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Efficient Multi-Level Inverter Design for High-Frequency Switched-Capacitor Integration in Three-Phase Induction Motors with PV and Battery Systems

[1]G. Madhusudhana Rao, [2]M. Pala Prasad Reddy, [3]G. V. Swathi, [4]K. Niranjan Reddy, [5]B. V. Sai Thrinath, [6]Abbaraju Hima Bindu

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Abstract: The advancement of transmission frequency offers significant advantages over low or medium-frequency distribution in various energy applications. High-frequency inverters are pivotal in high-frequency AC power distribution systems, yet achieving simplicity in circuit topology and modulation techniques often compromises efficiency and performance. This research proposal aims to address the complexity inherent in designing high-frequency inverters by integrating principles from cascaded multilevel inverters. The proposed design features a switched capacitor front end combined with an H-Bridge back end. By dynamically adjusting series and parallel connections, the switched capacitor front end enhances the number of voltage levels, thereby reducing output harmonics and minimizing the overall component count. This work advocates for the use of asymmetric triangular waveform modulation, chosen for its straightforward analog implementation and lower modulation frequency relative to traditional multicarrier modulation techniques. This innovative approach seeks to balance efficiency, performance, and simplicity in high-frequency inverter design, meeting the stringent requirements of modern energy applications.

Keywords: *DC Converter, Battery, Power Distribution System, H-Bridge inverter, Frequency Distribution, Switched Capacitor.*

1. Introduction

Electricity distribution involves generating, transferring, and delivering electrical energy to customers. Transformers play a crucial role in adjusting voltage levels efficiently, making alternating current (AC) preferable to direct current (DC) for widespread use. Customers receive electricity from generating stations through transmission and distribution networks. The system connecting customers' meters to the substation, aided by transformers, is known as the AC distribution system. This system is organized to ensure the effective delivery of electricity to customers. However, the electrical system that runs between the consumers' meters and the step-down substation that is fed by the transmission system is generally referred to as the AC distribution system. Three categories apply to the AC distribution system: (i) Primary distribution system; and (ii) Secondary distribution system.

[1]*Professor, Dept. of EEE, CMR Institute of Technology, Hyderabad, Telangana*
[2]*Associate Professor, Dept. of EEE, Institute of Aeronautical Engineering. Hyderabad*
[3]*Assistant Professor, Dept. of EEE, ACE Engineering College, Hyderabad*
[4]*Professor, Dept. of ECE, CMR Institute of Technology, Hyderabad, Telangana*
[5]*Assistant Professor, Dept. of EEE, Mohan Babu University, Tirupati*
[6]*Department of EEE, Annamacharya Institute of Technology and Sciences, Boyanapalli, India*
[1]*gmrgurrala@gmail.com*, [2]*prasadreddy.mule@gmail.com*, [3]*swathiarshakota@gmail.com*, [4]*nianreddy@gmail.com*, [5]*connectbvst@gmail.com*, [6]*ahimabindu.eee@gmail.com*

(i) Primary distribution system: - The higher voltage section of the air conditioning distribution system manages substantial amounts of electrical energy, exceeding typical low-voltage consumer needs. The voltage utilized for essential distribution is determined by the amount of energy to be transmitted and the required distance between substations. Common distribution voltages include 11 kV, 6.6 kV, and 3.3 kV. To address financial considerations, a three-phase, three-wire system is commonly implemented for primary distribution.

(*ii*) Secondary distribution system:- This segment of the AC distribution system encompasses the range of voltages used by the end consumer for electrical energy consumption. Secondary distribution typically employs a 400/230 V, 3-phase, 4-wire system to deliver power to consumers efficiently.

2. Background

This Work presents a research proposal focused on addressing the complexity of designing high-frequency inverters for energy applications. It begins by highlighting the advantages of increasing transmission frequency in energy distribution systems. However, it acknowledges the trade-offs involved, particularly in terms of efficiency and performance, when opting for high-frequency inverters. To tackle these challenges, the proposal suggests integrating principles from cascaded multilevel inverters. This involves a novel approach incorporating a switched capacitor front end and an H-Bridge back end. The switched capacitor front end is designed to increase the number of voltage levels by adjusting series and parallel connections. This not only reduces output harmonics but also minimizes component count, potentially enhancing efficiency and performance. Moreover, the proposal advocates for the use of asymmetric triangular waveform modulation. This modulation technique is preferred for its simplicity in analog implementation and lower modulation frequency compared to traditional multicarrier modulation techniques. These characteristics make it promising for high-frequency inverters, where simplicity and efficiency are paramount. Overall, the proposed research aims to develop a high-frequency inverter design that strikes a balance between simplicity, efficiency, and performance through the integration of innovative techniques from cascaded multilevel inverters and asymmetric waveform modulation.

