UNIVERSITY KASDI MERBAH – OUARGLA

Faculty of New Information and Communication Technologies

Department of Electronics and Telecommunications

Master Thesis

Domain: Science and technologies

Field: Automation

Specialty: Automation and systems

Presented by**:**

Gheribi Mohammed Anes

Bensaci Madjd-Eddin

Control of the Quasi-Z-source inverter using model predictive control

Before the jury:

Mr. BOUZIDI Mansour	**Prisedent**	**MCA**	**UKM OUARGLA**
Mr. Rachdi mohmed yacine	**Examinator**	**MCA**	**UKM OUARGLA**
M.me CHAIB Ibtissam	**Supervisor**	**MCB**	**UKM OUARGLA**

University Year: 2025/2026

ملخص:

تُقدِّم هذه الرسالة دراسة شاملة حول العاكس من نوع quasi-Z-source (qZSI) والتحكم به باستخدام تقنية التحكم التنبؤي النموذجي .(MPC) تبدأ الدراسة باستكشاف الخصائص البنيوية والمبادئ التشغيلية لعائلة العواكس من نوع Z-source، مع التركيز بشكل خاص على العاكس quasi-ZSI نظراً لأدائه المحسَّن، وتياره الداخل المستمر، وانخفاض الضغط على مكوناته. كما يتم استعراض مختلف استراتيجيات التحكم، مع التركيز على نهج التحكم التنبؤي. تم تصميم نموذج لاستراتيجية MPC وتنفيذه بهدف تحسين أداء النظام من خلال تقليل خطأ التتبع وإدارة سلوك التبديل. وقد أُجريت دراسة محاكاة تفصيلية باستخدام برنامج MATLAB/Simulink للتحقق من فعالية استراتيجية التحكم المقترحة. تم تقييم الأداء تحت ظروف تحميل مختلفة من حيث خرج تيار المحث، واستقراره، مما يدل على قدرة هذه التقنية على تحسين جودة الخرج وضمان التشغيل المستقر حتى في ظل انخفاض جهد الدخل.

الكلمات المفتاحية :العاكس(quasi-Z-source (qZSI ، التحكم التنبؤي النموذجي(MPC) ، حالة الإطلاق(shoot-through) ، خرج تيار المحث، تموج التيار، استقرار النظام.

RESUME

This dissertation presents a comprehensive study of the quasi-Z-source inverter (qZSI) and its control using Model Predictive Control (MPC). The study begins by examining the structural characteristics and operational principles of the Z-source inverter family, with a particular focus on the quasi-ZSI due to its improved performance, continuous input current, and reduced component stress. Various control strategies are reviewed, with special emphasis on the predictive control approach. The MPC strategy is modeled and implemented to enhance system performance by minimizing tracking error and managing switching behavior. A detailed simulation study is conducted using MATLAB/Simulink to verify the effectiveness of the proposed control scheme. The performance is evaluated under varying load conditions in terms of inductor current output and its stability, demonstrating the technique’s ability to improve output quality and ensure stable operation even under low input voltage conditions.

Keywords: quasi-Z-source inverter (qZSI), Model Predictive Control (MPC), shoot-through state, inductor current output, current ripple, system stability.

ACKNOWLEDGEMENT

first of all, we thank Allah, the Almighty and Most Merciful, for giving us the strength, patience, and help to finish this work.

We would like to say a big thank you to our parents for always supporting us, encouraging us, and being there for us during our studies.

We also thank the jury members for reading our work and for giving helpful comments and suggestions.

We are very grateful to all our teachers who taught us and supported us during all these years.

Finally, we thank everyone who helped us, in any way, to complete this project

DEDICATION

First and foremost, all praise and gratitude are due to Allah, the Most Gracious the Most Merciful,

who blessed me with strength, patience, and the light of knowledge to complete this journey. Without His mercy, none of this would have been possible.

To my dear father Djamel,

your wisdom, hard work, and silent strength have been a guiding force in my life. Thank you for always believing in me, even when I didn't believe in myself. May Allah bless and protect you always.

To my beloved mother,

your endless love, heartfelt prayers, and constant presence have been A source of strength for me. Your sacrifices and care are etched into every achievement of mine May Allah reward you abundantly in both this life and the next.

To my cherished grandparents,

your legacy, values, and gentle love have shaped who I am. Though words can never fully express my gratitude, your influence lives on through this work.

To my dear brothers and sisters, your presence, laughter, and encouragement have been my fuel through tough times and joyful moments alike.

To my friends,

thank you for walking this road with me, sharing the stress, the hope, and the victories.

And to every teacher and mentor,

your guidance, patience, and wisdom have left an indelible mark on my heart and mind.

With sincere appreciation and love, I dedicate this thesis to all of you

MOHAMMED ANES

DEDICATION

To my dear parents

To my sisters and brothers

To all my family

To all my teachers

To all my friends and colleagues

To the entire family of the Department of

Electronics and Telecommunications

I dedicate this modest work

MADJD EDDIN

TABLE OF CONTENT:

LIST OF FIGURES:

LIST OF TABLES:

LIST OF ABBREVIATIONS AND SYMBOLS:

ZSI: z-source inverter

ST: shoot-through state

MBC: maximum boost control

MCBC: maximum constant boost control

CBC: constant boost control

SBC: simple boost control

PWM : pulse width modulation

QZSI : quasi z-source inverter

VSI : Voltage Source Inverter

CSI : Current Source Inverter

C1: Z-source impedance capacitor

C2: Z-source impedance capacitor

L1: Z-source impedance inductor

L2: Z-source impedance inductor

B: boost factor

d: duty cycle

G : the voltage gain

T: the control cycle

T_{sh}: shoot − through time

T0: Time interval of the zero vector U0

T1: time interval of active vector U1

T2: Time interval of the active vector U2

U1: active vector 1

U2 : active vector 2

m: modulation index

V_{dc}: input voltage of the impedance network

Vc: capacitor voltage of impedance network

Vi: output voltage of impedance network

Vn: negative straight line

Vp: positive straight line

DC: direct current

AC: Alternating Current

PV: Voltage Positive

PN: Voltage Negative

RHP: Right-Half Plane

MPC: Model predictive control

P_{o-ref}: output power

v_{c-ref}: capacitor voltage reference

i_{L-ref}: inductor current reference

i_{o-ref}: output current reference

$v_{c1}(k)$: capacitor voltage

$i_{L1}(k)$: inductor current

$g(x)$: cost function

THD: Total harmonic distortion

NST: Non-Shoot-Through

ST: Shoot-Through

PI: proportional -Integral control

C: Capacitor

L: Inductor

GENERAL INTRODUCTION

The increasing demand for high-efficiency, reliable, and flexible power conversion systems has led to an unparalleled evolution in the field of power electronics. Among these evolutions, the integration of renewable energy resources, such as photovoltaic (PV) systems, into the electrical grid has presented further challenges in terms of voltage regulation, dynamic response, and control complexity. These challenges call for new inverter topologies and intelligent control strategies for stable and optimum performance under various operating conditions [1].

Traditional voltage source inverters (VSIs) and current source inverters (CSIs) have limitations in handling wide input voltage variation and bidirectional power flow without additional converters. To this end, the Z-Source Inverter (ZSI) and its derivatives, especially the Quasi-Z-Source Inverter (QZSI), have emerged as promising options due to their unique impedance network that can provide both voltage boost and inversion in a single stage [2]. These topologies provide improved reliability, reduced component count, and improved system efficiency [3][4].

Control of these non-linear and time-varying systems needs sophisticated techniques more than traditional linear controllers. Model Predictive Control (MPC) has attracted great interest in the last few years due to its capability in managing constraints, predicting future behavior, and its fast dynamic response. MPC, when used with QZSI, presents accurate control of system dynamics, thus being an attractive candidate for renewable energy systems.

MPC operates by using a dynamic model of the system to predict future trajectories of system variables (such as current and voltage) over a specified prediction horizon. Based on these predictions, a cost function is defined, which represents the control objectives — such as minimizing tracking error, reducing voltage ripple, or maintaining current within safe limits — while respecting operational constraints (e.g., voltage, current, and switching limitations). An optimization algorithm is then used to find the best control action that minimizes this cost function. Only the first optimal control input is applied, and the entire process is repeated at every sampling interval in a receding horizon fashion. [5][6].

This thesis is organized in four chapters:

Chapter 1 provides an extensive overview of the Z-Source Inverter, its classifications, operating principles, and control strategies, with specific focus on the Quasi-ZSI and comparison with the conventional ZSI.

Chapter 2 introduces the fundamental concepts of Model Predictive Control, its advantages and limitations, and a step-by-step application of MPC to QZSI, including system modeling, prediction, and cost function design.

Chapter 3 is dedicated to simulation studies and performance evaluation of the QZSI under MPC. The system is modeled and simulated in MATLAB/Simulink, where the effectiveness of the proposed control strategy is validated with various test scenarios and performance.

The objective of this work is to explore the synergy between MPC and QZSI topology for enhancing system performance in renewable energy conversion systems. Through theoretical development and simulation analysis, this study contributes to the existing development of intelligent power electronics control

CHAPTER 1:

MODELING AND CONTROL OF THE Z-SOURCE INVERTER (ZSI)

1.1 Introduction:

The Z-source inverter (ZSI) is a sophisticated single-stage power conversion topology which combines voltage boosting and inversion functions tackling the issues pertaining to traditional voltage-source inverters (VSI) and current-source inverters (CSI). In contrast to other inverters, the ZSI allows shoot-through states which enhances system dependability, while allowing for both voltage buck and boost operations. This chapter explores the working principles, pros, modeling techniques, and control methods of the ZSI [7].

1.2. Z-Source Inverter:

The Z-source inverter (ZSI) is a type of power converter that overcomes the inherent limitations of traditional Voltage Source Inverters (VSIs) and Current Source Inverters (CSIs). It achieves this by incorporating a unique impedance network composed of two inductors and two capacitors, configured in an "X" shape, which links the power source to the inverter bridge. This innovative topology enables the inverter to regulate input voltage fluctuations and achieve voltage boosting without the need for a separate DC-DC converter. Figure (2-1) presents the Simplified diagram of a ZSC inverter [1].

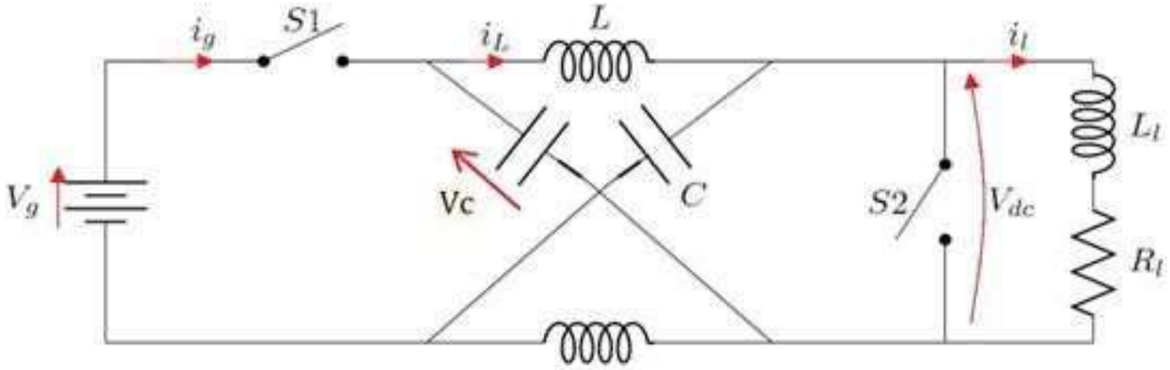


Figure (1-1): Simplified diagram of a ZSC inverter

1.3. Advantages and disadvantages of ZSI:

The ZSI not only includes a Buck-boost capability but also lacks the traditional suppression time seen in regular inverters. The benefits of the ZSI compared to conventional VSI or CSI are extensive and include various aspects [8]:

The Zero Voltage Switching Inverter, or ZSI, serves as a flexible DC input option that encompasses more than just batteries. It can also utilize different sources such as voltage or current inputs and handle loads like diode rectifiers, transistor converters, inductors, capacitors, and several others. This adaptability enables the ZSI to be used in many settings, including variable output voltages from sources like fuel cells and solar power systems. With the ZSI, the AC voltage can be modified to any level between zero and very high values.

In contrast to VSI (Voltage Source Inverter) or CSI (Current Source Inverter), the ZSI functions as a Buck-Boost inverter, which provides distinct benefits. Moreover, various PWM (Pulse Width Modulation) techniques can be employed to control the ZSI, enhancing its operational flexibility. Therefore, the ZSI proves effective across all ranges of power conversion, underscoring its multifunctional abilities. However, a drawback exists: the identified RHP zero in the Z-source impedance network cannot be resolved merely by modifying Z-source parameters. There is a need for more research into compensation strategies [8].

1.4. TOPOLOGIES:

1.4.1. Bidirectional ZSI:

The basic ZSI topology can be modified to create a bidirectional ZSI (BZSI), as shown in Figure (2-2). In this topology, the input diode (D) is replaced by a bidirectional switch (S7). This operates in regenerative mode in the same way as the diode operates in inverter mode, Its gate signal is the complement of the ST signal. The BZSI can exchange energy. between AC and DC energy storage in both directions. [9] [10].

