MULTI-LEVEL INVERTER TOPOLOGIES FOR HIGH POWER APPLICATIONS

A Mini Project Report submitted in Partial Fulfillment of the Degree of

MASTER OF TECHNOLOGY

IN

POWER ELECTRONICS AND POWER SYSTEMS

Submitted by

LIKHITHA S SHENOI

ASI23EEPP01

Second Semester

Department of Electrical & Electronics Engineering

Adi Shankara Institute of Engineering & Technology

Vidya Bharathi Nagar, Mattoor, Kalady, Ernakulam-683574

May 2024

Department of Electrical and Electronics Engineering

Adi Shankara Institute of Engineering and Technology,

Vidya Bharathi Nagar, Mattoor, Kalady, Ernakulam-683574

CERTIFICATE

This is to certify that the M-Tech Mini Project Report titled **“Multi-Level Inverter Topologies for High Power Applications”** submitted by Ms. **Likhitha S Shenoi** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Power Electronics and Power Systems, Electrical & Electronics Engineering, is an genuine record of the thesis work completed by her under our supervision and guidance. No form of this study has ever been submitted to another university or institute for any purpose.

Project Guide	**Coordinator**	**Head of the Department**
Sreehari S	Dr. S Subiramoniyan	Dr. Deepa Sankar
Asst. Prof.	Asso. Prof.	Asso. Prof.
Dept. of EEE	Dept. of EEE	Dept. of EEE

ACKNOWLEDGEMENT

I want to start by thanking God, who gave me the knowledge and skills necessary to effectively finish Mini project. My sincere gratitude to Principal **Dr. MS Murali** for giving the facilities required to complete this work.

I want to express my deep gratitude to **Dr. Deepa Sankar,** the head of the electrical and electronics engineering department, for all of her assistance, inspiration, and direction during the project.

I would like to express my gratitude to my project coordinators **Dr. S Subiramoniyan** (Associate Professor) and my guide **Sreehari S** (Assistant Professor), **Department of Electrical and Electronics Engineering** for their valuable advice and assistance during the mini project.

I would like to express my sincere thanks to all Teaching and Non-Teaching faculty in the Department of Electrical & electronics for their valuable guidance. I also thank my Parents, Friends and all my well-wishers who had supported directly and indirectly, during the course of the mini project.

LIKHITHA S SHENOI
Reg. no. ASI23EEPP01
Second Semester
POWER ELECTRONICS AND POWER SYSTEMS
Adi Shankara Institute of Engineering & Technology
Vidya Bharathi Nagar, Mattoor, Kalady, Ernakulam -683574

DECLARATION

I undersigned hereby declare that the mini project report ("**Multi-level Inverter Topologies for High Power Application**"), submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Asst. Prof. Sreehari S. This submission represents my ideas in my own words and where ideas or words of others have been included; I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

ABSTRACT

A high-power multi-level inverter that can be used in electric trucks and cars is extended from a 5-level T-Type inverter. When compared to common topologies like Neutral Point Clamped, Flying Capacitor, and Cascaded H-bridge, the suggested inverter has a number of advantages. The primary benefits include fewer parts, a projected reduction in weight and cost, smaller size, and the use of a single DC voltage source for each phase. This topology can be implemented for any required odd number of voltage levels. The most recent multilevel inverter (MLI) development is using medium voltages in industrial drives to supply power. For high power applications in the power industry, MLI technologies are attracting more attention. Results of simulation using Matlab-Simulink are demonstrated to prove the usefulness of this scheme.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC	Alternating Current
CHB	Cascaded H-Bridge
DC	Direct Current
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
EVs	Electric Vehicles
PWM	Pulse Width Modulation
PV	Photo Voltaic
SDCs	Separate Direct Current Sources
SVM	Space Vector Modulation
HVDC	High Voltage Direct Current
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
UPS	Uninterruptible Power Supply
THD	Total Harmonic Distortion
NPC	Neutral Point Clamped
MLI	Multi-Level Inverter

CHAPTER 1

INTRODUCTION

Multi-level inverters gained popularity during the last decade. They are commonly employed in high-power and high-voltage applications, including ship, electric train, and vehicle converters, reactive power compensators, wind turbine converters, PV inverters, active filters, UPS, and HVDC systems. Multi-level inverters offer various advantages over regular inverters. The first advantage is a series connection of many switches, which decreases voltage drop on each switch and hence inverter switching losses. Furthermore, this enables the use of inverters in systems with high voltage and power. Another benefit is the large number of levels, which lower output voltage and current THD. The third benefit is lesser voltage jumps at each level, resulting in less dv/dt voltage spikes on the load. This feature reduces insulation faults and extends the load's lifetime. Common multi-level inverter layouts include Neutral Point Clamped (NPC), Flying Capacitor, and Cascaded H-Bridge.