High-Frequency Ac Power Distribution System

A potential replacement for traditional DC distribution techniques is the introduction of high-frequency Alternating Current (HFAC) power distribution systems. Because of their affordability and ease of use, HFAC systems are a desirable choice for several applications. It finds applications in various fields such as computing, telecommunications, electric vehicles, and micro grid infrastructure for renewable energy. High-frequency Alternating Current (HFAC) systems do have difficulties, including power constraints, greater EMI, and higher power losses, even if they show promise. An HF transmission line, several voltage-regulation modules (VRMs), and a high-frequency inverter are the standard components of an HFAC power distribution system. All of these parts work together to make the system's power transmission and control efficient. The realization of HFAC systems' potential as practical substitutes for conventional DC distribution techniques hinges on resolving their associated challenges. The HF inverter converts power to meet the load requirements efficiently. Multilevel inverters indeed present a solution to augment power capacity without encountering synchronization issues. By leveraging multiple levels of DC voltage sources, they effectively synthesize AC voltage with reduced harmonic distortion. This feature allows multilevel inverters to generate higher output voltages while minimizing voltage fluctuations, thereby enhancing power capacity without necessitating strict synchronization among the switching devices. Consequently, multilevel inverters offer a robust solution for applications requiring increased power capacity while mitigating synchronization challenges commonly encountered in traditional inverter designs. Making it easier to achieve higher power limits with reduced stress on switches because of their brief transmission pathways, high-frequency alternating current (HFAC) systems do reduce problems like harmonic distortion. This feature makes it easier to create pure sinusoidal waveforms with low Total Harmonic Distortion (THD). Furthermore, like stair-stepped voltage outputs in multilevel inverters, adding more voltage levels to HFAC systems effectively lowers the overall harmonic distortion of the output waveform. As a result, these developments significantly improve the overall performance of HFAC systems by guaranteeing minimal distortion and high-quality power transmission, which adds to their appropriateness for a range of applications. High-frequency power distribution is valid for electric vehicles (EVs), given the compact size of the power system and successful weight reduction. The choice of operating frequency requires a trade-off between air conditioning inductance and insulation considerations. Therefore, leveraging a multilevel inverter with a 20 kHz output frequency represents a practical and efficient solution for powering HF EVs, offering numerous benefits in terms of performance, range, and integration. Multilevel inverters are divided into diode-clamped and capacitor-clamped types, each with its unique design for precise voltage regulation and control. The cascaded H-Bridge topology is a modular multilevel inverter with multiple H-Bridge cells arranged in series, simplifying voltage regulation and reducing system complexity compared to diode-clamped and capacitor-clamped inverters. The cascaded H-Bridge topology is favoured for its scalability, ease of control, and reduced component count, making it a popular choice for high-power applications. The fundamental circuit resembles the traditional H-Bridge DC-DC converter. The cascaded structure enhances system reliability due to shared circuit cells, control structures, and balancing. However, challenges faced by this structure include increased switches and multiple inputs. A cascaded H-Bridge topology achieves staircase output with desired voltage levels by cascading multiple H-Bridge cells, allowing precise control of overall output voltage. To achieve two voltage levels in a staircase output, a single H-Bridge with four power switches can be used, but additional cascading in series can be used for more levels. Cascaded H-Bridge topologies offer scalability and flexibility, making them ideal for multilevel inverter applications, enabling high-quality AC waveforms with reduced harmonic distortion and enhanced efficiency. Research has explored methods to increase voltage levels in inverters, including supercapacitor-based multilevel circuits, single-phase five-level pulse width-modulated inverters, and SC-based multilevel inverters. However, these methods face challenges in control strategies and electromagnetic interference, and their practical applicability is limited by their intricate control requirements and high component count. Additional investigation has looked into the series/parallel conversion of SCs. However, because of the limits of multicarrier

PWM, this approach is not appropriate for applications with high-frequency output.

3. Multilevel Inverter

This suggestion presents a different approach to maximise renewable energy resources at the lowest possible cost by utilising DC voltage sources. This paper proposes a new method for cascading multilayer inverters using supercapacitor (SCs). There is a detailed analysis of the 9-level circuit topology. By using a much fewer number of switching devices for operation, the suggested design outperforms traditional cascaded multilevel inverters.

Because of its simple operation and low switching frequency, symmetrical PSM (Pulse Symmetrical Modulation) is a single-carrier modulation technology that was used. Results from simulations and experiments confirm that the suggested circuit and modulation technique are feasible. Integrating the supercapacitor (SC) front end allows for additional voltage level increases above traditional full-bridge H-bridge topologies. For example, in a circuit with nine levels, the number of voltage levels doubles every half cycle, and in a circuit with thirteen levels, the number of voltage levels triples every half cycle. The composition completely stops in the levels of output due to the exponential increase in the number of voltage levels, which is particularly notable because of the straightforward and adaptable circuit design. Thus, pulse width modulation of voltage levels can achieve fine control, enabling the proposed multilevel inverter to operate as a regulated and low-distortion high-frequency power source. The emphasis of this study is on the nine-level configuration. For some, the research and design methodology are equally crucial as the proposed solution.

The proposed inverter can be seamlessly integrated into a grid-connected photovoltaic system and the electrical system of electric vehicles (EVs), as various DC sources are readily available, including solar panels, batteries, ultra capacitors, and fuel cells. In this setup, we utilize both PV panels and batteries to optimize output performance. By harnessing energy from solar panels during the day and storing excess energy in batteries for use during periods of low sunlight or at night, we can maximize the efficiency and reliability of the system while reducing dependency on the grid. This integrated approach allows for a sustainable and resilient power solution for both stationary and mobile applications.