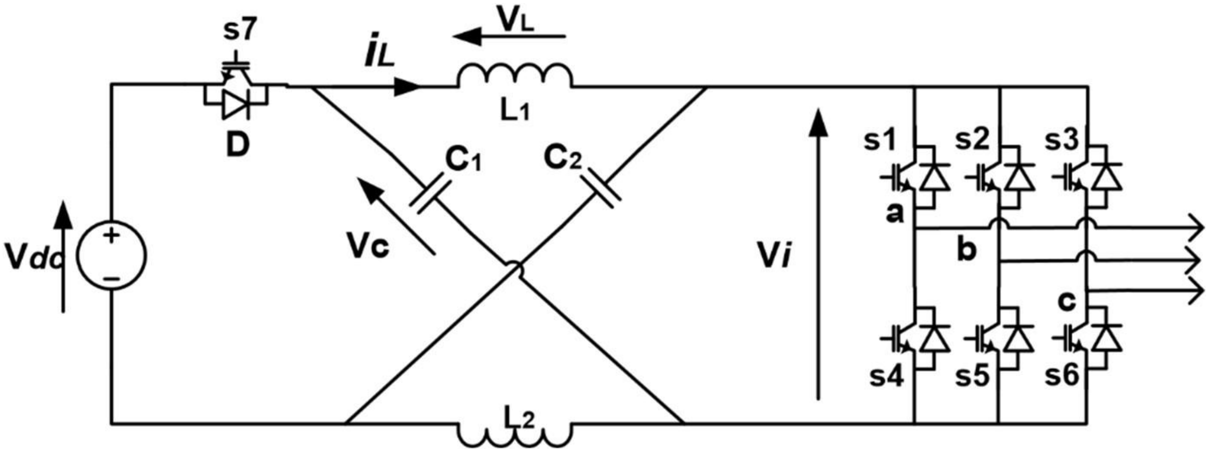


Figure (1-2): Bidirectional ZSI

1.4.2 High-performance ZSI:

As shown in Figures (2-3), the high-performance ZSI (HP-ZSI) can operate at a wide load range. a small Z-network inductor. It eliminates the possibility of DC link voltage drops and It also simplifies the Z-network inductor design. The HP-ZSI is derived from the basic ZSI topology. by incorporating an additional capacitor (C) and a bidirectional switch (S7). [11]

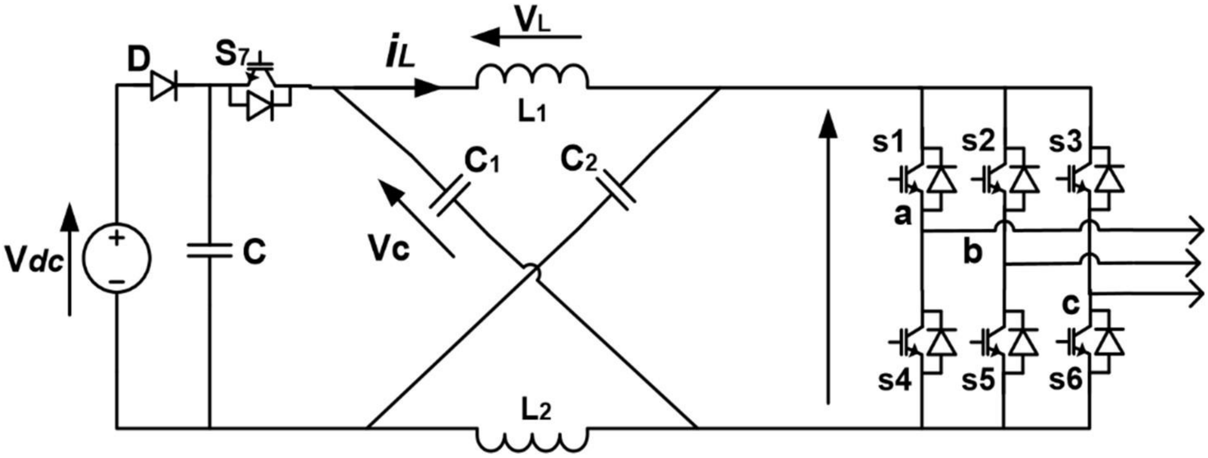


Figure (1-3): The high-performance ZSI

1.4.3. The improved ZSI:

A huge inrush current exists at the start-up of the ZSI. The initial voltage across the Z-source capacitors are zero, so the capacitors are charged immediately to half the input voltage. Then, the resonance of the Z-source capacitors and inductors begins, resulting in a large voltage and current surges, which could damage the devices. Due to the inherent current path in the basic ZSI topology at start up, the soft-start capability required to suppress resonant current at startup. The improved ZSI (IZSI), as shown in Figures (2–4), is derived from the basic ZSI topology by exchanging the positions of the inverter bridge and the input diode, and by inverting their connection directions. The elements used are exactly the same as in the basic ZSI topology. Although the IZSI produces the same voltage boost, the capacitor voltage stress can be significantly reduced. In addition, it has an inherent inrush current limitation ability, as there is no current path at start up [12].

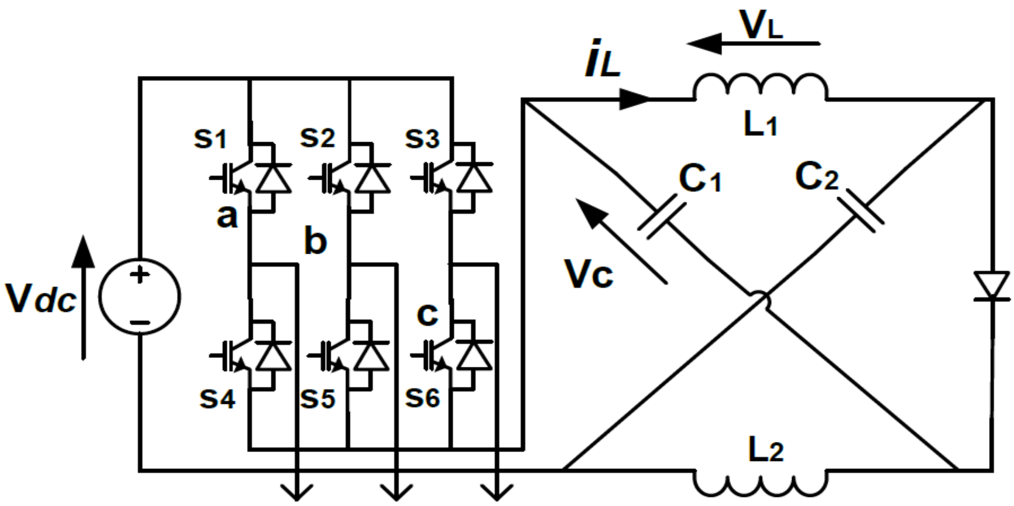


Figure (1-4): The improved ZSI

1.4.4 Neutral point ZSI:

In [13], a four-wire ZSI (FWZSI) based on the HP-ZSI topology was proposed, which involved adding an additional bidirectional switch in the negative current path, as well as splitting the input DC capacitor to obtain a neutral point, as shown in Figures (2–5). Another solution was proposed in [14]:

The addition of a fourth inverter leg to create a virtual DC link at a zero point, known as a four-leg ZSI (FLZSI), as shown in Figure (2-6).

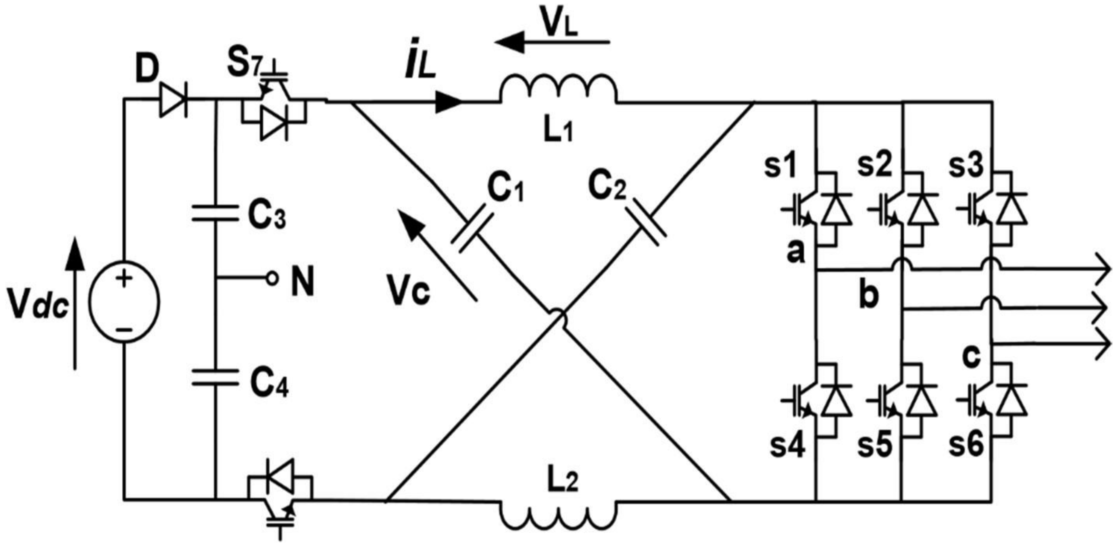


Figure (1-5): four-wire ZSI

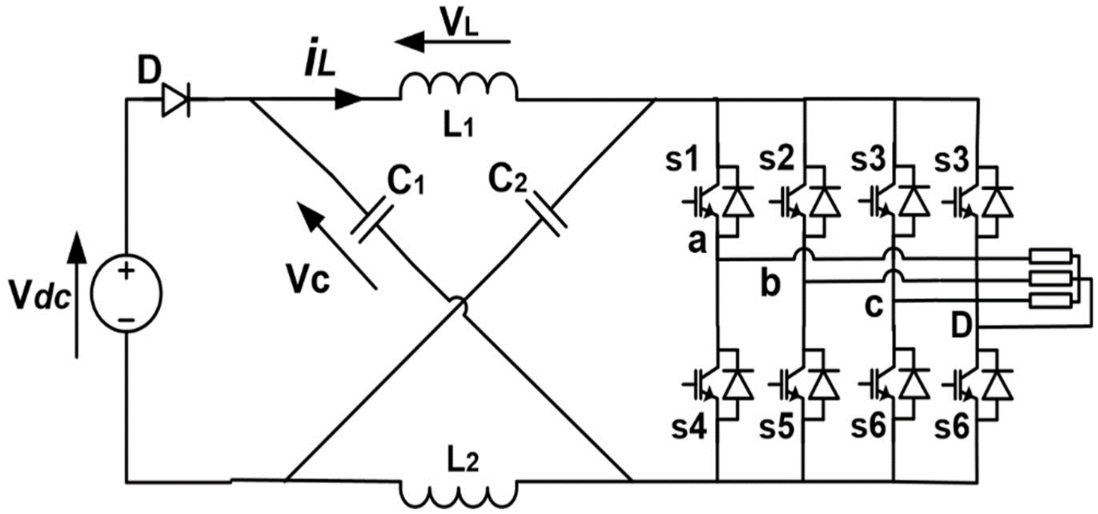


Figure (1-6): four-leg ZSI (FLZSI)

1.4.5 The quasi-ZSI (QZSI):

The quasi-ZSI (QZSI) with discontinuous input current has been proposed in [3, 4] and is shown in Figure (2-7). It has several advantages over the basic ZSI topology, including a lower component rating (Z-network capacitors voltages are lower than in the case of the basic

ZSI topology), the common grounding of the input power source and the DC link, which reduces the common mode noise in the system.

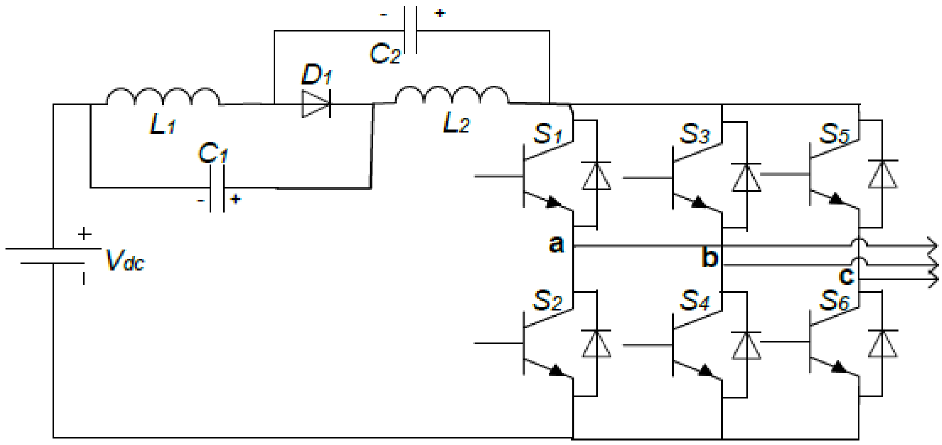


Figure (1-7): The quasi-ZSI (QZSI) with discontinuous input current

A QZSI with a continuous input current has been proposed in [4]. The topology is shown in Figure (2-8). It has another advantage over the discontinuous input QZSI. Its input current is continuous due to the presence of an input inductor, which buffers the source current and reduces the source voltage [2].