In this configuration, DC-link capacitors divide the voltage from the DC source that supplies each phase. The main disadvantage of this architecture is the large number of switches (diodes and IGBTs). The biggest disadvantage is the large number of components. The high number of capacitors in this design necessitates complex voltage balancing control to ensure equal voltage across all DC-link capacitors. The Cascaded H-Bridge topology uses cascaded H-bridges, each powered by a single DC voltage source. This topology offers straightforward structure and control, making it advantageous. The main issue is that each H-bridge requires an individual DC voltage supply. In the hybrid cascaded H-bridge topology, each H-bridge has unique DC sources. The hybrid arrangement

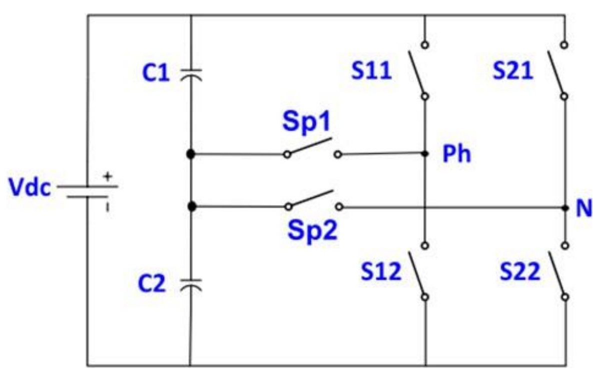

Fig 1: One phase of 5 level cell

allows for more voltage levels than traditional cascaded H-bridge topologies. This design has the advantage of requiring only one DC voltage source per phase, regardless of the number of voltage levels. It also reduces the amount of inverter components compared to other topologies. We estimate that it can reduce the inverter's weight and size. This design can support several voltage levels, making it suitable for electric transportation applications. The inverter's cells are modular and easily replaceable in event of a failure. The proposed topology uses a multi-cell method, with a 5-level basic cell (see Fig. 1). This cell consists of four IGBT switches (S11, S12, S13, and S14) and two extra bi-directional switches (Sp1, Sp2) made up of two back-to-back coupled IGBTs. Table 1 details all of this cell's switching options. The capacitors C1 and C2 divide the Vdc supply voltage evenly, resulting in five voltage levels: 0, Vdc, -Vdc, Vdc/2, and -Vdc/2. To keep capacitor voltages stable, use the voltage balancing algorithm. Otherwise, the inverter's output voltage waveform will be distorted due to the capacitor voltage imbalance [1].

Switching State	Engaged Capacitors	Output Voltage	Sp1	Sp2	S11	S12	S21	S22
1	-	0	0	0	1	0	1	0
2	-	Vdc	0	0	1	0	0	1
3	-	-Vdc	0	0	0	1	1	0
4	C1	Vdc/2	0	1	1	0	0	0
5	C2	Vdc/2	1	0	0	0	0	1
6	C1	-Vdc/2	1	0	0	0	1	0
7	C2	-Vdc/2	0	1	0	1	0	0

Table 1: Switching options of 5-level cell

Power electronics and switching devices led to the creation of multilayer inverters, which are suitable for grid connections. There are various types of multilevel inverters with diverse operations. Power converter technology connects structures to renewable energy systems, enabling power generation. Researchers are focusing on developing topologies with diverse switching patterns to reduce part count while improving system performance.

In this relation, multilayer inverters are cascaded with input voltage sources to achieve high-quality output voltage and input current. In the power sector's medium voltage range, cascaded multi-level inverters (MLIs) are replacing earlier trends [2].

CHAPTER 2

MULTI-LEVEL INVERTER FOR HIGH POWER APPLICATION

Traditional level inverter technology has limitations in terms of total harmonic distortion (THD) and switching losses at higher frequencies. Due to these disadvantages, two-level inverters have proven unprofitable in high-power applications. Multilevel inverters (MLIs) are used to improve output waveform characteristics (e.g., minimal THD) and provide a variety of inverter topologies and switching techniques. Multilevel inverters are popular in high-power applications because of their ability to meet significant issues that such systems provide. One significant advantage is their improved voltage management, which is critical for ensuring stability and reliability in high-power situations. By providing several voltage levels, they allow for better control and regulation, maintaining optimal performance even under changing load conditions. Additionally, multilevel inverters reduce harmonic distortion, which is a typical issue in high-power systems. Their capacity to generate cleaner output waveforms lowers interference, protects sensitive equipment, and improves overall grid efficiency. Furthermore, their modular architecture distributes voltage stress across numerous components, extending the life of the inverter and adding to system longevity. Furthermore, multilevel inverters are scalable, allowing for smooth integration into expanding high-power networks without requiring costly engineering efforts. This flexibility causes them indispensable in applications ranging from renewable energy systems to high-capacity industrial operations, where reliability, efficiency, and performance are paramount.

Multi-level inverters play an important role in electric vehicles (EVs) by efficiently converting DC power from the battery to AC power for the motor. They are preferred in EVs for high-power applications because they provide smoother output waveforms, which can increase motor performance and economy. Additionally, multi-level inverters can assist reduce electromagnetic interference and motor noise, resulting in a quieter and more reliable driving experience in electric vehicles.