4. Methodology:

Concept of Multi-level inverters:

Multi-level inverters convert DC power into AC with multiple voltage levels, resulting in higher quality output waveforms, lower harmonic distortion, and improved efficiency. They combine multiple DC voltage sources to control output voltage at different levels, typically through power semiconductor switches like MOSFETs or IGBTs, regulating the output voltage to achieve the desired waveform. Multi-level inverter topologies, including diode-clamped, capacitor-clamped, and cascaded H-bridge configurations, are used in renewable energy systems, motor drives, grid-tied inverters, and high-voltage DC transmission systems for producing high-quality AC waveforms with reduced harmonic distortion. Figure 1 illustrates a schematic diagram of one phase leg of inverters with various levels, depicting the operation of the power components.

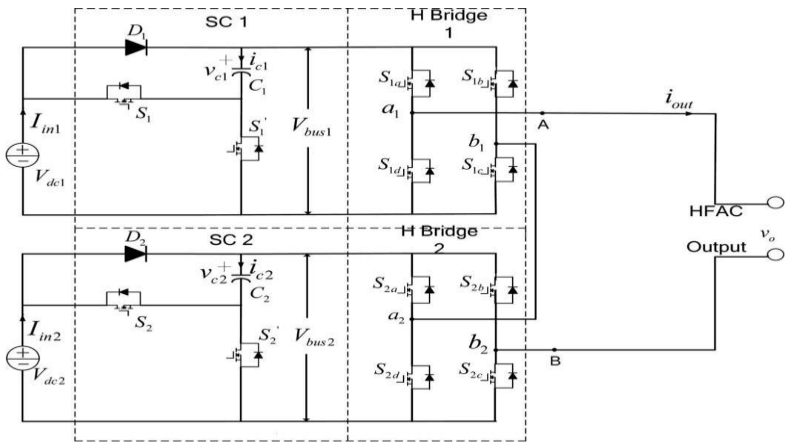

Fig 1: illustrates a schematic diagram of one phase leg of inverters

Topologies of multi-level inverter:

The primary function of a multi-level converter is to combine multiple levels of direct current voltages, typically from capacitor voltage sources, to create a voltage waveform that closely resembles a sinusoid. In multi-level inverters, the synthesized output waveform indeed resembles a staircase-like wave with more steps as the number of voltage levels increases. This staircase waveform gradually approximates the desired sinusoidal waveform more closely. Additionally, as the number of levels and steps in the waveform increases, its harmonic distortion diminishes, and it approaches ideal sinusoidal properties. Each voltage level in the waveform corresponds to a specific combination of switching states of the power semiconductor switches in the inverter circuit. These switches, controlled by a switching or control function (SF_n) at each node, determine the magnitude and polarity of the output voltage during each half-cycle of the AC waveform. The SF_n function typically accepts a binary value of 0 or 1, representing the ON or OFF state of the switch. By appropriately controlling the switching states of the semiconductor switches, the output voltage waveform can be synthesized to closely approximate a sinusoidal waveform with minimal distortion. This control mechanism enables multi-level inverters to achieve high-quality AC output suitable for various applications, including renewable energy systems, motor drives, and grid-tied inverters.

Thus, the peak output voltage is

$$V_{a0}(peak) = (m-1)E_m = V_{dc}$$

Additional switches in the circuit layout enable the inverter to effectively synthesize the complete AC waveform, including both positive and negative voltage values. This capability is essential for providing power to loads that require AC voltage with alternating polarity, such as electrical motors and grid-connected devices. So that

$$V_{ab} = V_{a0} + V_{0b}$$

$$V_{ab} = V_{a0} + V_{b0}$$

9-level cascaded inverter designed supercapacitor:

A SC-based cascaded inverter with a nine-level output is a type of multilevel inverter configuration that utilizes supercapacitor (SCs) to achieve multiple voltage levels in its output waveform.

Super capacitors (SCs): Integrate the supercapacitor into the circuit to enhance the voltage levels and improve the overall performance of the inverter. The supercapacitor can serve as an energy storage element to supplement the power supply and reduce voltage fluctuations.

Cascaded Structure: The inverter is structured in a cascaded manner, meaning that multiple power electronic switches are stacked in series to create voltage levels. Each level of the inverter is typically formed by a combination of switches and SCs.

Control Strategy: The control strategy for the inverter involves modulating the switching of the power electronic switches to achieve the desired output voltage waveform. This typically involves generating pulse-width modulation (PWM) signals to control the switching of the switches.

Nine-Level Output: With the cascaded structure and appropriate control strategy, the inverter is capable of generating a nine-level output voltage waveform. This waveform consists of multiple voltage levels, allowing for a smoother and more sinusoidal output compared to traditional inverters with fewer levels.

Optimization and Fine-Tuning: Fine-tune the control parameters and circuit parameters to optimize the performance of the cascaded inverter. This may involve adjusting the switching frequencies, modulation techniques, or component values to achieve the desired results.