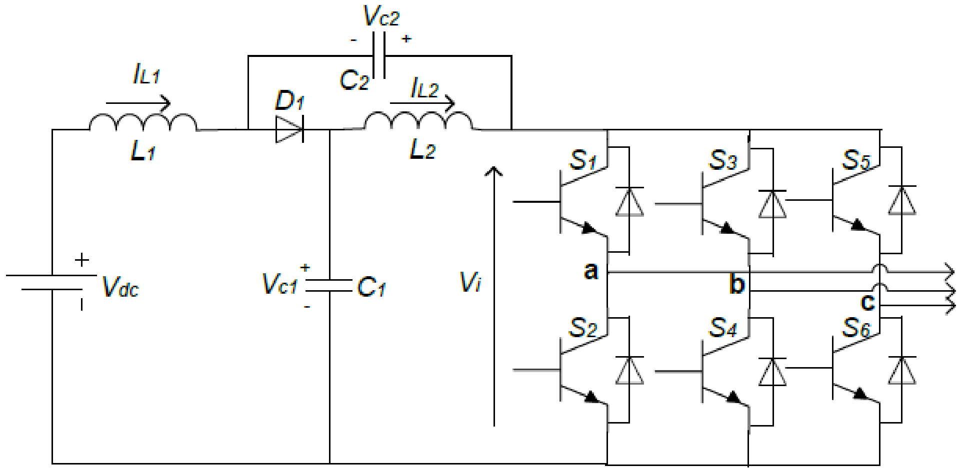


Figure (1-8): QZSI with a continuous input current

All Z-source inverter (ZSI) topologies are based on the principle of controlling the shoot-through state to achieve voltage boosting at the input. The variations among these topologies lie in the arrangement of components, efficiency, and intended applications. Among them, the quasi-Z-source inverter (QZSI) is currently one of the most widely adopted configurations, particularly in photovoltaic (PV) systems), due to its ability to provide a continuous and low-ripple input current, which is essential for the stable operation of solar energy systems.

1.5. Comparison between ZSI and QZSI:

Several modifications and improvements have been proposed to the original ZSI (Z-Source Inverter) to overcome the disadvantages of the traditional ZSI and improve its performance. Some have succeeded in increasing the boost factor, while others have reduced the capacitor voltage and the start-up inrush current. As a result, each ZSI-derived inverter topology has its own advantages and disadvantages in solving the problems of the original configuration, making it difficult for users to quickly and accurately select the appropriate network in practice. Table (2.1) summarises the differences between the ZSI and the QZSI (quasi-Z source inverter) in terms of components and characteristics. Table (2.2) compares the topologies in terms of their advantages and disadvantages [15].

Table (1.1): Comparison of ZSI and qZSI configurations

type	D	C	L	Integrated winding	Continuous input current	Inrush current	Common ground
ZSI	1	2	2	-	No	Yes	No
QZSI	1	2	2	-	Yes	No	Yes

Table (1.2): Comparison of ZSI and qZSI.

Structure	Advantages	Disadvantages
ZSI	Overcoming the problems of VSI and CSI Simultaneous switching of switches in the same leg Suitable for PV applications	Discontinuous input current High inrush current at startup High capacitor voltage requires large capacitance Shoot-through duty ratio less than 0.5
QZSI	Continuous input current Reduced capacitor sizing Lower current stress compared to ZSI Suitable for PV applications	Shoot-through duty ratio less than 0.5 Not suitable for very low DC sources

1.6. Principle of operation and modeling of the ZSI:

1.6.1. State shoot- through:

The Z-Source Inverter (ZSI) uses shoot-through states, where both the upper and lower switches of a phase leg are turned on at the same time, to increase the DC bus voltage [16].

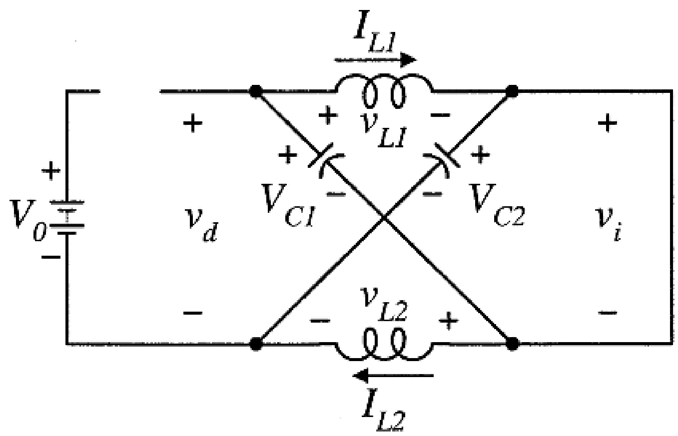


Figure (1-9): Equivalent circuit shoot-through zero state of the ZSI viewed from the dc link.

The circuit is in a shoot-through zero state. As a result, the capacitor voltage is boosted. During this state, the sum of the two capacitors' voltages is greater than the DC source Voltage (V_{C1} + V_{C2} > V_0). The diode is reverse biased and the capacitors charge the inductors. The voltages across the inductors are [16]:

$$\begin{cases} V_{L1} = V_{C1} \\ V_{L2} = V_{C2} \end{cases} \qquad (1)$$

Assuming the capacitor voltage is constant, the inductor current increases linearly. Remains constant during this period. Due to the symmetry (L_1= L_2= L) and (C_1= C_2= C), Of the circuit, (V_{L1}=V_{L2} =V_L), (I_{L1}=I_{L2} =I_L) and (V_{C1}= V_{C2} =V_C) [16].

Through the above, we get:

$$V_C = V_L \, , V_D = 2V_C \quad \text{and} \quad V_i = 0 \qquad (2)$$

1.6.2. Active states (Non-shoot-Through State):

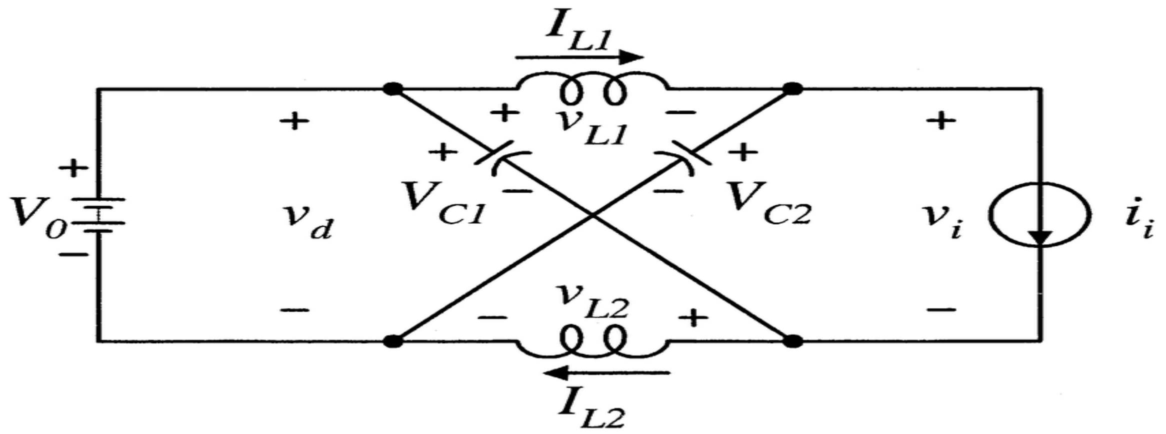


Figure (1-10): Equivalent circuit non-shoot-through switching states of the ZSI viewed from the dc

The inverter is in a non-shoot-through state, which is (one of six active states and two traditional zero states) and the inductor current satisfies the following equation:

$$I_L > \frac{1}{2} I_i \qquad (3)$$

Due to the circuit's symmetry, the capacitor current I_{C1} andI_{C2}, as well as the inductor currents

$I_{L1}$and I_{L2}, should be equal to each other, respectively.

In this configuration, the input current from the DC source is as follows:

$$I_{in} = I_{L1} + I_{C1} = I_{L1} + (I_{L2} - I_i) = 2I_L - I_I > 0 \qquad (4)$$

Therefore, the diode is conducting and the voltage across the inductor is:

$$V_L = V_0 - V_C \qquad (5)$$

$$V_D = V_0 \qquad \text{(V0 is DC source voltage)} \qquad (6)$$

Over time, the inductor current decreases until it reaches a level at which the condition of (3) can no longer be met. At this point, the input current I_{in}or the diode current decreases to zero [14].

In addition to the previous two types, ZSI has new modes that may exist. for small inductance and high inductance ripple [16].

1.6.3. Calculation of the elevation factor β:

Set the non-shoot-through state for an interval of T_1 in one switching cycle T.

We have $T = T_0 + Ts$. So, From Figure (2-10) we can see that the equivalent circuit is [17].

$$V_I = V_C - V_L \qquad (7)$$

According to relationship (5) we have:

$$V_i = 2V_C - V_0 \qquad (8)$$

The relationship between the switching period, the voltage of the capacitor and the dc source is:

$$\frac{V_C}{V_0} = \frac{T_S}{T_S - T_0} \qquad (9)$$

The peak DC-link voltage across the inverter bridge is expressed in equation (2) It can be rewritten as follows:

$$V_i = V_C - V_L = 2V_C - V_0 = \frac{T_S}{T_S - T_0} V_0 = \beta . V_0 \qquad (10)$$

- **β** is boosting factor: $\beta = \frac{T}{T_S - T_2} = \frac{1}{1 - 2(\frac{T_0}{T_S})} \geq 1$ (11)

Where T is total time period, T_0 is the shoot through period, and D_0 is the ST duty ratio.

$$D_0 = \frac{T_0}{T_S} \qquad (12)$$

The output peak phase voltage from the inverter can be expressed as:

$$V_{AC} = M \frac{V_1}{2} = M.\beta \frac{V_0}{2}$$ (Where M is the modulation index) (13)

From this equation, we can see that the output AC voltage can be controlled by the value of M and β, the boost factor [17].

1.7. Boost control techniques for Z-source inverter:

1.7.1. Simple boost control:

. The simple-boost method is used to control the shoot-through duty ratio. Figure (2.11) illustrates this method, where two horizontal lines (Vp and Vn) are employed. VP is equal to or higher than $V - ref$, and V_nn is equal to or lower than $V - ref$. Whenever the triangular carrier exceeds V_p or falls below Vn, the Z-source inverter (ZSI) is in the shoot-through state; otherwise, the ZSI keeps the same active states as a conventional inverter.

In this method the maximum shoot-through duty ratio, $Dmax$, decreases as the modulation index M increases. The maximum value of D is given by:

$$D_{max} = 1 - M \qquad (14)$$

The formulae for the relationship between the modulation rate M and the overvoltage factor B discussed in [18] are:

$$B_{max} = \frac{1}{1-2D_{max}} = \frac{1}{1-2(1-M)} \qquad (15)$$

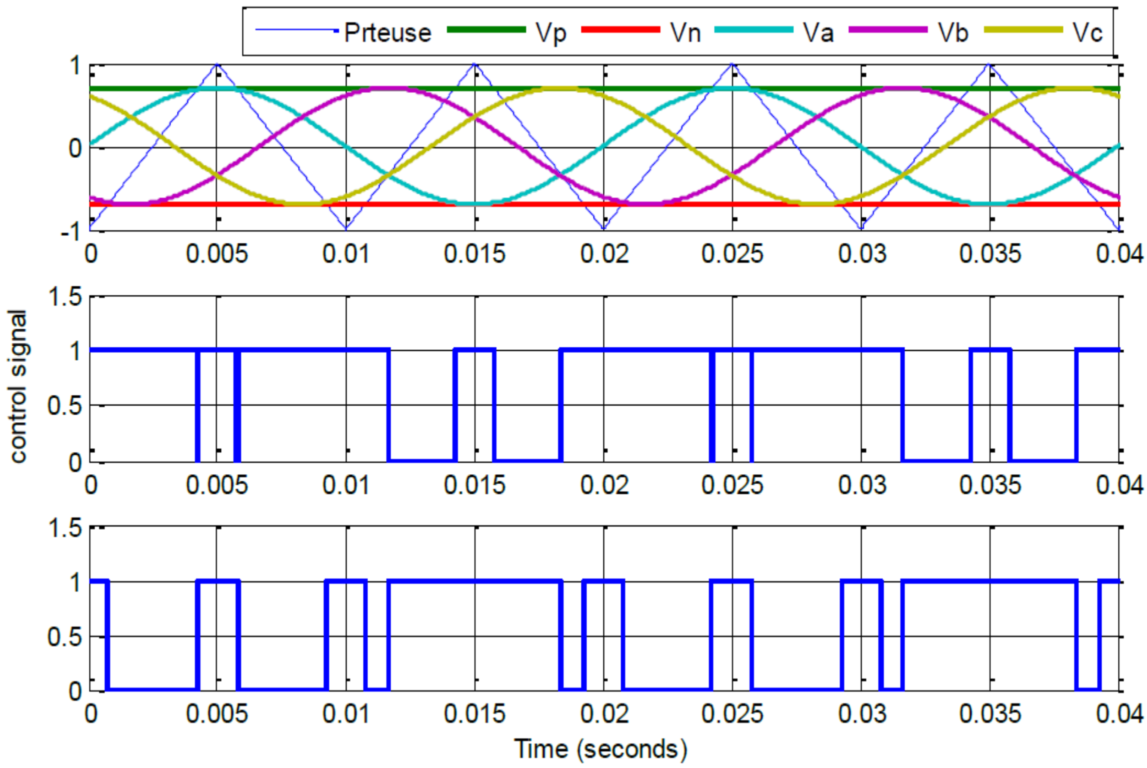


Figure (1-11): The simple boost command

$$M = \frac{B+1}{2B} \qquad (16)$$

We will finally have the gain:

$$G = M \times B = \frac{V_{ac}}{v_g/2} = \frac{B+1}{2} \qquad (17)$$

We obtain the max gain as a function of M:

$$G_{max} = \frac{M}{2M-1} \qquad (18)$$

1.7.2 Maximum boost control:

This method converts all the zero states of a conventional inverter into shoot‑ through states (almost the same as in conventional PWM) while preserving the active states. In this technique the maximum and minimum of the reference signals are compared with the triangular carrier: if the maximum is lower than the carrier or the minimum is higher than the carrier, the Z‑ source inverter (ZSI) enters the shoot‑ through state. With this approach the shoot‑ through duty ratio D repeats every 120 degrees $\frac{3}{\pi}$.