CHAPTER 3

LITERATURE REVIEW

Sl No	Author & Title	Findings
1.	Dmitry Baimel, Eli Barbie, Svetlana Bronshtein, Moshe Sitbon, Ilan Aharon, Alon Kuperman "High power T- type-based multi-level inverter for electric vehicles" energy Reports 9 (2023) 220–225 https://doi.org/10.1016/j.egyr.2023.09.181	• Number of voltage levels increases and the predicted price, weight, and dimensions decrease. As a result, this converter is ideal for high-powered electric vehicle applications. • The necessity for only one DC source per phase, which is a great advantage compared to the Cascaded H-bridge topology. • The proposed topology can be constructed for any odd number of voltage levels. • It can be implemented in very high power and voltage applications.
2.	B. Pragathi, Sonu Kumar, P Rajani Kumari and Arvind R. Singh "Performance evaluation of hybrid multilevel inverter with a high-frequency switching technique" Journal of Engineering and Applied Science (2023) 70:101 https://doi.org/10.1186/s44147-023-00267-9	• The proposed MLI significantly reduces the number of higher frequencies switching devices. • The voltage, current, and associated THDs are recorded, as well as the rapid drop in voltage that caused the system to operate at half of its rated voltage. • According to the findings, an overall THD loss of 50% is approximately equivalent to the

		rated output voltage and is most commonly observed in cascaded multilevel inverters.
3.	"Multilevel Inverter using Switch Reduction Technique", Shashank K S, Dr. Meharunnisa S P, Vol. 10 Issue 09, September-2021, published by: https://www.ijert.org/	• For the suggested multilevel inverter, this paper has given a unique PWM exchanging component. • To form the PWM signals in this paper, as it where one reference signal is compared to a triangular wave signal. • In this multi-level inverter, there are three partitioned DC voltage levels used. • In this study, a multi-carrier pulse width modulation technique is used to generate the fifteen-level output voltage
4.	"A Pencil Shaped 9-Level Multilevel Inverter with Voltage Boosting Ability: Configuration and Experimental Investigation", Volume 10, 2022 Sheikh t. Meraj, m. S. Abd rahman, Nor zaihar yahaya, (senior member, IEEE), Pin jern ker, (senior member, IEEE), Touhid M. Hossain, m. S. Hossain lipu, kashem m. Muttaqi, (senior member, IEEE), And M. A. Hannan, https://creativecommons.org/licenses/by/4.0/	• The study of a minimized component pencil shaped (PS) 9- level inverter constructed with just two DC supplies is presented in this research. • Since this MLI has a reduced quantity of power electronic switches, it is more efficient. • To determine their optimum capabilities, the proposed inverter parameters' simplified formulas are constructed.

5.	"Switching Angle Estimation using GA Toolbox for Simulation of Cascaded Multilevel Inverter" Volume 73– No.21, July 2013, Kaibalya Prasad Panda, Bishnu Prasad Sahu, Debashis Samal, Yatindra Gopal	▪ Inverters may convert DC to AC with appropriate voltage and frequency. ▪ There are two types: single level and multilayer inverters (MLI). This paper focuses on the Cascaded H-Bridge MLI topology among others. ▪ MLI offers advantages such as low harmonic distortion, reduced EMI, and the ability to operate at various voltage levels. ▪ IGBTs are managed by generating correct switching angles using optimization techniques. ▪ Here a genetic algorithm (GA) to optimize switching angles and compare it to traditional Newton-Raphson methods.

CHAPTER 4
METHODOLOGY

4.1 MULTI-LEVEL INVERTER METHODOLOGY

Designing and executing a multi-level inverter requires a comprehensive approach that includes numerous intricate phases to assure robustness, efficiency, and performance. At the outset, selecting the suitable inverter topology is critical because it determines the system's core architecture and performance. Engineers compare topologies such as diode-clamped (neutral-point-clamped), cascaded H-bridge, and flying capacitor inverters, comparing voltage levels, power ratings, and harmonic reduction capabilities against the application's specific needs. Following topology selection, thorough component selection is performed to create a system that adheres to the chosen topology and achieves performance objectives. This includes carefully selecting semiconductor devices such as insulated gate bipolar transistors (IGBTs) or metal-oxide-semiconductor field-effect transistors (MOSFETs), as well as passive components like capacitors and Inductors. Considerations include voltage and current ratings, switching frequency, thermal characteristics, and cost-effectiveness to ensure optimal performance and reliability [1].

As a result, developing a sophisticated control technique is critical for regulating the output voltage waveform and maintaining voltage balance across various levels of the inverter. Control algorithms are intended to execute modulation techniques like as pulse width modulation (PWM) and space vector modulation (SVM), which produce precise switching signals for semiconductor devices. These solutions seek to achieve desirable performance metrics like as low total harmonic distortion (THD), rapid dynamic response, and high efficiency, while also addressing issues such as voltage balancing and harmonic abatement. Another crucial issue is the design of gate driver circuits, which are responsible for providing precise control signals to semiconductor devices, assuring smooth and efficient operation while protecting against overvoltage, overcurrent, and short-circuit events such as gate drive voltage levels, switching speed, isolation requirements, and electromagnetic compatibility (EMC) considerations are carefully evaluated to optimize gate driver performance and reliability.

