possible to visualize the generated signals and analyze the inverter performance according to the applied control technique.

Moreover, the sampled voltages allow the study of the waveform quality and the observation of the switching behavior inside the inverter.



FigureIII37:Output voltage waveforms

III.11. Results Analysis

III.11.1 Analysis of Inverter Output Signals

Figure III.32 The results shown in the figure represent the output currents of the three-phase inverter. It can be observed that the three signals are similar in shape and amplitude, with a phase shift of approximately 120° between each phase and the others, which confirms the effectiveness of the system operating according to the principle of three-phase power supply. It is also noticeable that the currents have a sinusoidal waveform with some ripples resulting from the switching operation inside the inverter and the PWM control technique used. This behavior is considered normal in inverter systems, since high-order harmonics are generated due to the rapid switching of the electronic power switches.

In addition, the similarity in amplitude values between the three phases indicates a good balance at the inverter output and the absence of significant differences between the phases, reflecting the stability of the system and the efficiency of the control process. Furthermore, the measured frequency is close to 60 Hz, which is near the standard frequency commonly used in electrical power systems.

The results shown in the **Figure III.33** indicate that the composite voltage at the inverter output allows the analysis of the generated signals and the determination of the effective value equivalent to a sinusoidal waveform at the fundamental frequency.

It can be observed that the waveform contains high-frequency ripples superimposed on the fundamental signal, which indicates that the switching operation inside the inverter is functioning correctly according to the applied control technique.

Moreover, the three displayed waveforms are very similar in shape and amplitude, indicating that the three-phase outputs operate with the same switching pattern, with a phase shift of 120° between each phase and the others, which is a characteristic feature of a three-phase system.

In addition, the similarity in amplitudes between the different measurements suggests that the inverter operates in a relatively balanced manner.

Figure III.34 The Sample Voltage was measured at the inverter outputs using an oscilloscope. The obtained results show pulsed switching waveforms generated by the fast commutation of the inverter power switches.

This waveform shape is considered normal for PWM signals, since the output voltage is not directly sinusoidal but composed of variable-width pulses.

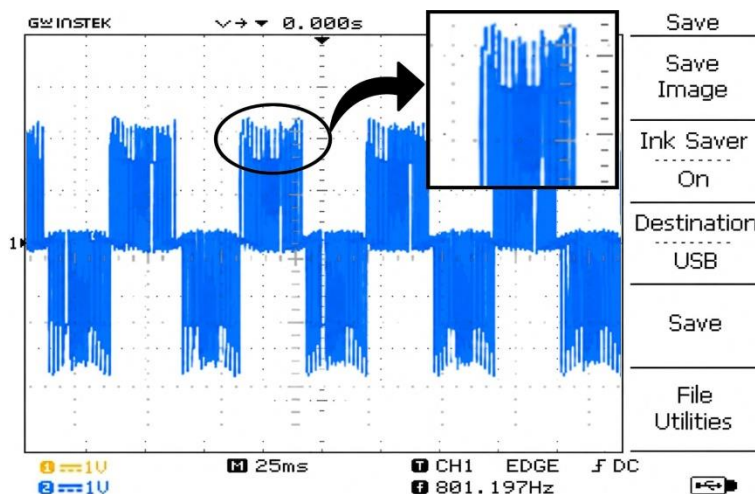
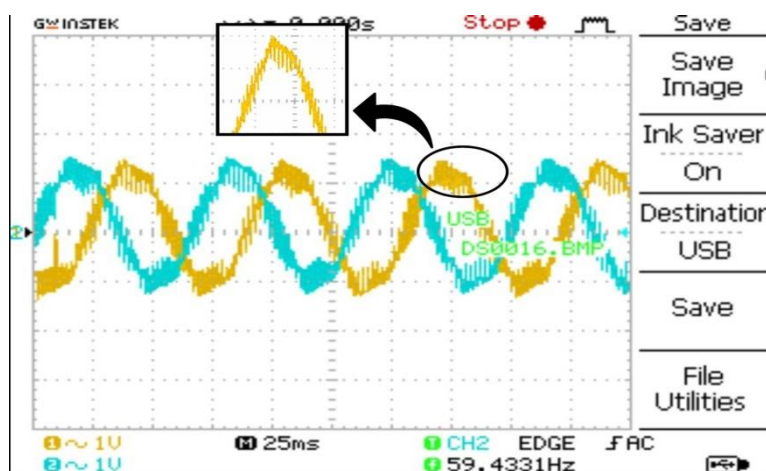
It can also be observed that the signals are regular and similar, which indicates stable control operation and proper inverter functioning.