The SC-based cascaded inverter with a nine-level output provides a versatile and efficient solution for various applications requiring high-quality AC power generation. The proposed circuit consists of two main parts: the SC frontend and the cascaded H-Bridge backend. The SC frontend utilizes super capacitors to generate a certain number of voltage levels, denoted as N1. The cascaded H-Bridge backend, on the other hand, also contributes to the generation of voltage levels, with its number denoted as N2. In the overall operation cycle, the total number of voltage levels produced is calculated as 2 multiplied by the product of N1 and N2, plus 1. This is because each voltage level from the SC frontend can be combined with each voltage level from the cascaded H-Bridge backend, resulting in multiple combinations. Additionally, there is an additional voltage level representing the zero voltage point. Therefore, by combining the voltage levels from both the SC frontend and the cascaded H-Bridge backend, the circuit can achieve a total of 2 × N1 × N2 + 1 voltage levels throughout the entire operation cycle.

5. Circuit Topology

Combining cascaded H-Bridge inverters with super capacitors can indeed result in a nine-level output voltage waveform. This topology is commonly used in power electronics applications where high voltage resolution and low total harmonic distortion are required. By utilizing super capacitors, you can achieve fast response times and high power density, which are beneficial in various energy storage and conversion systems..

Supercapacitor Frontend: The front end of the circuit consists of super capacitors arranged in series or parallel configurations. These super capacitors act as voltage sources and provide the necessary voltage levels for the inverter operation. The levels of voltage generated by the supercapacitor front end are denoted as N_1.

Cascaded H-Bridge Backend: The backend of the circuit comprises cascaded H-Bridge inverters. Each H-Bridge inverter consists of four power electronic switches (typically insulated gate bipolar transistors or IGBTs) arranged in an H configuration. These H-Bridge inverters are stacked in series, with each contributing additional voltage levels to the output waveform. The levels of voltage generated by the backend of the cascaded H-Bridge are denoted as N_2.

Control Strategy: The strategy of control for the inverter involves modulating the switching of the power electronic switches in the H-Bridge inverters. Pulse-width modulation (PWM) techniques are commonly used to control the switching of these switches, allowing for precise control of the output voltage waveform.

Combination of Voltage Levels: The voltage levels generated by the supercapacitor frontend and the cascaded H-Bridge backend are combined to create the final nine-level output voltage waveform. This combination results in a smooth and nearly sinusoidal output voltage, with reduced harmonic distortion compared to inverters with fewer voltage levels. Additionally, the use of super capacitors allows for rapid energy storage and release, making the system suitable for applications requiring high-power delivery and fast response times.

The cascaded inverter which is designed with a nine-level circuit topology provides a versatile and efficient solution for various applications requiring high-quality AC power generation. Demonstrates the nine-level inverter's circuit topology (N_1 = 2, N_2 = 2), where the exchanging devices of SC circuits (SC_1 and SC_2), S_1, S_2, S_{11}, and S_{21}, are used to alter the parallel association or arrangement of C_1 and C_2. The exchanging devices of the fell H-Bridge are S_{1a}, S_{1b}, S_{1c}, S_{1d}, S_{2a}, S_{2b}, S_{2c}, and S_{2d}. The data voltages are V_{dc1} and V_{dc2}. The diodes D_1 and D_2 limit the current heading. I out and Vo stand for the yield voltage and current, respectively.

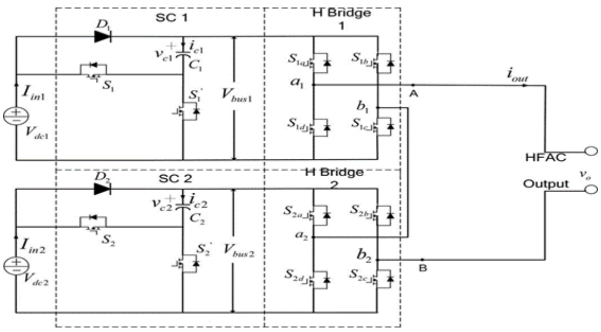

Fig 2: Circuit topology of cascaded nine-level inverter (N_1 = 2, N_2 = 2).

The critical feature of the proposed inverter's backend circuit is its configuration of cascaded H-Bridges. The cascaded H-Bridge inverter configuration combined with supercapacitor provides robustness and versatility in managing various load scenarios. The ability to handle both inductive and resistive loads in different modes ensures continuous conduction and efficient operation under different conditions. This adaptability is crucial for applications where load characteristics may vary, ensuring stable and reliable performance of the inverter system. It's a great example of engineering design aimed at maximizing efficiency and reliability in power electronics systems.

Symmetrical Modulation:

Modulation techniques like SVM, PWM, and selective harmonic removal are commonly used to control multilevel inverters, offering improved output waveform quality and reduced harmonic distortion. Modulation techniques increase carrier frequency over output frequency for better waveform resolution and voltage control, but also increase switching losses and device demands. Engineers balance output waveform quality with component losses, using modulation techniques, switching devices, and control strategies. Advancements in semiconductor technology and control algorithms improve efficiency and performance in multilevel inverters.

Symmetrical Phase Shift Modulation (PSM) is a crucial technique for multilevel inverters, ensuring symmetrical output voltages for each full bridge, resulting in improved output waveform quality and reduced harmonic distortion. It precisely controls phase shifts between carrier signals. Figure 4.2(a) illustrates the symmetrical PSM technique, a modulation technique used in multilevel inverters for precise control of output voltage levels while maintaining high efficiency and low harmonic distortion, making it a powerful tool for various applications.