Simultaneously, the incorporation of strong protection and safety measures is critical to protecting both the inverter system and linked equipment from failures and abnormal operating situations. This includes the inclusion of extensive protection features like overcurrent, overvoltage, short-circuit, temperature monitoring, and fault detection techniques. These steps improve system reliability, reduce risk, and extend the life of the inverter system. Prior to physical implementation, powerful simulation tools like MATLAB/Simulink, PLECS, and LTspice are used to perform rigorous simulation and validation. Simulation enables engineers to model the behavior of the multi-level inverter system under a variety of operating situations, validate the control strategy, and identify potential problems or improvements. After validation, the design is prototyped and subjected to extensive laboratory testing to ensure its performance, reliability, and compliance with specifications. Finally, efficiency optimization efforts are made to fine-tune the design parameters and control algorithms, resulting in reduced losses, improved thermal management, and increased overall system efficiency. This iterative process seeks to strike a balance between performance, dependability, and cost-effectiveness, ensuring that the multi-level inverter satisfies the demanding needs of modern industrial, renewable energy, and grid-tied power applications. By adhering to this complete technique, engineers may reliably design and construct multi-level inverters adapted to the specific needs of varied applications. [3]

4.2 CONCEPT AND PRINCIPLE OF OPERATION

A multilevel inverter works by modulating multiple levels of DC voltage to produce an AC output voltage. Unlike typical inverters, which switch between two voltage levels, multilevel inverters use a variety of topologies, including diode-clamped, flying capacitor, and cascaded H-bridge designs. These topologies enable the management of semiconductor devices such as IGBTs and MOSFETs, resulting in output voltages with several discrete levels. Multilevel inverters can provide output waveforms that are very similar to sinusoidal shapes by using specialized switching strategies and pulse width modulation techniques. The fundamental concept behind multilevel inverters involves the generation of an output voltage from several levels of DC voltages. These inverters are aptly named “multilevel” because their outputs can achieve more than two voltage levels. Traditional inverters, by contrast, are typically limited to two levels. The multilevel inverter achieves its output waveform by the sequential switching of power electronic switches. These switches connect the DC voltage sources to the output in such a way that the synthesized waveform approximates a desired sinusoidal voltage. This method eliminates harmonic distortion and improves waveform quality, making multilevel inverters appropriate for applications requiring high-quality AC power, such as renewable energy systems, motor drives, and grid-tied inverters. To convert a DC signal into an AC signal, we need to switch the DC signal quickly, which allows us to have different levels. This results in a staircase wave that is remarkably similar to a sine wave. [6]

4.2.1 Multilevel inverters are generally classified into three types:

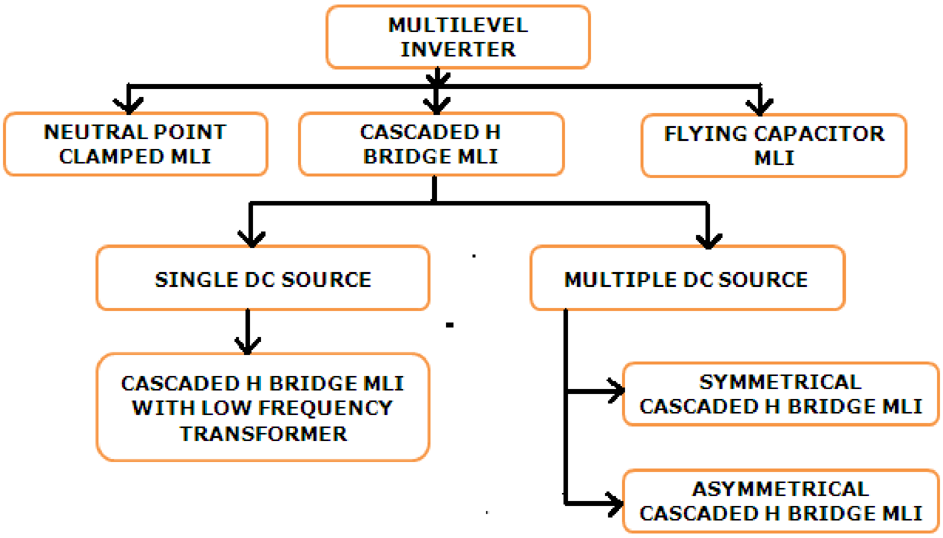

Fig 4.2.1: Classification of Multi-level Inverter

1. Cascaded H-Bridge: With H-Bridge Cascaded multilevel inverters, we can invert up to three voltage levels. Different locations of switches result in different voltage levels. The circuit consists of diodes and switches. This is the most popular type of inverter, which often employs separate DC sources (SDCs). However, with recent improvements, single DC source H-Bridge Cascaded inverters can now be created.

2. Diode Clamped: In this sort of inverter, capacitors and diodes are used for inversion. The goal is to convert DC voltage to capacitor voltage. Proper precautions should be taken to avoid overcharging capacitors.

3. Flying Capacitor: This is a more sophisticated form of inversion because the capacitors must be pre-charged, and it is comparable to the diode clamp approach. The distinction is that clamping is done with capacitors rather than diodes. It is sometimes called an imbricated cell multilevel inverter.

4.3 ADVANTAGES

- The ability to achieve higher voltages with a lower voltage rating of individual power electronic switches.
- Improved output waveform quality, reducing the need for complex filtering circuits.
- Lower electromagnetic interference (EMI), which is particularly beneficial in sensitive environments.
- Reduced stress on electronic components due to lower voltage swings, resulting in increased lifespan and reliability. [6]

4.4 CHALLENGES AND SOLUTIONS IN MULTILEVEL INVERTER DESIGN

While multilevel inverters offer significant advantages, they also present a number of obstacles. The primary differences are the greater complexity of control techniques and the higher component count as compared to standard inverters. Control tactics are more challenging because they must balance DC voltage sources or capacitor voltages. Furthermore, an increase in the number of components might result in higher costs and, potentially, reduced reliability owing to component failure. However, advancements in semiconductor technology, digital signal processing, and control algorithms are resolving these problems. More robust and efficient power electronic switches are being developed, lowering the number of components and increasing reliability. Similarly, new control algorithms simplify the process of balancing DC voltages, reducing the complexity of control techniques. [6]

4.5 APPLICATIONS

Multilevel inverters have numerous applications across different industries due to their advantages over conventional inverters. Some common applications include:

1. Renewable Energy Systems: Grid-connected solar and wind power systems use multilevel inverters to convert DC electricity from renewable sources into AC power that can be fed into the grid.