Assuming the switching frequency is much higher than the modulation frequency, the shoot‑ through ratio within a single switching cycle over the interval $\left[\frac{\pi}{6}, \frac{\pi}{2}\right]$

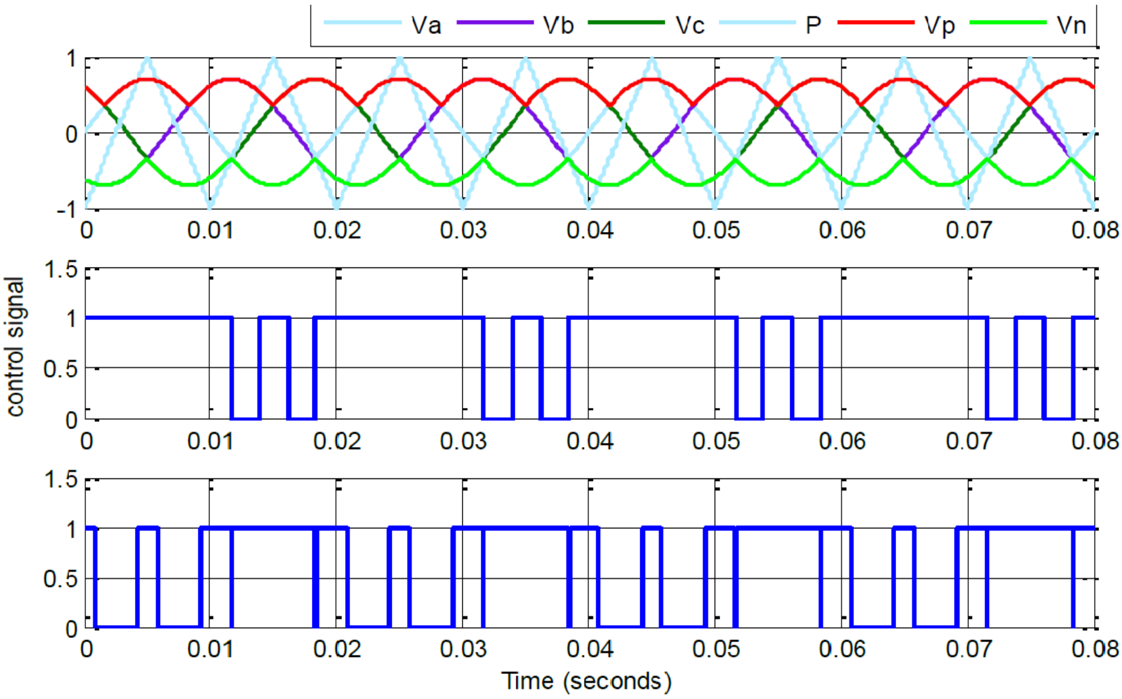


Figure (1-12): Waveforms of maximum boost control**.**

The duty cycle of the shoot-through average can be calculated as follow:

$$\frac{\bar{T}_{sh}(\theta)}{T_s} = \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \frac{2-\left(m\sin\theta - m\,\sin\left(\theta-\frac{2\pi}{3}\right)\right)}{2}\, d\theta = \frac{2\pi - 3\sqrt{3m}}{2\pi} \qquad (19)$$

$$B=\frac{1}{1-(2\bar{T}_{sh}/T_s)}=\frac{\pi}{3\sqrt{3}} \quad (20)$$

For a specified boost factor B, the modulation index corresponding to the MBC strategy can be determined:

$$m=\frac{\pi(B+1)}{3\sqrt{3B}} \quad (21)$$

the voltage gain is defined as:

$$G=m.\,B=\frac{\pi(B+1)}{3\sqrt{3}} \quad (22)$$

1.7.3. Maximum constant boost control method control:

To reduce volume and cost, it is important to keep the duty cycle constant. At the same time, for any given modulation index, a greater voltage boost is desired to reduce the voltage stress on the switches.

The maximum constant boost control achieves the maximum voltage gain while always keeping the shoot-through duty ratio constant [19]. Figure (2.13) shows the sketch map of maximum constant boost control with third harmonic injection. In this method, the third harmonic is injected with the modulating signal. This means that to the reference (sine wave) is added another sine wave with exactly three times the frequency of the reference and an amplitude generally one-sixth of the modulating wave. The new expression of the reference signal is given by

$$\grave{V_a}(t)=m\sin(\omega t)+\frac{m}{6}\sin(3\omega t) \quad (23)$$

This signal reaches a maximum amplitude of $\frac{\sqrt{3}}{2}m$, from which we can derive the following expressions for the two straight lines:

$$\begin{cases} V_P=\frac{\sqrt{3}}{2}m \\ V_n=-\frac{\sqrt{3}}{2}m \end{cases} \quad (24)$$

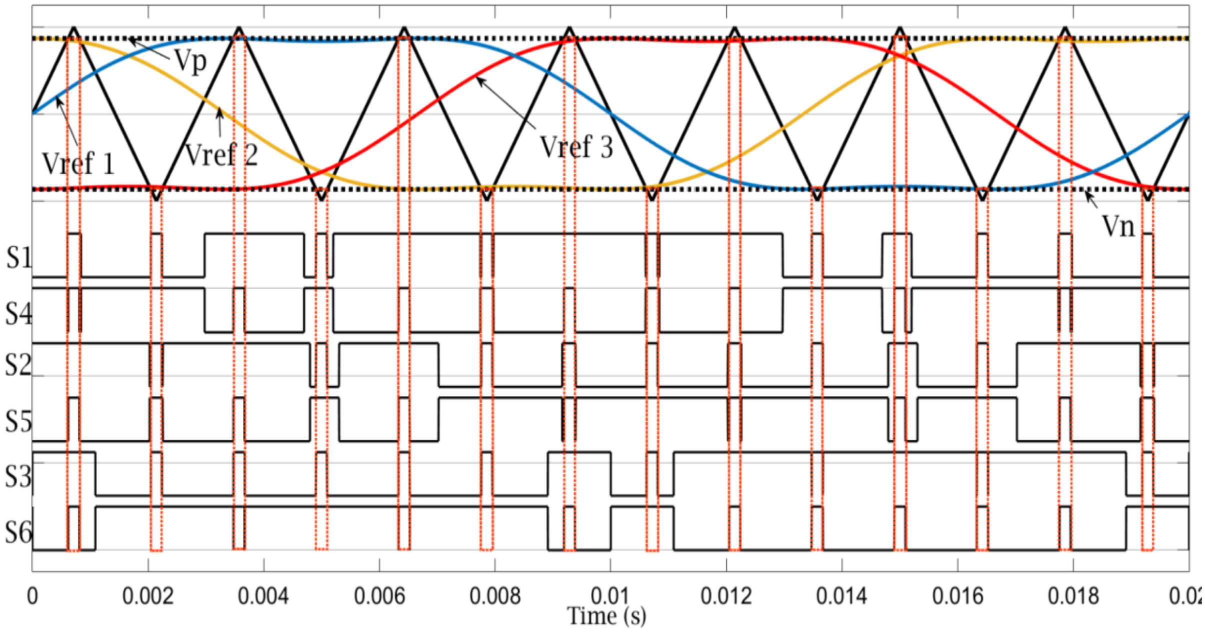


Figure (1-13): Maximum constant boost control method

The value of d can be determined using the same method applied in the SBC strategy, and it is calculated as follows:

$$d = 1\frac{\sqrt{3}}{2m} \quad (25)$$

By substituting the latest expression for the duty cycle d into the relevant equations, we obtain the expressions for the amplification factor B and the total gain G of the inverter as functions of the modulation index m, as follows:

$$B = \frac{1}{\sqrt{3}m-1} \quad (26)$$

$$G = \frac{m}{\sqrt{3}m-1} \quad (27)$$

Thus, the voltage gain as a function of the boost factor can be expressed as:

$$G = \frac{1+B}{\sqrt{3}} \quad (28)$$

1.8. ZSI control strategies:

1.8.1. Space vector pulse width modulation (SVPWM) control:

Space Vector Pulse Width Modulation (SVPWM) is a technique designed for three-phase AC motor inverter control. It works depending on a special switching sequence. The effect is the combination of different pulse widths. As a result, the windings in the AC motor will generate three-phase sinusoidal waves with a 120° phase shifts and fewer harmonic [17].

Compared with SPWM, SVPWM is widely used in variable-frequency drives applications due to its various advantages, such as:

- higher DC voltage utilisation.

- higher fundamental component and fewer harmonics.

-SVPWM allows for better control of the AC motor by a digital control system.

1.8.2. Model predictive control (MPC):

One of the most advanced power electronics control methods available today is a predictive controller. Simplifying the primary control criteria and goal function will increase the effectiveness of this control strategy. In addition to cutting down on the quantity of computations per cycle of sampling. In ZSI, the output load currents, inductor current, and inverter capacitor voltage are all controlled to their predetermined points by identifying the necessary condition, either active or shoot through [20][21].

The bloc diagram of the MPC is displayed in Figure (2-14)

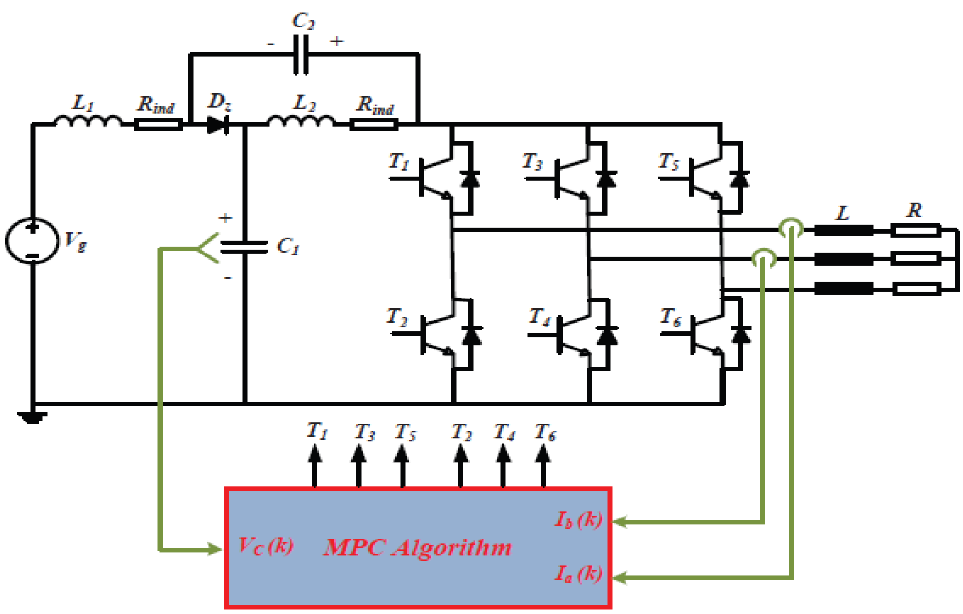


Figure (1-14): Model predictive control (MPC)

1.1. Conclusion:

The Z-Source Inverter provides certain distinct benefits concerning its boost capability of voltage and fault tolerance. Different modeling and control techniques are applied to enhance its performance for various applications. The feasibility and efficiency of ZSI systems are still improved with innovations like the QZSI and advanced control methods such as MPC.

CHAPTER 2:
Model Predictive Control for QZSI

2.1. Introduction:

In advanced power electronics and control systems, the integration of intelligent and predictive control strategies is essential to achieve high performance, efficiency and robustness. Among these strategies, Model Predictive Control (MPC) has emerged as a powerful method due to its ability to handle multivariable systems with constraints, its predictive capabilities, and its optimization-based decision framework [20]. This chapter discusses the principles of MPC, its application to QZSI, modelling approaches and performance analysis through simulation.

2.2. Principle of model predictive control (MPC):

Model Predictive Control (MPC) has emerged as a promising strategy for addressing the control challenges associated with power electronic systems such as quasi-Z-source inverters (qZSI). MPC utilizes a predictive model of the system to estimate future behavior over a finite prediction horizon and selects the optimal control action by minimizing a predefined cost function at each sampling instant. Its capability to explicitly incorporate system constraints, manage multiple control objectives, and directly operate on the discrete switching states of the inverter makes it particularly suitable for qZSI-based applications [22].