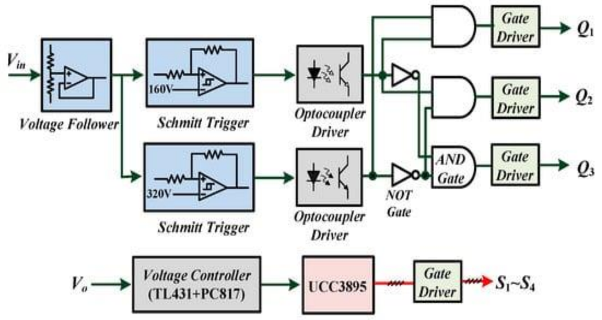

Fig 3: Control block of the proposed converter.

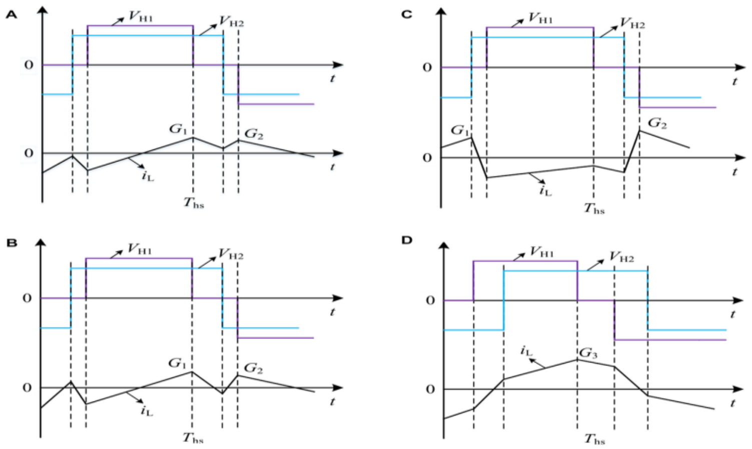

Fig 4: Circuit and operational waveforms of symmetrical PSM. (a) Circuit of symmetrical PSM. (b) Operational waveforms of symmetrical PSM.

The logic operations of gate signals are

gate1 = *XOR {Q* (*RS*), *Q* (*D*)*}*

gate2 = *XOR {Q* (*RS*), *Q* (*D*)*}*

gate3 = *XOR {AND {Q* (*RS*), *NOT* (*PWM*)*}, Q* (*D*)*}*

gate4 = *XOR {AND {Q* (*RS*), *NOT* (*PWM*)*}, Q* (*D*)*}*

Symmetric Pulse Width Modulation (PWM) is achieved through a balanced comparison between a modulation signal (V_m) and a triangular carrier waveform (Vc). When the rising edge of the carrier waveform aligns with Vm, it triggers a polarity reversal in the main bridge. Conversely, when the falling edge of the carrier waveform aligns with Vm, it induces a polarity reversal in the trailing bridge. This symmetrical modulation ensures that gates 1 and 3 shift in opposite directions in response to changes in V_m, denoted as 'V_m'. Consequently, the output voltage V_{ab} remains symmetrical relative to Vc. This balanced control mechanism underpins the symmetrical PWM modulation, ensuring stability and efficiency in the inverter output.

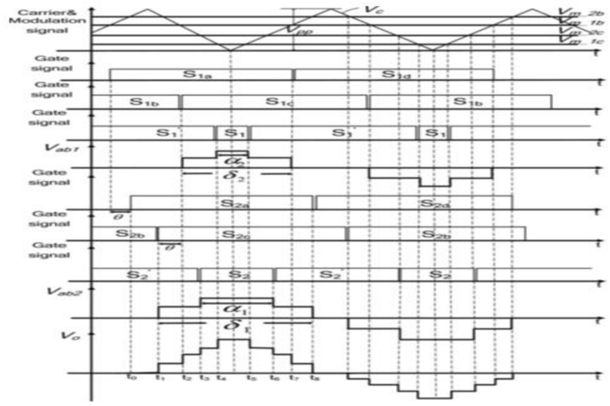

Figure (a)

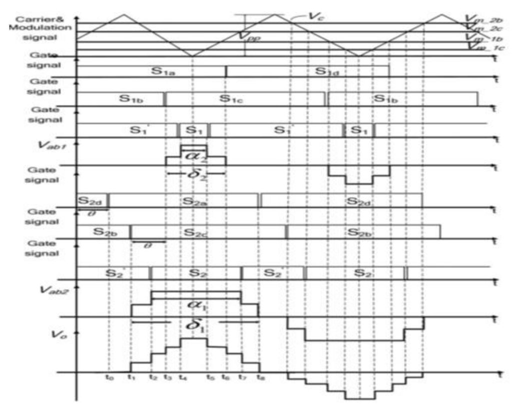

Figure (b)

Fig 5: Operational waveforms of the proposed multilevel inverter (a) Operational mode 1. (b) Operational mode 2. Active circuits for different operation intervals in the operational mode 2: (a) $t_2 - t_3$; (b) $t_6 - t_7$