2. Motor Drives: They are used in variable speed motor drives for industrial and traction applications, providing precise control over motor speed and torque while minimizing harmonic distortion.

3. Electric Vehicles (EVs): Multilevel inverters play an important role in electric vehicle propulsion systems by efficiently converting DC battery power into AC power to drive the motors.

4. Grid-Connected Power Systems: They are used in grid-tied power systems to regulate voltage, compensate for reactive power, and correct power factor, which improves the electrical grid's stability and efficiency.

5. Uninterruptible Power Supplies (UPS): UPS systems use multilevel inverters to provide backup power during power outages while maintaining a consistent and high-quality output voltage.

6. High-Voltage Direct Current (HVDC) Transmission: Multilevel inverters at converter stations convert AC power to high-voltage DC for efficient long-distance transmission, and vice-versa.

7. Industrial Applications: They are used in a variety of industrial applications, including steel processing, cement manufacture, and oil drilling, where precise control of power conversion and low harmonic distortion are required.

CHAPTER 5

SIMULATION MODEL & RESULTS

5.1 EXISTING MODEL

The existing topology is based on a multi-cell approach where the basic cell is 5-level. This cell is comprised of four IGBT switches (S11, S12, S13, S14) and two additional bi-directional switches (Sp1, Sp2) comprised of two back-to-back connected IGBTs. In order to keep capacitors' voltages stable, the voltage balancing algorithm should be applied. Otherwise, the capacitors voltage imbalance will cause distortion of the inverter's output voltage waveform. The voltage balancing can be fulfilled by redundant switching states, where voltage levels of Vdc/2 and –Vdc/2 can be obtained from both C1 and C2 capacitors. The voltage balancing algorithms could be applied by the carrier-based PWM or by SVM methods. To validate the existing 5 level multi-level technique with the basic five level cascaded H bridge (CHB) Inverter using sine pwm technique fig is modeled in the MATLAB/Simulink. [1]