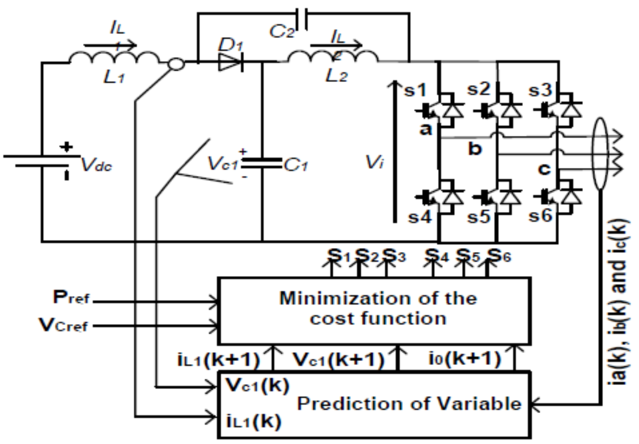


Figure (2-1): Model predictive control (MPC)

Figure (1) illustrates the basic structure of the MPC approach, while Figure (2) highlights the sequential process from system modeling to the final application of the optimal switching state, which follows the following stages:

2.2.1. Reference calculations:

The MPC process begins with the generation of reference signals based on the desired output power (P_{o-ref}). These reference values include the capacitor voltage reference (v_{c-ref}

), inductor current reference (i_{L-ref}), and output current reference (i_{o-ref}). This block ensures that the control system continuously tracks the desired operating point of the inverter under varying load and input conditions.[23]

2.2.2.System modeling and state measurement:

The second stage involves real-time measurement of system states such as capacitor voltage ($v_{c1}(k)$) and inductor current ($i_{L1}(k)$). These measurements serve as the initial conditions for the discrete-time model of the qZSI, which predicts the system's future behavior over the next sampling interval. The model outputs include the predicted capacitor voltage ($v_{c1}(k+1)$), inductor current ($i_{L1}(k+1)$), and output current ($i_o(k+1)$). This predictive capability is essential in handling the unique shoot-through operation of the qZSI, which differentiates it from conventional inverters. [23]

2.2.3. Prediction and optimization:

Using the predicted variables and the previously computed references, the controller evaluates a cost function $g(x)$ for all possible switching states. This cost function quantifies the deviation between the predicted and reference values of key variables. It typically incorporates performance indices such as tracking error, voltage ripple, and possibly total harmonic distortion (THD). [23]

2.2.4. Selection of optimal switching state:

After evaluating all candidate switching states, the one that minimizes the cost function is selected. This switching state either shoot-through or non-shoot-through (e.g., $S_0, S_1, .S_5$) is then applied to the qZSI at the next control interval. This closed-loop decision-making process ensures real-time tracking of reference signals, while satisfying system constraints and optimizing inverter performance. [23]

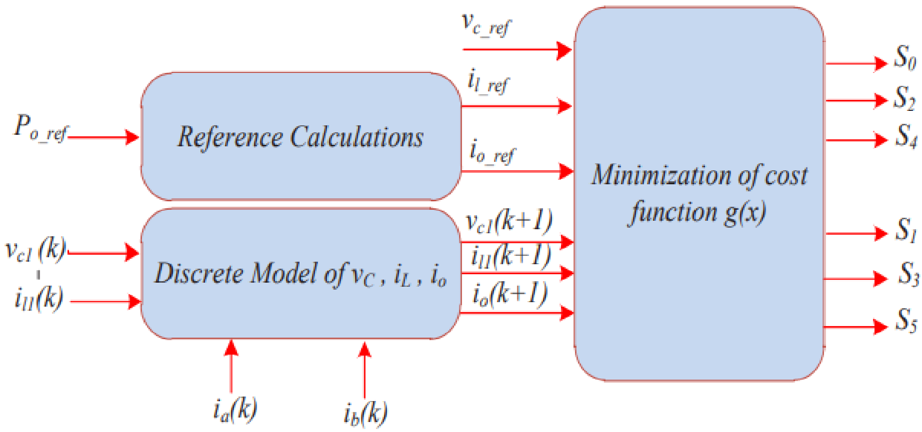


Figure (2-2): MPC strategy for QZSI

2.3. Advantages and disadvantages of MPC:

2.3.1. Advantages:

•Direct control of currents and voltages without the need for modulation units such as Pulse Width Modulation (PWM).

•Incorporates system constraints—such as voltage limits, current limits, and capacitor voltage—within the same control algorithm.

•Fast dynamic response compared to conventional control methods such as Proportional-Integral (PI) control.

•Multi-objective optimization is achievable through a single cost function.

•High flexibility in adaptation and customization for various applications (e.g., photovoltaic systems, motor drives, and power conversion systems).

•Reduction of Total Harmonic Distortion (THD) in current or voltage through precise control.

•Robust performance under load variations or generation conditions, such as solar irradiance fluctuations.

2.3.2. Disadvantages:

•High computational burden due to the need for fast execution of prediction calculations and optimal vector selection at each sampling period.

•Strong dependency on the accuracy of the converter's mathematical model—any modeling error may lead to performance degradation.

•Variable switching frequency (in Finite Control Set MPC), which complicates the design of output filters.

•Tuning of cost function weights can be challenging and may require extensive trial-and-error procedures.

•Higher implementation complexity in both programming and real-time execution compared to conventional methods like PI with PWM.

•Potential increase in power losses under certain conditions if the prediction algorithm is not optimally designed.

2.4.MPC modeling for QZSI:

This section details the dynamic behavior of the internal elements of the quasi-Z-Source Inverter (qZSI) under both operational modes: Non-Shoot-Through (NST) and Shoot-Through (ST). In addition, it includes the prediction model of the load voltage and current, which is essential for implementing the Model Predictive Control (MPC) strategy, the section provides the mathematical formulation of the cost function and outlines the implementation strategy of the control algorithm.

Table (2.1): inverter output voltage during various switching states

Output voltage		s_1	s_2	s_3	s_4	s_5	s_6
NST	v_0	Off	Off	Off	On	On	On
	v_1	On	Off	Off	Off	On	On
	v_2	On	On	Off	Off	Off	On
	v_3	Off	On	Off	On	Off	On
	v_4	Off	On	On	On	Off	Off
	v_5	Off	Off	On	On	On	Off
	v_6	On	Off	On	Off	On	Off
ST	v_7	Off	Off	On	Off	Off	On

2.4.1. State equations:

2.4.1.1. State Non-Shoot-Through (NST):

In the Non-Shoot-Through (NST) state, energy is transferred from the DC input source and inductors to the AC load while simultaneously charging the capacitors. The dynamic behavior of the internal elements, specifically the inductor L1 and the capacitor C1, can be described by the following set of differential equations [24]:

$$\begin{cases} L_1 \frac{di_{L_1}(k)}{dt} = v_{c_1}(k) - v_{DC}(k) + R_{ind} i_{L1}(k) \\ C_1 \frac{dv_{C_1}(k)}{dt} = i_{L_1}(k) - i_{inv}(k) \end{cases} \quad (29)$$

The inverter output current is given by:

$$i_{inv}(k) = i_a(k)S_a + i_b(k)S_b + i_c(k)S_c \quad (30)$$

The discrete-time prediction of the inductor current and capacitor voltage is:

$$\begin{cases} i_{L_1}(k+1) = \frac{T_s\left(v_g(K)-v_{c_1}(k)\right)+L_1 i_{L_1}}{L_1+R_{ind}T_s} \\ v_{c_1}(k+1) = v_{c_1(k)} + \frac{T_s}{C_1}(i_{L_1}(k+1) - i_{inv}(k+1)) \end{cases} \quad (31)$$

Were:

- R_{ind} is the stray resistance of the inductor.

- v_{DC} (k) is the input dc voltage, which is constant in the proposed algorithm.

- $i_{inv}(k)$ is the inverter output current.

- i_a , $i_b$and i_c are the three phase leg current.

2.4.1.2. State Shoot-Through (ST):

In the Shoot-Through (ST) state, energy is primarily stored in the inductors. The governing differential equations for the same internal components under this mode are [24]:

$$\begin{cases} L_1 \frac{di_{L_1}(k)}{dt} = v_{c_1}(k) - +R_{ind} i_{L1}(k) \\ C_1 \frac{dv_{C_1}(k)}{dt} = -i_{L_1}(k) \end{cases} \quad (32)$$

The corresponding discrete-time model becomes:

$$\begin{cases} i_{L_1}(k+1) = \frac{T_s v_{C_1}(k)+L_1 i_{L_1}(k)}{L_1+R_{ind}T_s} \\ v_{c_1}(k+1) = v_{c_1(k)} - \frac{T_s}{C_1} i_{L_1}(k+1) \end{cases} \quad (33)$$

2.4.1.3. Load Voltage and Current Prediction Model:

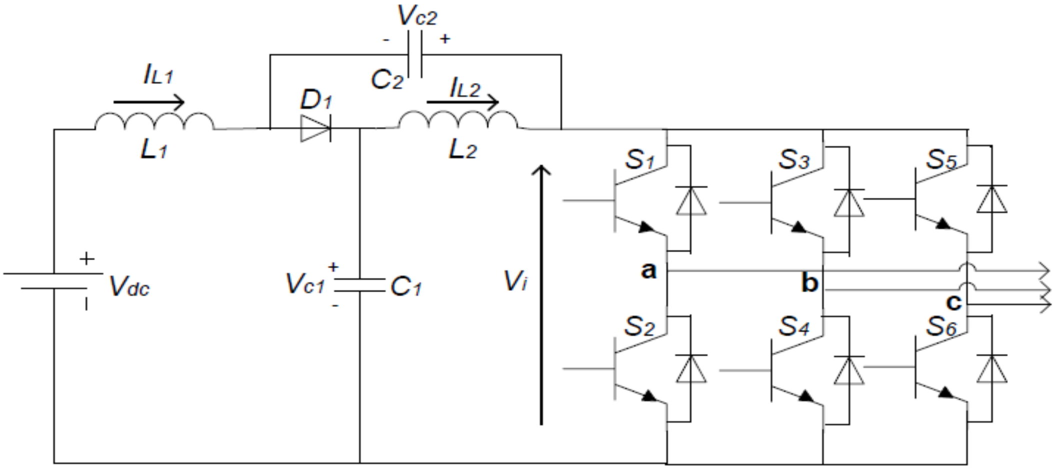


Figure (2-3) : circuit quasi Z-Source Inventer

For any switching condition within a specific sector, the output voltage area vector can be expressed in the fixed reference frame (α, β) and based on Figure (3 2) we express them as follows:

$$V_X(K+1) = \frac{2V_{DC}}{3}(S_a + aS_b + a^2 S_c) \quad (34)$$

To incorporate the load dynamics, the voltage can alternatively be described for an RL-type load as:

$$Vx(k+1) = R_{i_0}(k) + L\frac{d_{i_0}(k)}{dt} \quad (35)$$

Using Euler's method to approximate the derivative:

$$\frac{d_{i_0}(k)}{dt} = \frac{i_0(k) - i_0(k-1)}{T_S} \quad (36)$$

Substituting into the RL model yields:

$$\mathrm{i}_0(\mathrm{k}+1) = \frac{\mathrm{T_S}\,\mathrm{V_X}(\mathrm{k}+1) + \mathrm{L}\,\mathrm{i}_0(\mathrm{k})}{\mathrm{L} + \mathrm{R}\,\mathrm{T_S}} \quad (37)$$

This expression forms the basis for predicting future current behavior in the model predictive control (MPC) algorithm. By evaluating this expression for all possible switching combinations, the optimal switching state that minimizes the control objective can be selected at each sampling instant.

2.4.3. Cost function and optimization:

The cost function is a quantitative performance index used to evaluate all possible switching states of the inverter QZSI. It is typically defined to measure the deviation between predicted and reference values of key system variables such as inductor current, capacitor voltage and output current. This function guides the Model Predictive Control (MPC) in selecting the optimal control action at each sampling instant [25].

• Mathematical modeling:

The cost function is mathematically formulated to evaluate the control performance for each candidate switching state:

$$g(x) = |i_{\alpha-ref}(k+1) - i_{\alpha-o}(k+1)| + |i_{\beta-ref}(k+1) - i_{\beta-o}(k+1)| + \lambda|i_{\alpha-ref}(k+1) - v_{c_1}(k+1)| \quad (38)$$

Were:

• $i_{\alpha-ref}(k+1), i_{\beta-ref}(k+1)$:Reference values for the α and β axis output currents at the future time step k+1.
• $i_{\alpha-o}(k+1), i_{\beta-o}(k+1)$: Predicted output currents on the α and β axes at time $k+1$
• $v_{c_1}(k+1)$: Predicted capacitor voltage at time k+1
• λ: A weighting factor used to penalize the error between the reference current and the capacitor voltage

⇒Minimization criteria:

The MPC algorithm minimizes the cost function by selecting the switching state that yields the smallest error between predicted and reference values. The minimization criteria often include:

- **Tracking error**: The difference between predicted and reference output currents, inductor current, and capacitor voltage. Minimizing tracking error ensures accurate current shaping and voltage regulation.
- **Voltage ripple**: By including capacitor voltage error in the cost function, MPC reduces voltage ripple on the DC-link, improving power quality and system stability.
- **Total Harmonic Distortion (THD)**: Although not always explicitly included in the cost function, minimizing current tracking error indirectly reduces THD in the output current waveform, leading to cleaner power delivery.

Some MPC formulations use squared errors in the cost function to emphasize larger deviations and facilitate smoother optimization. Others use absolute errors for simplicity [5].

⇒System constraints:

MPC for qZSI respects several system constraints during optimization:

- **Switching state constraints:** Only feasible switching vectors (including shoot-through states unique to qZSI) are considered.
- **Physical limits**: Inductor current and capacitor voltage must remain within safe operating ranges to avoid component damage.
- **Computational constraints**: The cost function and optimization process are designed to be computationally efficient for real-time implementation, sometimes by reducing the number of switching states evaluated or simplifying the cost function.
- **Voltage boost requirements**: The shoot-through duty ratio is constrained to ensure proper voltage boosting without compromising inverter operation.