Operational cycle

Mode 1 circuits typically involve power electronic circuits where switches operate in a specific sequence to achieve desired voltage or current outputs. At time t_0 to t_1, switches S_{1a}, S_{1b}, S_{2a}, and S_{2b} are determined by the gate-source voltage. During this time period, both H-Bridges 1 and 2 are in a freewheeling state, meaning they are not actively conducting and the output voltage is zero. Bus 1 and Bus 2 have input voltages V_{IN}, but there is no output voltage generated. At time t_1 to t_2, switches S_{1a}, S_{1b}, S_{2a}, and S_{2c} are determined by the gate-source voltage. During this period, H-Bridge 2 enters a positive conduction condition, while H-Bridge 1 remains freewheeling. As a result, the voltage output approaches V_{IN}. From t_1 to t_3 the gate-source voltage determines switches S_{1a}, S_{1c}, S_{2a}, and S_{2c}. During this time period, both H-Bridges 1 and 2 are in a positive conduction state. The voltage output is parallel to $2V_{IN}$, meaning it is double the input voltage V_{IN}. Additionally, Bus 1 and Bus 2 maintain voltages of V_{IN}. Figure 4.3(b) and 4.3(c) likely illustrate the current flow throughout the respective time intervals, showing how the current behaves in the circuit as the switches change states and the H-Bridges conduct in different directions. This detailed description provides a clear understanding of how the circuit operates dynamically over different time intervals and how the voltage and current behave under various conditions.

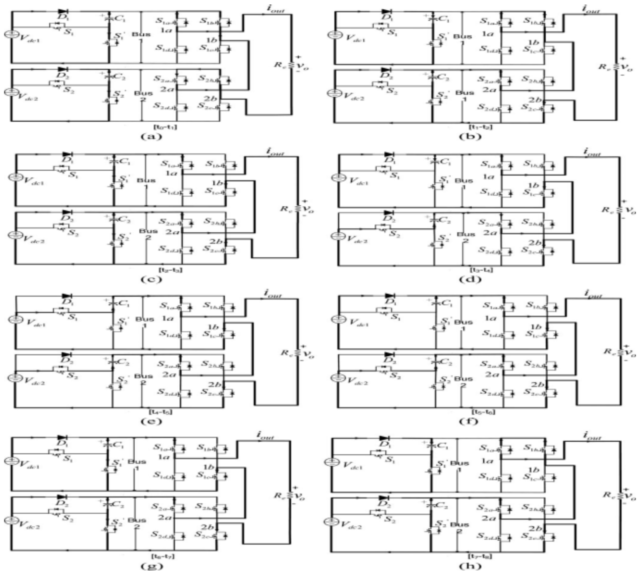

Fig 6: Active circuits for different operation intervals in the operational mode 1: (a) $t_0 - t_1$; (b) $t_1 - t_2$; (c) $t_2 - t_3$; (d) $t_3 - t_4$; (e) $t_4 - t_5$; (f) $t_5 - t_6$; (g) $t_6 - t_7$; (h) $t_7 - t_8$;

Table 1: Relation of ON state switches and output voltages

Mode 1		
On-state switches	Output Voltage	Capacitor State
S_{1a}, S_{1c}, S_{2a}, S_{2c}, S_1, S_2	$4V_{in}$	C_1, C_2 Discharging
S_{1a}, S_{1c}, S_{2a}, S_{2c}, S_1, S_2	$3V_{in}$	C_2 Discharging
S_{1a}, S_{1c}, S_{2a}, S_{2c}, S_1, S_2	$2V_{in}$	C_1, C_2 Charging
S_{1a}, S_{1b}, S_{2a}, S_{2c}, S_1, S_2	V_{in}	C_1, C_2 Charging
S_{1a}, S_{1b}, S_{2a}, S_{2b}, S_1, S_2 or S_{1c}, S_{1d}, S_{2c}, S_{2d}	0	C_1, C_2 Charging
S_{1c}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-Vin	C_1, C_2 Charging
S_{1b}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-2Vin	C_1, C_2 Charging
S_{1b}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-3Vin	C_2 Discharging
S_{1b}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-4Vin	C_1, C_2 Discharging

During the time interval t_3 to t_4 in Figure 5(a):

- The gate-source voltage determines the states of switches S_{1a}, S_{1c}, S_{2a}, and S_{2c}.
- Both H-Bridges 1 and 2 are in a positive conduction state.
- The output voltage is maintained at 3 volts.
- Capacitor C1 remains charged to V_{IN} (where V_{dc1}=V_{dc2}=$V_{IN,}$ when switches S_{11} and S_{21} are activated, while capacitor C_2 is discharged.
- Bus 1 has a voltage of V_{IN}, and Bus 2 has a voltage of $2V_{IN}$.

This description suggests a specific operational mode of the circuit, likely involving voltage regulation or power conversion, where the switches' states and capacitor charges are carefully controlled to achieve desired voltage levels and current flow. The accompanying figure likely illustrates the current flow pattern during this time interval, providing further insight into the circuit's behaviour.