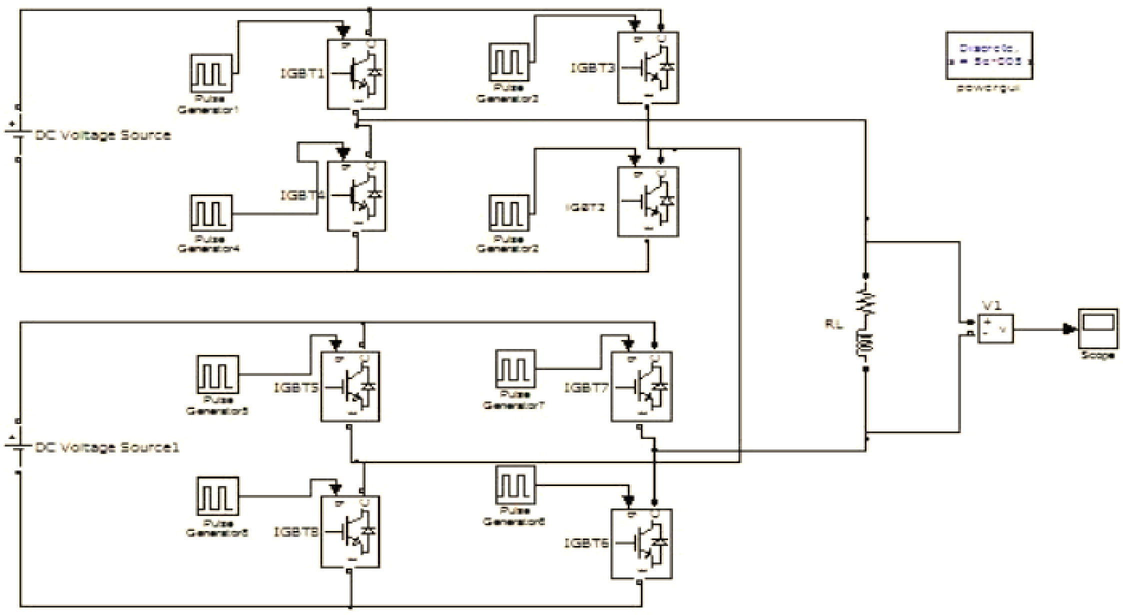

Fig 5.1: Simulink Model of basic 5 level CHB

5.1.1 OUTPUT WAVEFORM

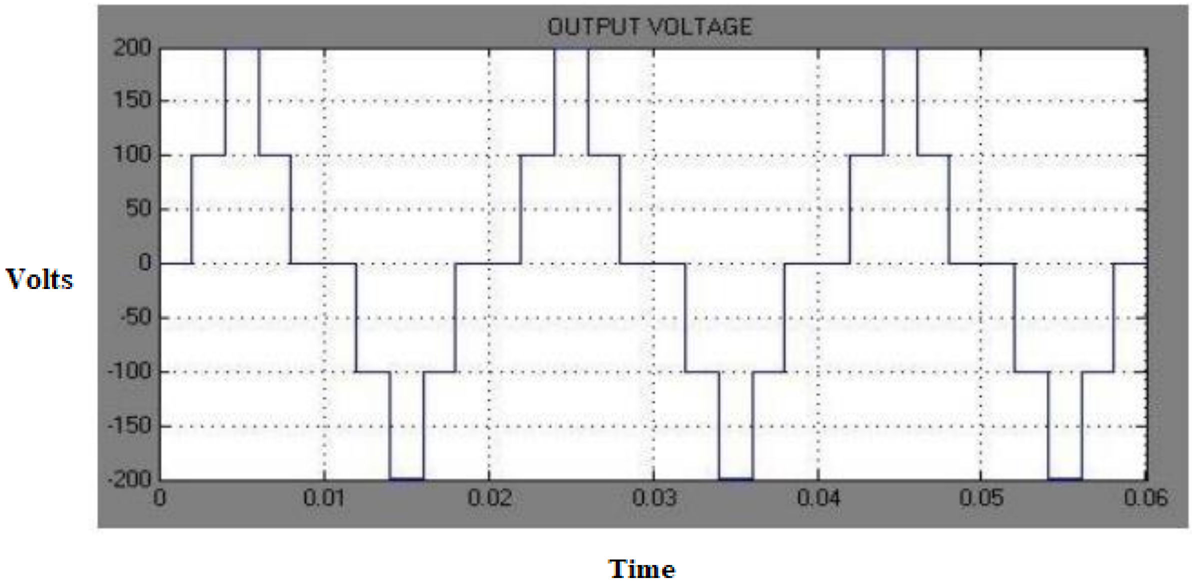

Fig 5.1.1: Output Waveform

5.1.2 FFT ANALYSIS OF 5 LEVEL INVERTER

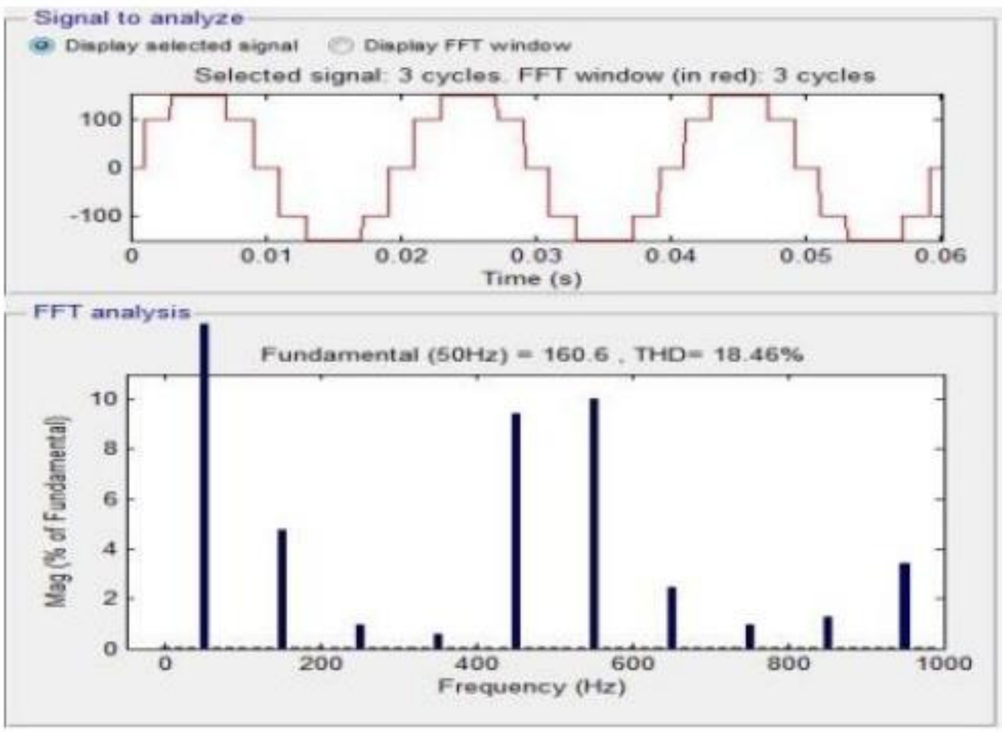

Fig 5.1.2: FFT Analysis

5.2 PROPOSED MODEL

The proposed model idea is implemented by reduced number of switches. The use of advanced semiconductor devices reduces the complexity of the model. Simplified modulation techniques like carrier-based pulse width modulation (PWM) are used and Harmonics and Switching losses can be reduced. Reduction of switches also reduces the cost. The benefit of this topology is that it uses fewer number of switches than conventional multi-level inverter topologies.