The variation in pulse width clearly reflects the application of the PWM modulation technique used to generate an AC output voltage from a DC source.

The obtained results confirm the successful generation of correct and balanced switching signals at the inverter outputs

III.11.2. Total Harmonic Distortion (THD)

THD (Total Harmonic Distortion) represents the total harmonic distortion ratio in the inverter output signal and is used to evaluate how close the waveform is to an ideal sinusoidal wave [52]. In inverter systems, the fast switching operation of electronic switches and the PWM technique generate harmonics that produce ripples and distortions in the output signal. The lower the THD value, the better the signal quality and the closer the waveform is to the desired sinusoidal shape, which improves load performance and reduces losses and vibrations. In our system, some distortions can be observed in the waveform, which slightly affects the inverter performance.



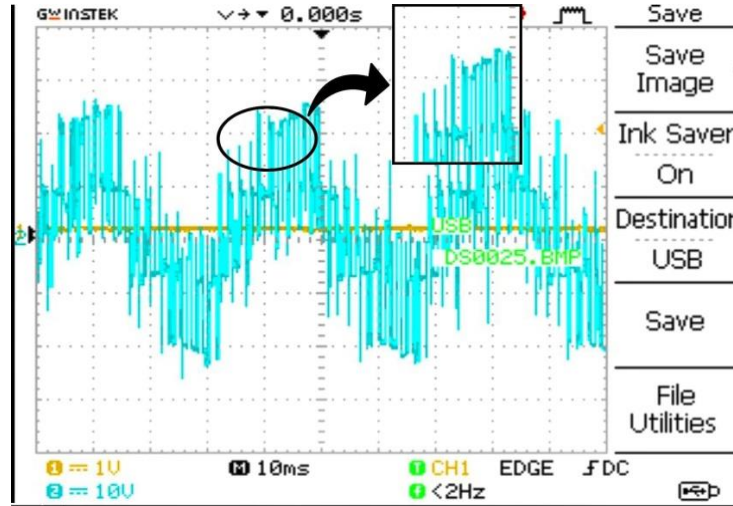
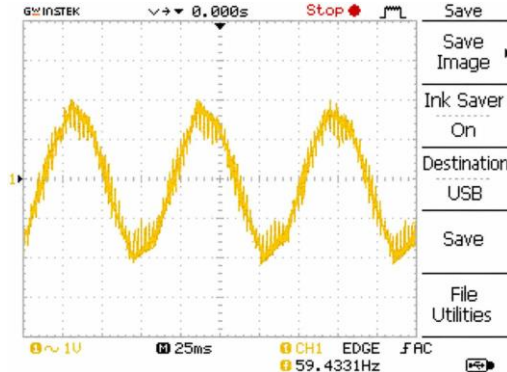


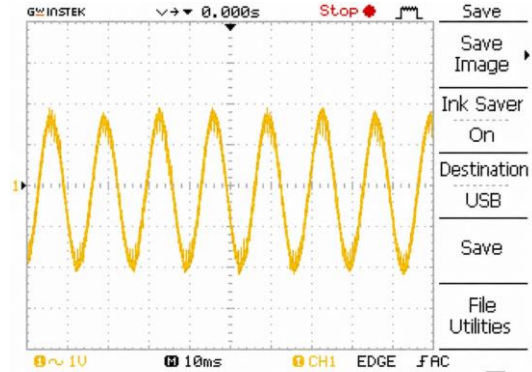
Figure III.38: Total Harmonic Distortion (THD)

III.11.3. voltage/frequency control

Represents an experimental result showing that increasing the frequency leads to an increase in speed.