Table 2: Relation of ON state switches and output voltages

Mode 2		
On-state switches	Output Voltage	Capacitor State
S_{1a}, S_{1c}, S_{2a}, S_{2c}, S_1, S_2	$4V_{in}$	C_1, C_2 Discharging
S_{1a}, S_{1c}, S_{2a}, S_{2c}, S_1, S_2	$3V_{in}$	C_2 Discharging
S_{1a}, S_{1c}, S_{2a}, S_{2c}, S_1, S_2	$2V_{in}$	C_1, C_2 Charging
S_{1a}, S_{1b}, S_{2a}, S_{2c}, S_1, S_2	V_{in}	C_1, C_2 Charging
S_{1a}, S_{1b}, S_{2a}, S_{2b}, S_1, S_2 or S_{1c}, S_{1d}, S_{2c}, S_{2d}	0	C_1, C_2 Charging
S_{1c}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-Vin	C_1, C_2 Charging
S_{1b}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-2Vin	C_1, C_2 Charging
S_{1b}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-3Vin	C_2 Discharging
S_{1b}, S_{1d}, S_{2b}, S_{2d}, S_1, S_2	-4Vin	C_1, C_2 Discharging

During the time interval t_4 to t_5 in Figure 5:

Switches S_{1a}, S_{1c}, S_{2a}, and S_{2c} are determined by the gate-source voltage. H-Bridges 1 and 2 remain in a positive conduction state. The output voltage is now $4V_{IN}$. With switches S_1 and S_2 turned on, both capacitors C_1 and C_2 are discharged. The voltages on Bus 1 and Bus 2 are both $2V_{IN}$. Similar operations occur during time intervals t_5 to t_6, t_6 to t_7, and t_7 to t_8, which are depicted in Figures 5(e) to 5(h) respectively. These time intervals exhibit operations similar to those observed during t_3 to t_4, t_2 to t_3, and t_1 to t_2, respectively, as illustrated in the dynamic circuits shown in Figures 6(f) to 6(h). Contrary to operational mode 1, operational mode 2 exhibits different dynamic circuits in two-time intervals. Specifically, during the time interval t_2 to t_3 in operational mode 2, as depicted in Figure 5(b): Switches S_{1a}, S_{1b}, S_{2a}, and S_{2c} are determined by the gate-source voltage. This description provides a comprehensive understanding of the dynamic operations of the circuit across various time intervals and operational modes, highlighting the changes in switch states, capacitor charges, output voltages, and current flow patterns.

During the time interval $t6 \leq t < t7$:

H-Bridge 1 is freewheeling, meaning it is not actively conducted. H-Bridge 2 is in a positive conduction state. The output voltage approaches $2V_{IN}$. With switches, $S_1$and S_2 turned on, the capacitor C_1 remains charged to V_{IN}, while capacitor C_2 is discharged. The voltage on Bus 1 is V_{IN}, and the voltage on Bus 2 is $2V_{IN}$. The current flow during this time interval is depicted in Figure 5(a). Similarly, the dynamic circuit for the time interval $t_6 \leq t < t_7$ is illustrated in the provided figure, likely showing the arrangement of switches and the flow of current in the circuit during this specific time interval. This description provides a detailed understanding of the operational behaviour of the circuit during the mentioned time interval, including the states of H-bridges, capacitor charges, output voltage, bus voltages, and current flow.

6. Implementation & Results

Proposed system:

The objective of this proposal is to utilize techniques employed in a cascaded H-Bridge multilevel inverter, coupled with switched capacitors, for high-frequency AC power distribution systems. The topology involves sourcing energy from both power devices and batteries, which is then fed into the cascaded multilevel inverter. Additionally, a novel topology is implemented to control the output of the multilevel inverter, and this controlled output is then supplied to an industrial application such as a single-phase induction motor. To achieve this, the entire system is designed and simulated using MATLAB software. The system design is facilitated through a graphical user interface (GUI) environment, allowing for intuitive interaction and visualization of the system components and their interactions. To implement the system, elements from the SIMULINK library are utilized, providing a comprehensive set of tools and components for system modeling and simulation. the project aims to leverage advanced multilevel inverter techniques, coupled with switched capacitors, to develop a robust and efficient high-frequency AC power distribution system. The use of MATLAB software, along with a GUI environment and SIMULINK library components, facilitates the design, simulation, and optimization of the overall system to meet specific performance objectives.

Advantages of the Proposed System:

By utilizing cascaded H-Bridge multilevel inverters and switched capacitors, the system can achieve higher efficiency in AC power distribution. This is crucial for applications where energy conservation and optimal performance are paramount. The use of both power devices and batteries as energy sources provides flexibility in energy management. This allows the system to adapt to varying energy demands and sources, enhancing overall system resilience and reliability. The implementation of a novel topology for controlling the output of the multilevel inverter enables precise management of the power distribution system. This control capability ensures that the system can meet specific performance requirements and respond effectively to dynamic operating conditions. Supplying the controlled output to industrial applications, such as single-phase induction motors, demonstrates the practicality and versatility of the developed system. This opens up opportunities for various industrial applications, ranging from manufacturing to transportation. The use of MATLAB software, GUI environment, and SIMULINK library components streamlines the system design and simulation process. This enables efficient development, testing, and optimization of the system before deployment, reducing time and costs associated with physical prototyping. the proposal’s approach offers a comprehensive solution for high-frequency AC power distribution systems, leveraging advanced techniques and tools to achieve efficiency, flexibility, and precise control.