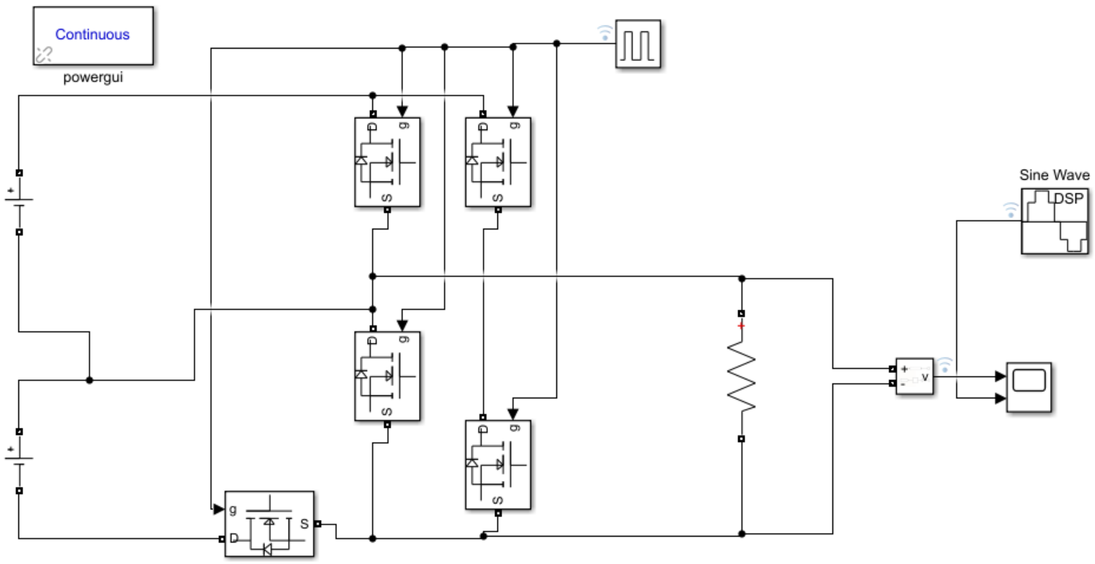

Fig 5.2: Simulink Diagram of reduced switches

5.2.1 OUTPUT WAVEFORM

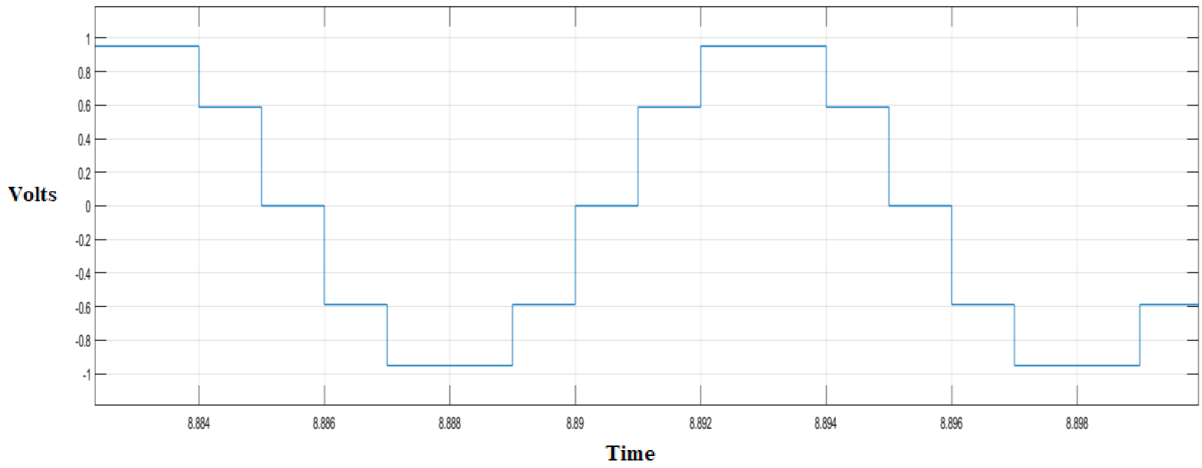

Fig 5.2.1: Output Waveform

5.2.3 SWITCHING STATES

Voltage Levels	S1	S2	S3	S4	S5
0	OFF	ON	OFF	ON	OFF
$V_{dc/2}$	OFF	ON	OFF	OFF	ON
V_{dc}	ON	ON	OFF	OFF	OFF
$-V_{dc/2}$	OFF	OFF	ON	OFF	ON
$-V_{dc}$	OFF	OFF	ON	ON	OFF

Table 5.2.3: Switching patterns of proposed 5-level inverter

.

- **Level 0:** To get the zero voltage, the switches S2 and S4 should be turned on. The load becomes short circuit and voltage across it is zero.
- **Level $V_{dc/2}$:** The voltage level of $V_{dc/2}$ is produced by switching ON the switches S2 and S5. In this case only bottom source is connected to the load and the voltage $V_{dc/2}$ appears across the load.
- **Level V_{dc}:** By switching on switches S1 &S2 we can get the voltage level of V_{dc}.
- **Level $-V_{dc/2}$:** This level of voltage is obtained by closing the switches S3 & S5.
- **Level $-V_{dc}$:** This level can be obtained by operating switches S3 & S4. Both voltage sources are connected to load with negative polarity.