PWM waveform(A)60-Hz



PWM waveform(A)120-Hz

Figure III.39: voltage/frequency control

The control of output frequency in voltage source inverters is a fundamental technique used to regulate the speed of AC machines in variable-speed drive systems. As discussed in modern power electronics literature, the synchronous speed of an induction motor is directly proportional to the supply frequency, making frequency variation an effective method for speed regulation. Increasing the output frequency results in an increase in motor speed, while decreasing it reduces the speed accordingly. Moreover, frequency changes influence the temporal behavior of the inverter output waveforms, affecting the current ripple and harmonic content. At higher operating frequencies, the switching dynamics become faster, which may slightly affect the Total Harmonic Distortion (THD) of the output signal. To maintain constant air-gap flux and avoid magnetic saturation in the motor, the voltage is adjusted proportionally with frequency using the well-established constant V/f control strategy, which ensures stable and efficient operation across a wide speed range [35].

III.12. Technical Challenges

III.12.1. Shoot-through Phenomenon

During the practical implementation of the inverter, particular attention was given to the shoot-through phenomenon, which is considered one of the serious faults that may occur in voltage source inverters. This phenomenon occurs when the upper and lower switches of the same inverter leg are turned on [51]. simultaneously, resulting in a direct short circuit across the DC power supply. Consequently, very high currents may flow, causing damage to the power devices and reducing the reliability of the system. To avoid this problem, an appropriate dead-time was inserted between the complementary control signals.

III.12.1. Overheating

The overheating of power electronic components is one of the important challenges observed during inverter operation. It results from conduction and switching losses in power transistors and driver circuits, which generate heat, especially when operating at high switching frequencies or for long periods. Excessive temperature rise can negatively affect system quality and component lifetime. Therefore, suitable cooling methods and appropriate component selection were taken into consideration to ensure safe and stable operation.

III.12.2. Signal Distortion

Some distortion was observed in the output voltage and current waveforms of the inverter due to rapid switching operations and the effects of components and non-ideal operating conditions. This distortion leads to an increase in harmonic content and a reduction in the quality of power supplied to the load. To minimize these effects, the Sinusoidal Pulse Width Modulation (SPWM) technique was adopted, which contributed to improving the waveform shape and reducing harmonic distortion.

III.12.3. Dead-Time Insertion and Protection Strategies

Dead-time insertion is a protection strategy that was implemented to enhance system reliability and protect the inverter from potential faults. Several protection strategies were applied, including the insertion of dead-time between complementary gate-drive signals to prevent shoot-through conditions. In addition, attention was given to proper printed circuit board design, adjustment of gate-drive signals, and monitoring of system performance during operation. These methods contributed to improving inverter stability and ensuring safe and efficient operation.

III.13 Conclusion

In conclusion, this chapter presented the design and practical implementation of the proposed three-phase inverter system. The different stages of inverter development were described, including the PCB design process, hardware implementation, and experimental setup. Furthermore, simulation and experimental results were analyzed to evaluate the performance of the implemented control strategy. The obtained results demonstrated the inverter's ability to generate balanced three-phase output voltages using the Sinusoidal Pulse Width Modulation (SPWM) technique. In addition, several practical challenges, such as shoot-through, overheating, and signal distortion, were identified and addressed through appropriate protection and control measures. Overall, the experimental results confirmed the quality and performance of the proposed inverter system and provided a solid foundation for future improvements and practical applications.

General Conclusion

General cConclusion

In this work, a complete three-phase inverter control system based on the SPWM technique was designed, simulated, and experimentally implemented. The study covered the theoretical principles of PWM modulation, inverter modeling in MATLAB/Simulink, hardware design of the power and driver stages, and real-time control using the TMS320F28379D development board. The simulation results confirmed the effectiveness of the proposed control strategy in generating balanced three-phase output signals with acceptable waveform quality. Furthermore, the experimental implementation validated the practical feasibility of the system, demonstrating successful generation of PWM signals, proper operation of the gate driver circuits, safe switching through dead-time insertion, and stable inverter performance under real operating conditions. The obtained voltage and current waveforms showed good agreement with the theoretical and simulation results, while the THD analysis highlighted the impact of switching harmonics on output quality. Despite some practical challenges such as signal distortion, component heating, and shoot-through risks, appropriate design solutions were implemented to ensure reliable and safe operation. Overall, the developed inverter system proved to be an effective solution for DC-to-AC power conversion applications. Future work may focus on implementing advanced control techniques such as SVPWM or closed-loop current control, improving output filtering, and enhancing efficiency and harmonic performance for high-power industrial and renewable energy applications.

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