Some advanced MPC algorithms incorporate these constraints directly into the optimization or use heuristic rules to select switching states that satisfy constraints while minimizing the cost function.[26][27]

2.4.4. MPC algorithm:

To achieve precise and efficient real-time control of the quasi-Z-source inverter (qZSI), the effective implementation of a Model Predictive Control (MPC) algorithm is crucial. The flowchart below outlines the structured sequence of the MPC procedure, which includes the evaluation of both shoot-through (ST) and non-shoot-through (NST) switching states.

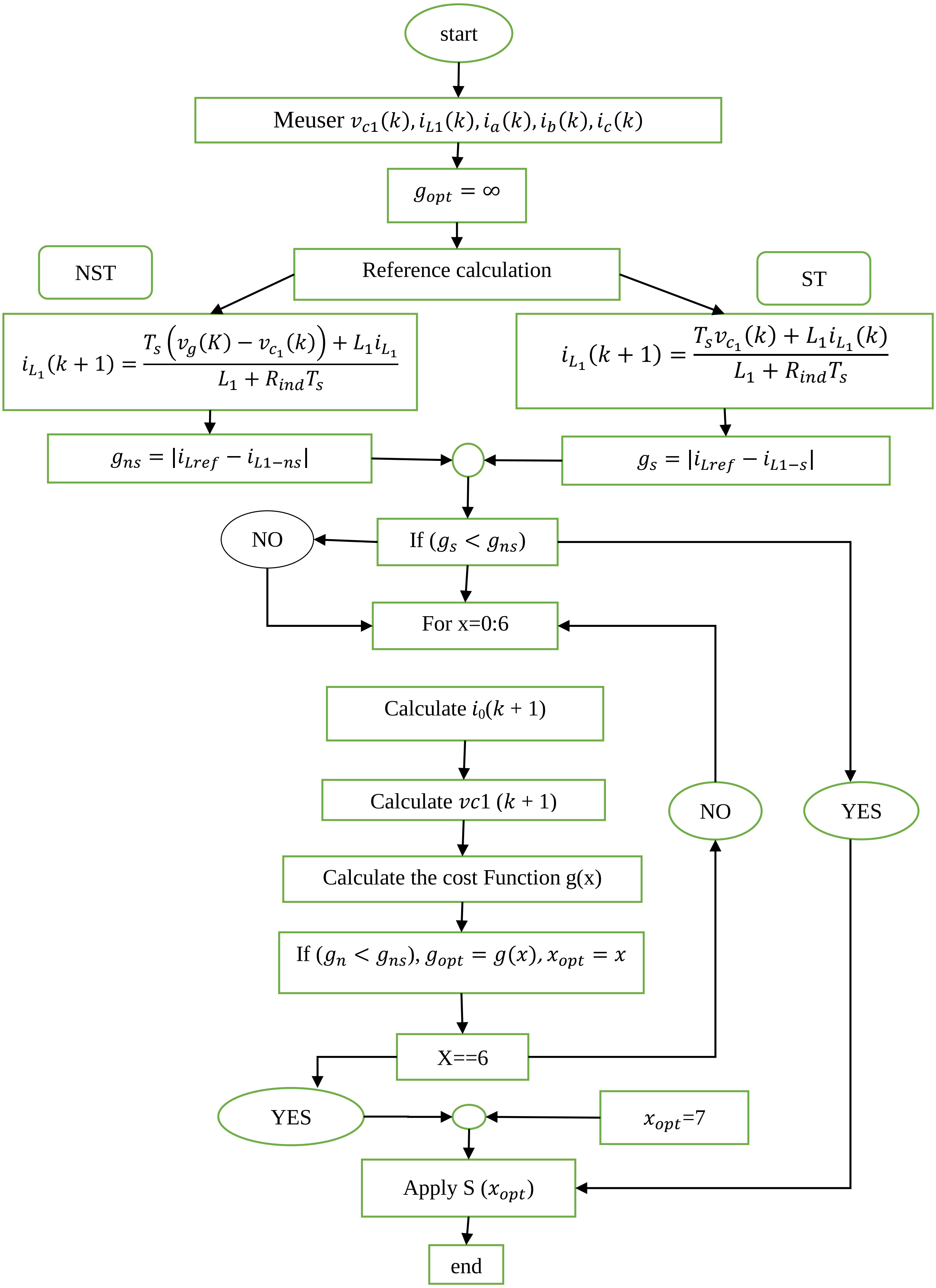


Figure (2-4): Flowchart of the MPC for QZSI.

In this case, the algorithm has three states to track: the voltage across the capacitor $vc(k)$, the current flowing through the inductor $iL(k)$, and the output currents for each of the three phases, which are given as $ia(k)$,$ib(k)$,$ic(k)$. With these inputs, reference current calculations are done and two operation modes are examined: Shoot-Through (ST) mode and Non-Shoot-Through (NST). In NST mode, the value of the inductor current in the next time step $iL(k+1)$ is predicted based on the voltage across the impedance network. In ST mode, the prediction accounts for the effect of the short-circuiting phase that increases energy within the network. The degrees of cost $gNST$and gST, which corresponds to the deviation of the inductor current from the reference value, are calculated in both modes. If ST mode offers lower cost, it is chosen first without further evaluation. Otherwise, the algorithm considers all valid switching vectors (where x is from 1 to 6). For each of these candidate vectors, the output currents and the output voltage of the capacitor are predicted. Based on the predicted currents and weights set earlier, cost function $g(x)$ is computed. The output of the algorithm with the smallest cost is selected as the optimal $xopt$, and the switching vector that will be executed S(x) is set to S(xop). From then on, any steps of computation that require time optimization will continuously be done at each time step without extra delays. These changes provide dynamic performance and fast response to changing values.

2.5. Conclusion:

This chapter provided a concise overview of applying Model Predictive Control (MPC) to the quasi-Z-source inverter (qZSI). It covered the core concepts of MPC, including system modeling, prediction, and optimal switching selection. The advantages and limitations of MPC were briefly discussed. Additionally, the modeling of qZSI under Shoot-Through and Non-Shoot-Through states was developed, leading to the formulation of state equations and a predictive control algorithm. This lays the groundwork for the simulation and evaluation in the next chapter.

CHAPTER 3:
SIMULATION RESULTS

3.1. Introduction:

This chapter aims to evaluate the performance of the Model Predictive Control (MPC) strategy applied to the quasi-Z-Source Inverter (qZSI), as described in the previous chapter. The evaluation focuses on the quality of the output current, inductor current, and DC-link voltage. To achieve this, a simulation model was developed in the MATLAB/Simulink environment to assess the system's performance under various operating conditions.

3.2. Simulation:

Two simulation subsystems were constructed: the first represents the detailed electrical model of the qZSI, while the second integrates the qZSI with the MPC controller and inverter to analyze system-level performance.

Figure (4.1) shows the electrical structure of the quasi-Z-Source Inverter, including its inductors, capacitors, diodes, and RLC branches. The system also includes measurement blocks for inductor current (il1), DC-link current (idc), and capacitor voltage (vc1). This model is essential for analyzing the internal behavior of the qZSI under dynamic switching conditions and forms the physical basis for control system integration.

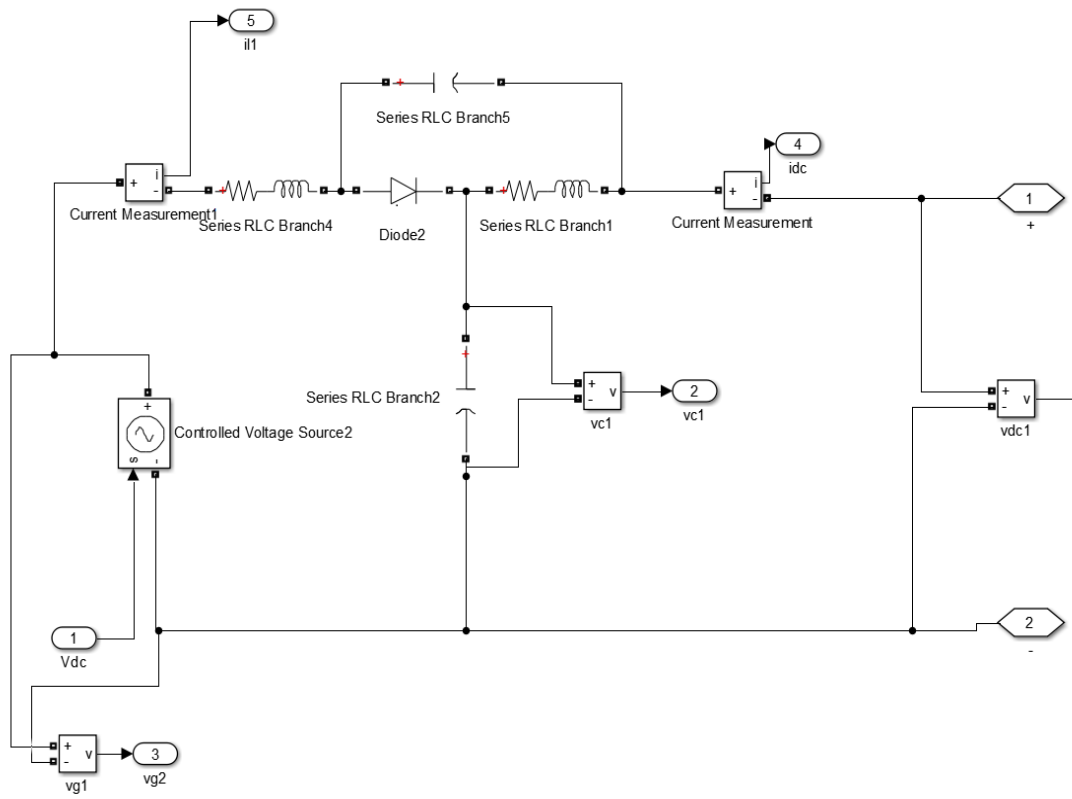


Figure (3.1): Bloc Diagram QZSI

Figure (4.2) illustrates the complete simulation model integrating the qZSI, the MPC controller (MPC1), and the three-phase inverter (onduluer) connected to multiple loads (load 1, load 2, load 3). The controller receives measured states such as inductor current (iL), capacitor voltage (Vc), and grid voltage (Vg) to compute the optimal switching sequence. The model outputs various signals, including load voltages and currents (Vch, Ich), which are stored and visualized using the To Workspace blocks for post-processing and analysis.

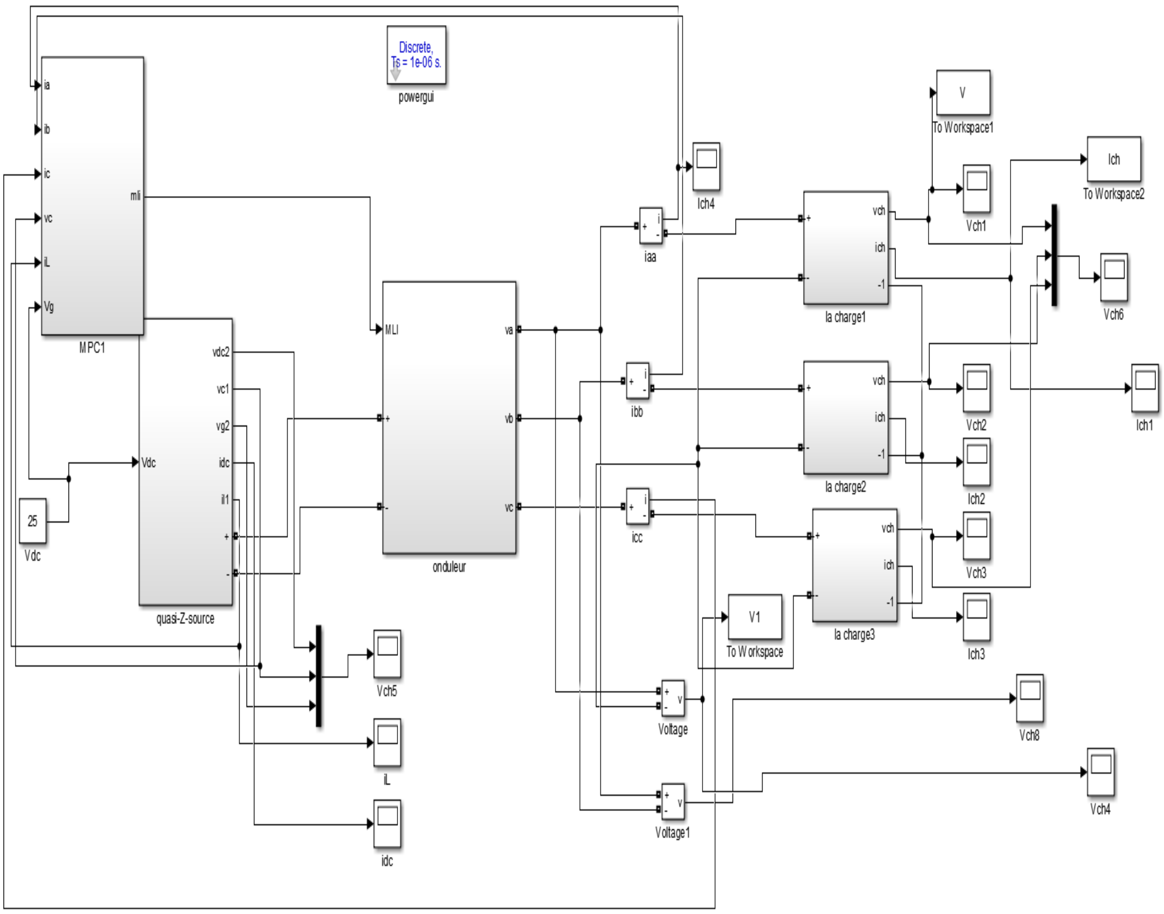


Figure (3.2): Complete Simulation Model of the qZSI with MPC Controller

These two models collectively enable comprehensive validation of the MPC algorithm's ability to regulate output voltage, suppress disturbances, and optimize dynamic response in real-time.