5.2.2 FFT ANALYSIS OF REDUCED SWITCHES

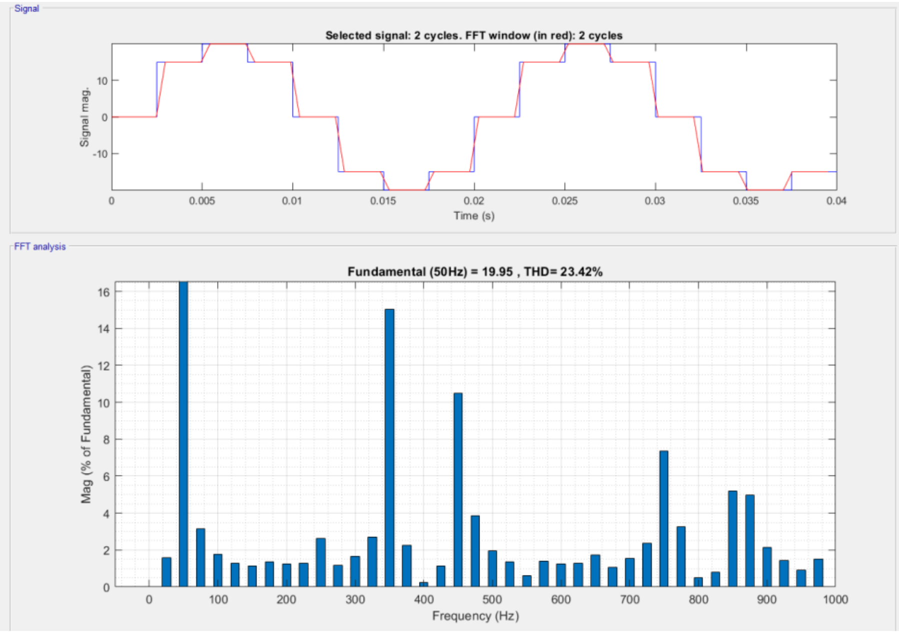

Fig 5.2.2: FFT Analysis

CHAPTER 6

CONCLUSION

This study presents a multi-level inverter for electric transportation applications. The proposed inverter has numerous significant advantages over traditional topologies. The first advantage is a reduction in the number of capacitors and diodes. This benefit becomes more significant as the number of voltage levels increases. The second advantage is a projected reduced price, weight, and smaller dimensions. As a result, this converter is ideal for high-powered electric vehicle applications. Compared to the Cascaded H-bridge architecture, this topology requires only two DC source per phase, providing significant advantages. Advancements in semiconductor technology have made multilevel inverters more feasible and cost-effective for various applications Including renewable energy systems, motor drives, and grid-connected applications. However, challenges remain, including the complexity of control algorithms and the need for careful management of voltage balancing in each level. Overall, the continued research and development in multilevel inverter technology promise to further enhance their performance and expand their applications in the future.

REFERENCES

1. Dmitry Baimel, Eli Barbie, Svetlana Bronshtein, Moshe Sitbon, Ilan Aharon, Alon Kuperman "High power T-type-based multi-level inverter for electric vehicles" energy Reports 9 (2023) 220–225 https://doi.org/10.1016/j.egyr.2023.09.181

2. B. Pragathi, Sonu Kumar, P Rajani Kumari and Arvind R. Singh "Performance evaluation of hybrid multilevel inverter with a high-frequency switching technique" Journal of Engineering and Applied Science (2023) 70:101 https://doi.org/10.1186/s44147-023-002679

3. Shashank K S, Dr. Meharunnisa S P, "Multilevel Inverter using Switch Reduction Technique", Vol. 10 Issue 09, September-2021, published by: https://www.ijert.org/

4. Sheikh t. Meraj, m. S. Abd rahman, Nor zaihar yahaya, (senior member, IEEE), Pin jern ker, (senior member, IEEE), Touhid M. Hossain, m. S. Hossain lipu, kashem m. Muttaqi, (senior member, IEEE), And M. A. Hannan, (senior member, IEEE), "A Pencil Shaped 9-Level Multilevel Inverter with Voltage Boosting Ability: Configuration and Experimental Investigation", Volume 10, 2022, https://creativecommons.org/licenses/by/4.0/

5. Kaibalya Prasad Panda, Bishnu Prasad Sahu, Debashis Samal, Yatindra Gopal, "Switching Angle Estimation using GA Toolbox for Simulation of Cascaded Multilevel Inverter", International Journal of Computer Applications (0975 – 8887) Volume 73– No.21, July 2013

6. https://www.electricity-magnetism.org/multilevel-inverter/

7. [7] Anderson, J.A., Hanak, E.J., Schrittwieser, L., Guacci, M., Kolar, J.W., Deboy, G., 2019. All-silicon 99.35% efficient three-phase seven-level hybrid neutral point clamped/ flying capacitor inverter. CPSS Trans. Power Electron. Appl. 4 (1), 50–61.

8. Liu, B., Song, W., Li, Y., Zhan, B., 2020. Performance improvement of DC capacitor voltage balancing control for cascaded H-bridge multilevel converters. IEEE Trans. Power Electron. 36 (3), 3354–3366.

9. Wang, K., Zheng, Z., Fan, B., Xu, L., Li, Y., 2018. A modified PSPWM for a five-level hybrid-clamped inverter to reduce flying capacitor size. IEEE Trans. Ind. Appl. 55 (2), 1658–1666.

10. Sadanala, C., Pattnaik, C., S, Singh, V.P., 2020. A flying capacitor based multilevel inverter architecture with symmetrical and asymmetrical configurations. IEEE J. Emerg. Sel. Top. Power Electron.