To support this simulation framework, a set of electrical parameters was carefully selected to ensure realistic and stable behavior of the qZSI system. The chosen values aim to minimize voltage and current ripples while maintaining an effective balance between dynamic performance and steady-state accuracy. Key electrical components such as inductors and capacitors were sized to provide adequate energy buffering and filtering, while resistances were tuned to reflect typical parasitic and load-related characteristics without imposing excessive power losses. The sampling time was also selected to be short enough to accurately capture the fast-switching dynamics required by the MPC algorithm. The selected parameter values used in the simulation model are summarized in the following table.

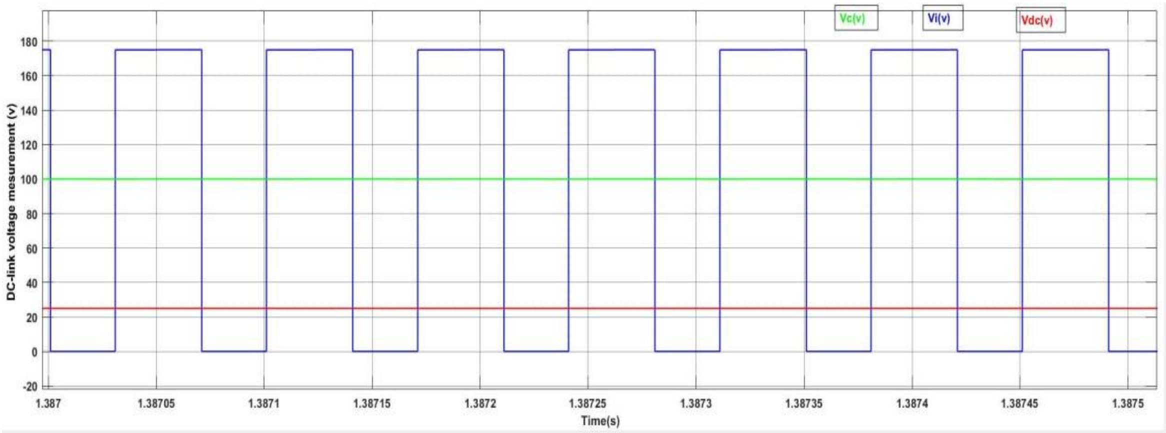
Table (3.1): Simulation and experimental parameters

Vdc	Lq	Cq	L_{load}	R_{load}	Ts	λ
25V	5mH	3300μF	40mH	11Ω	5μs	10

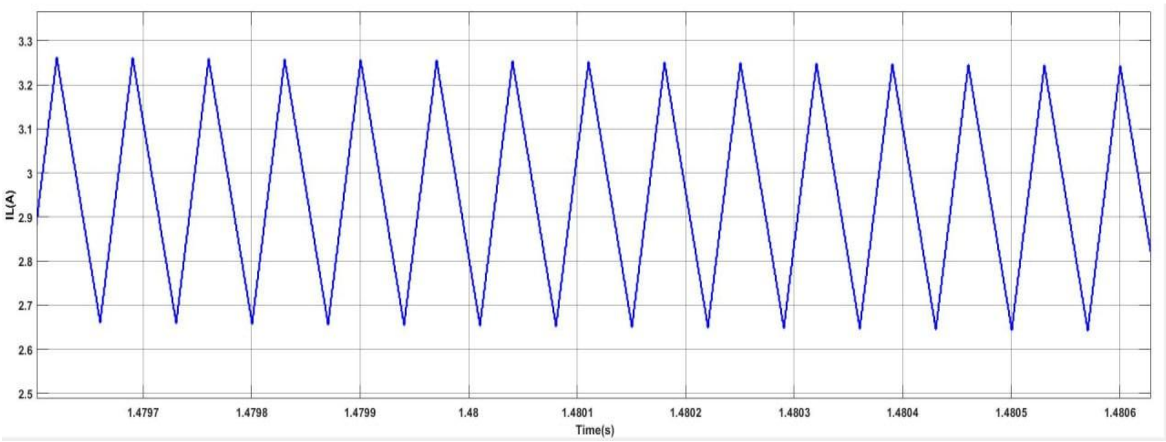
3.3. Results:

In the simulation model, the quasi-Z-source inverter (qZSI) was evaluated under various operating conditions to assess the effectiveness of the proposed Model Predictive Control (MPC) strategy. The reference values were selected to represent typical steady-state operating scenarios of the inverter. In particular, the reference inductor current (il_ref) was varied between 3 A, 5 A, and 7 A to simulate different load conditions. The reference capacitor voltage (vc_ref) was fixed at 100 V, while the input voltage (Vin) was maintained at a constant 25 V throughout the entire simulation period. Additionally, the reference output current $ich - ref = 2A$ was set to 2 A to evaluate the system's performance under a controlled output load condition.

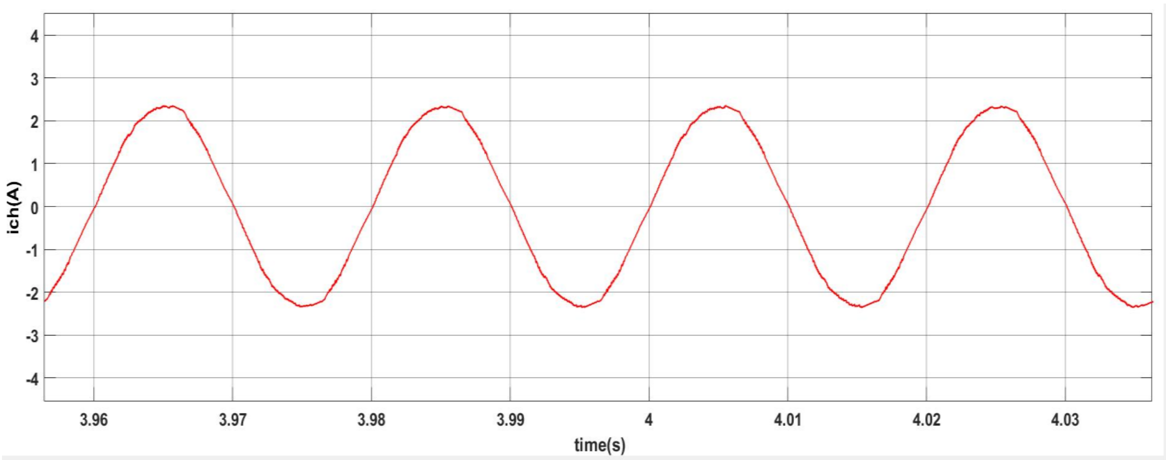
•When i_{l-ref}=3A, $v_{c-ref} = 100V$, *Vin=25,* $ich - ref = 2A$**:**



(A)



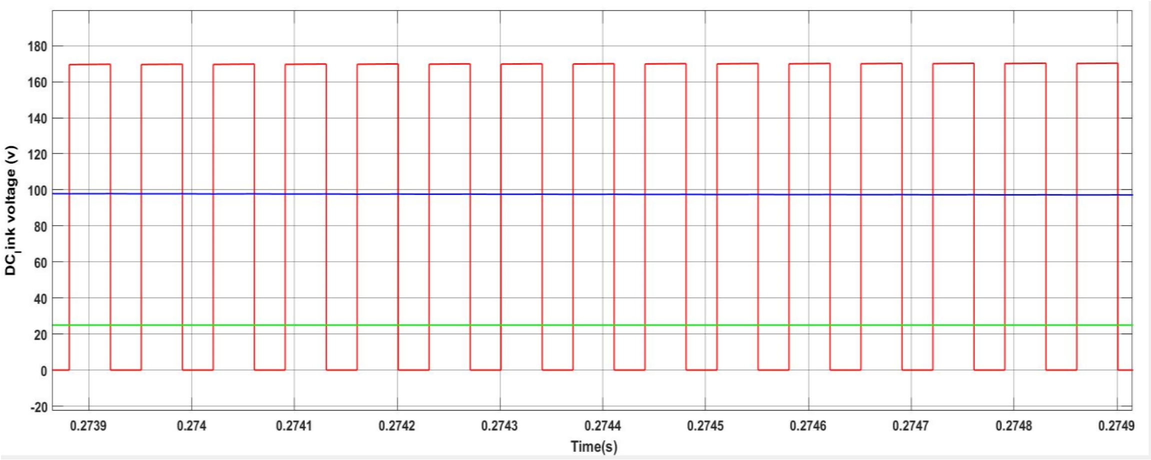
(B)



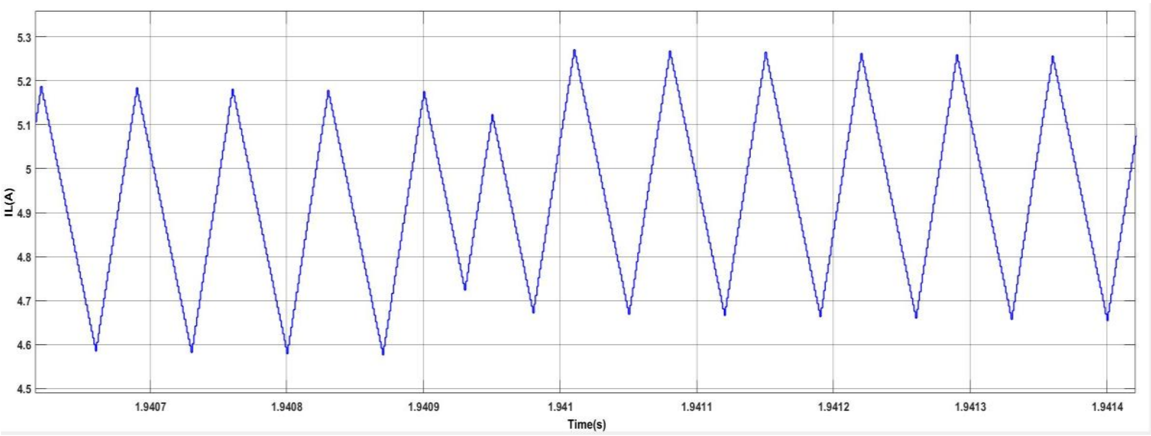
(C)

Figure (3.3): Simulation results for iL_ref=$3A$:(A) DC link voltage; (B) Inductor current iL; (C) Output current

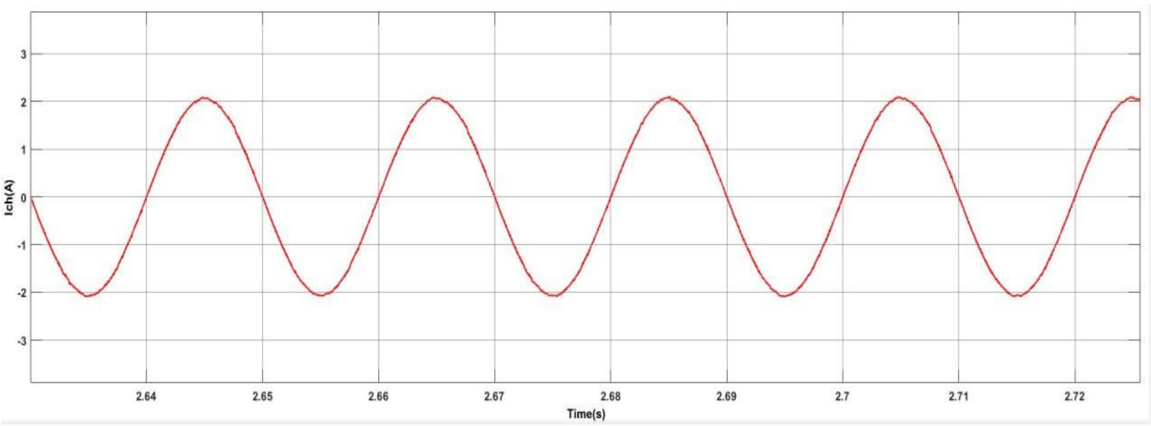
•When i_{l-ref}=5A, $v_{c-ref} = 100V$, Vin=25, $ich - ref = 2A$**:**



(A)



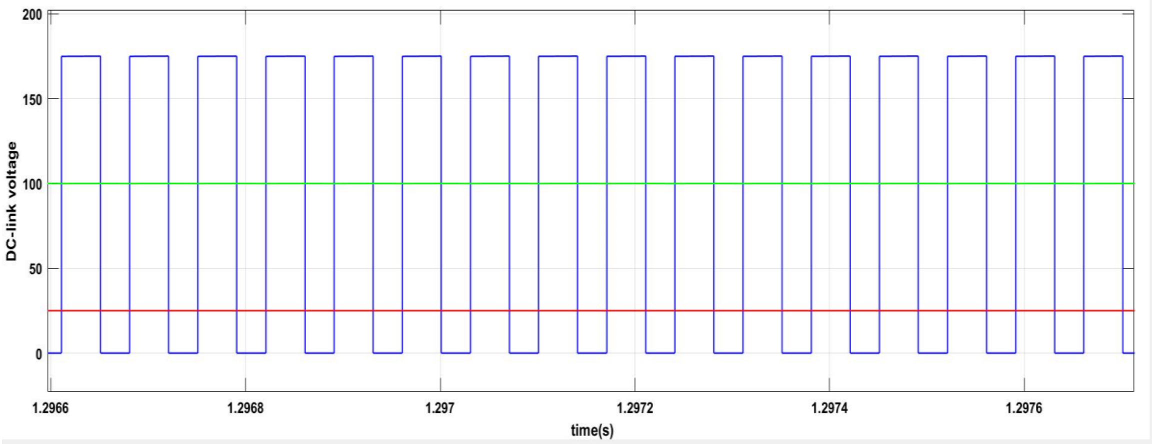
(B)



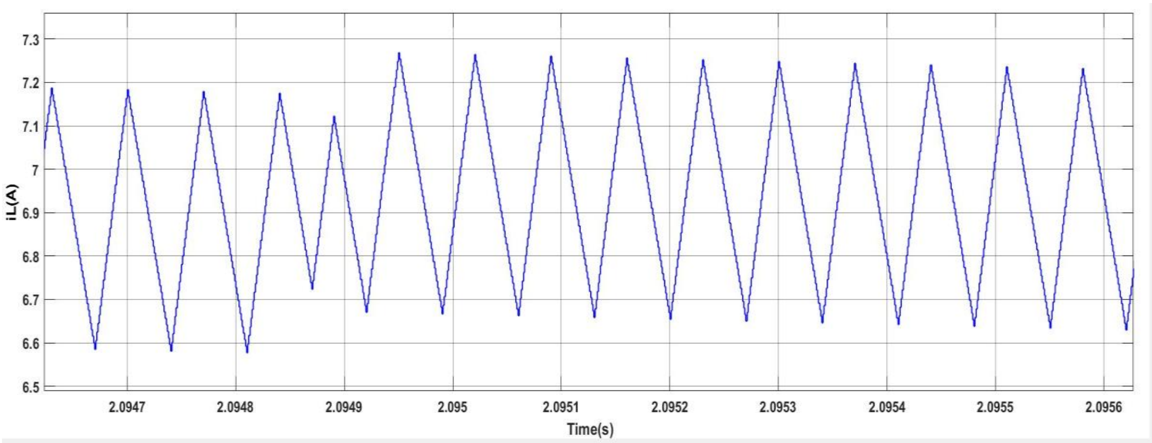
(C)

Figure (3.4): Simulation results for iL_ref=$5A$:(A) DC link voltage; (B) Inductor current iL; (C) Output current

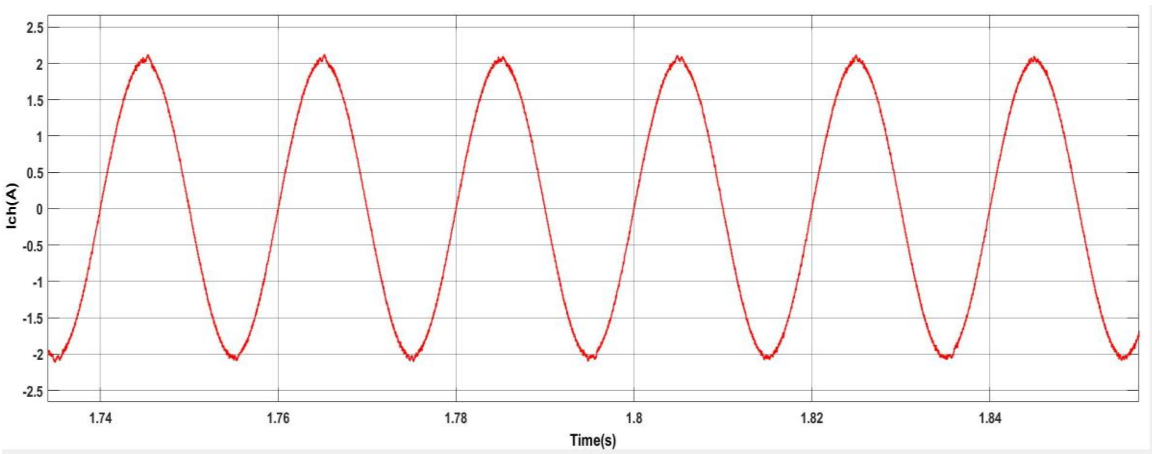
•**When** i_{l-ref}=7A, $v_{c-ref} = 100V$, Vin=25, $ich - ref = 2A$:



(A)



(B)



(C)

Figure (3.5): Simulation results for iL_ref=$7A$:(A) DC link voltage; (B) Inductor current iL; (C) Output current

Comment:

The simulation results demonstrate that the Model Predictive Control (MPC) ensures optimal reference tracking for both the inductor current and the capacitor voltage on the DC side, as well as fast tracking of the output current on the AC side. Additionally, the capacitor voltage remains stable without oscillations.

3.4. CONCLUSION:

This chapter validates the proposed MPC-based control of the quasi-Z-source inverter through extensive MATLAB/Simulink simulations. The results confirm that MPC provides a superior dynamic response, improved voltage regulation and reduced current ripple.

These advantages demonstrate the potential of predictive control to enhance the performance of qZSI systems, particularly in applications such as renewable energy integration.

GENERAL CONCLUSION

This thesis has addressed the modeling and control of the Quasi-Z-Source Inverter (QZSI) through Model Predictive Control (MPC) for the enhancement of performance, efficiency, and accuracy of control in power conversion systems—particularly those with renewable energy integration. Taking into account the increased demand for smart and reliable power electronics, the QZSI topology offers a great leap forward compared to traditional inverter topologies through its ability to boost the voltage and invert in a single stage without sacrificing reliability and continuity of the input current.

To effectively control this topology, Model Predictive Control, a modern control technique, was employed. This technique is known for its ability to predict future dynamics of the system and optimize switching maneuvers in real time, given system constraints. The technique harmonizes itself with the non-linear and time-varying nature of the QZSI.

The methodology of the research was founded on a combination of theoretical modeling and simulation-based validation. The control strategy and inverter model were tested and analyzed using MATLAB/Simulink, which enabled the system's dynamic response, steady-state behavior, and robustness to be tested for different operating conditions. Simulation outcomes indicated that the presented control technique guarantees quick response, improved stability, and less ripple in both voltage and current.

In conclusion, the amalgamation of QZSI and MPC is a strong and versatile tool for modern power conversion applications. The findings of this paper provide a solid theoretical and simulation-grounded basis for ongoing research, particularly in the direction of real-time control, implementation in hardware, and experimental validation on real-world system

REFERENCES

[1] H. Abu-Rub, M. Malinowski, and K. Al-Haddad, Power Electronics for Renewable Energy Systems, Transportation and Industrial Applications. Hoboken, NJ: Willy,2014

[2] B. Ge, H. Abu-Rub, F. Z. Peng, Q. Lei, A. T. De Almeida, F. J. Ferreira, D. Sun, and Y. Liu, "An energy-stored quasi-Z-source inverter for application to photovoltaic power system," IEEE Transactions on Industrial Electronics, vol. 60, pp. 4468-4481, 2012.

[3] J. Anderson and F. Z. Peng, "A class of quasi-Z-source inverters," in *2*008 IEEE Industry Applications Society Annual Meeting, 2008, pp. 1-7.

[4] J. Anderson and F. Z. Peng, "Four quasi-Z-source inverters," in 2008 IEEE Power Electronics Specialists Conference, 2008, pp. 2743-2749.

[5] A. Bakeer, M. A. Ismeil, and M. Orabi, "A powerful finite control set-model predictive control algorithm for quasi-Z-source inverter," IEEE Transactions on Industrial Informatics, vol. 12, pp. 1371-1379, 2016.

[6] Y. Xu, Y. He, and S. Li, "Logical Operation Based Model Predictive Control for Quasi Z-source Inverter Without Weighting Factor," IEEE Journal of Emerging and Selected Topics in Power Electronics, 2020.

[7] Peng, F. Z. (2003). Z-source inverter. IEEE Transactions on Industry Applications, *39*(2), 504–510.

[8] Shen, M., Joseph, A., Wang, J., Peng, F. Z., & Adams, D. J. (2004). Comparison of Traditional Inverters and Z-Source Inverter. IEEE Power Electronics in Transportation

[9] Zope, Pankaj Hiraman. "Modeling and simulation of z source inverter design and control strategies." Thesis doctor, Jodhpur National University, 2012.

[10] J. Rabkowski, “The bidirectional Z-source inverter for energy storage application,” in Proc. European Conf. Power Electronics and Applications, Sept. 2–5, 2007, 2007, pp. 1–10.

[11] X. Ding, Z. Qian, S. Yang, B. Cui, and F. Peng, "A high-performance Z-source inverter operating with small inductor at wide-range load," in *APEC 07-Twenty-Second Annual IEEE Applied Power Electronics Conference and Exposition*, 2007, pp. 615-620.

[12] Y. Tang, S. Xie, C. Zhang, and Z. Xu, "Improved Z-source inverter with reduced Z source capacitor voltage stress and soft-start capability," *IEEE Transactions on Power Electronics*, vol. 24, pp. 409-415, 2009.

[13] A. S. Khlebnikov and S. A. Kharitonov, "Application of the Z-source converter for aircraft power generation systems," in *2008 9th International Workshop and Tutorials on Electron Devices and Materials*, 2008, pp. 211-215.

[14] E. Dos Santos, J. Muniz, and E. da Silva, "Dc-ac three-phase four-wire Z-source converter with hybrid PWM strategy," in IECON 2010-36th Annual Conference on IEEE Industrial Electronics Society, 2010, pp. 409-414.

[15] Anderson, J., & Peng, F. Z. (2008). Four quasi-Z-source inverters**.** *2008 IEEE Power Electronics Specialists Conference*, 2743–2749

[16] Rajesh, Kammari. "Design Analysis for Various Controlling Methods of a Z-Source Inverter." International Journal of Electrical Engineering. ISSN 0974-2158 Volume 10, Number 2 (2017), pp. 271-288. M.Tech, G.Pulla Reddy Engineering College, Kurnool, India.

[17] Huang, Zhe. "SVPWM Switching Pattern for Z-source Inverter, Simulation and Application." (2014).

[18] E. C. dos Santos, J. H. G. Muniz, E. P. X. P. Filho, and E. R. C. Da Silva, “Dc-ac three-phase four wire Z-source converter with hybrid PWM strategy,” in Proc. 36^{th} Annu. Conf. IEEE Industrial Electronics Society, IECON, Nov. 7–10, 2010, pp. 409–414.

[19] F. Z. Peng, M. Shen, and Z. Qian, "Maximum boost control of the Z-source inverter," IEEE Transactions on Power Electronics, vol. 20, pp. 833-838, 2005.

[20] Bayhan, S., Abu-Rub, H., & Balog, R. S. (2016). Model predictive control of quasi-Z-source four-leg inverter. IEEE Transactions on Industrial Electronics, 63(7), 4506-4516.

[21] Abdi, A., Baker, A., Allawi, H., Boozed, M., Hashab, A., Chub, A., & Zaid, S. A. (2024). Model-Free Predictive Control for Improved Performance and Robustness of Three-Phase Quasi Z-Source Inverters. IEEE Access.

[22] Mesa, M., Ella ban, O., Kouzes, A., Abu-Rub, H., & Rodríguez, J. (2013, March). Model predictive control applied for quasi-Z-source inverter. In 2013 Twenty-Eighth Annual IEEE Applied Power Electronics Conference and Exposition (APEC) (pp. 165-169). IEEE.

[23] Baker, A., Dab our, S. M., Goad, I. A., Aboushady, A. A., Elgenedy, M. A., & Farrag, M. E. (2022, August). Enhanced finite control set-model predictive control for three-phase split-source inverters. In 2022 57th International Universities Power Engineering Conference (UPEC) (pp. 1-6). IEEE.

[24] Chai, A., Berkus, E.-M., & Nassereddine, S. (2022). A model predictive current

controller for Quasi Z-source inverter. ResearchGate. IEEE Access
[25] Bakeer, A., Ismeil, M. A., & Orabi, M. (2016). A powerful finite control set-model predictive control algorithm for quasi-Z-source inverter. IEEE Transactions on Industrial Informatics, 12(4), 1371-1379.
[26] Abdi, A., Bakeer, A., Allawi, H., Boozed, M., Hashab, A., Chub, A., & Zaid, S. A. (2024). Model-Free Predictive Control for Improved Performance and Robustness of Three-Phase Quasi Z-Source Inverters. IEEE Access.
[27] Bakeer, A., Ismeil, M. A., Kouzou, A., & Orabi, M. (2015, May). Development of MPC algorithm for quasi-Z-source inverter (qZSI). In 2015 3rd International Conference on Control, Engineering & Information Technology (CEIT) (pp. 1-6). IEEE.
[28] May, A. (2024). Contribution to the predictive control of multilevel and quasi-Z-source type inverters dedicated to the energy management of a photovoltaic installation connected to the electrical grid (Doctoral dissertation).
[29] Ismeil, M. A., Abdel-Rahim, O., Hussein, H. S., & Abdelhameed, E. H. (2023). Implementation of New Optimal Control Methodology of Quazi Z-Source Inverter Based on MPC. IEEE Access, 11, 56453-56462.