PV system:

A photovoltaic system is a solar power system, sometimes referred to as a solar PV system, photovoltaic system, or just solar system, that uses photovoltaic technology to capture useful solar energy. In order to create a working system, it needs a solar inverter to change the electrical current from direct current (DC) to alternating current (AC), solar panels to collect and convert sunlight into electricity, mounting hardware, cabling, and other electrical accessories. Moreover, since battery storage solutions are becoming more affordable, they can include a solar tracking system to maximize the system's total performance.

Inverter:

Static inverters are electronic devices used to convert direct current (DC) into alternating current (AC) without the need for any mechanical components or moving parts. Instead, they rely entirely on electronic circuitry to perform the conversion process. The core principle behind static inverters is based on electronic switches, typically semiconductor devices such as transistors or thyristors, arranged in a specific configuration to generate an AC output waveform from a DC input. These switches are controlled by electronic circuitry to switch on and off at precise times, effectively simulating the alternating nature of AC power. Static inverters offer several advantages over traditional rotary inverters, including higher efficiency, faster response times, and reduced maintenance requirements due to the absence of moving parts. They are commonly used in various applications such as uninterruptible power supplies (UPS), solar power systems, and vehicle inverters for powering household appliances or electronic devices from DC sources.

Batteries:

An electric battery comprises one or multiple electrochemical cells that convert stored chemical energy into electrical energy. Each cell includes a positive terminal called the cathode and a negative terminal called the anode. Electrolytes facilitate the movement of ions between these terminals, enabling the flow of electric current out of the battery to power various devices and perform tasks. In general, the battery's chemical reactions transform chemical energy that has been saved into electrical energy that may be used to power different gadgets or complete tasks. Because reversible electrochemical processes can occur in rechargeable batteries, recharging them involves reversing the direction of the reactions with an external electrical current.

Induction motor:

An induction motor is an AC electric motor that produces torque by inducing electric currents from the magnetic field generated by the stator. Unlike other types of motors, it doesn't rely on mechanical commutation or self-excitation mechanisms. Induction motors can come in different configurations, such as wound or squirrel-cage types. In industrial applications, three-phase squirrel-cage motors are common, while single-phase motors are often found in household appliances. These motors are increasingly being paired with variable-frequency drives (VFDs) to enable precise control of motor speed, making them suitable for applications requiring variable-speed operation. This combination allows for efficient energy usage and improved performance across a wide range of operating conditions.

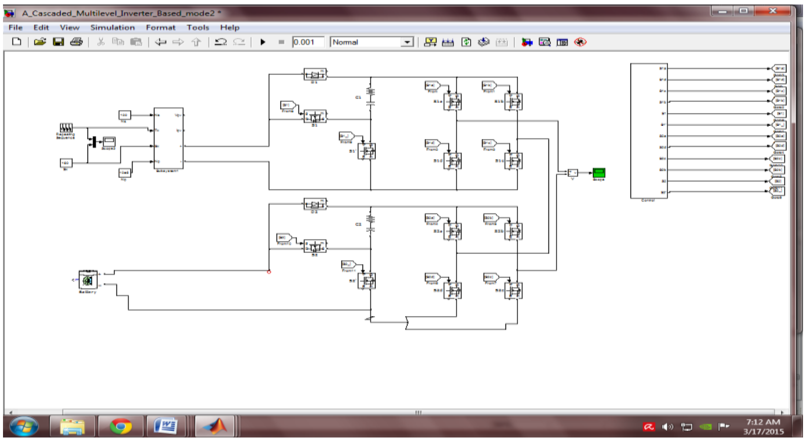

Fig 7: Main diagrams for the proposed system

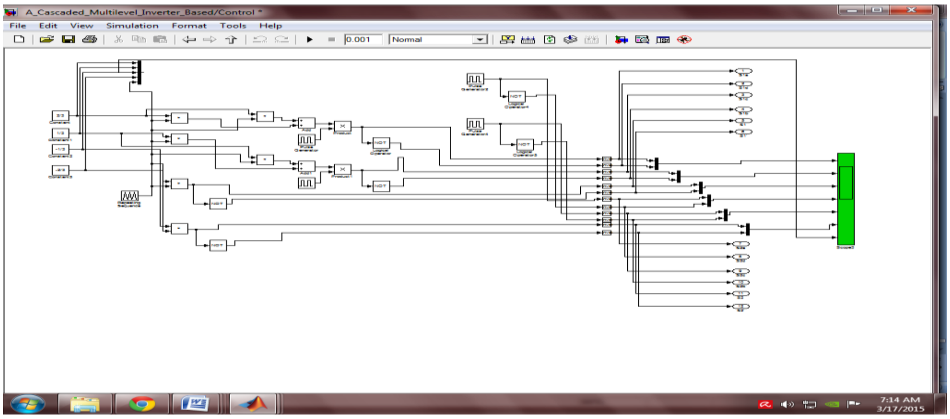

Fig 8: Control Diagram

Existing model

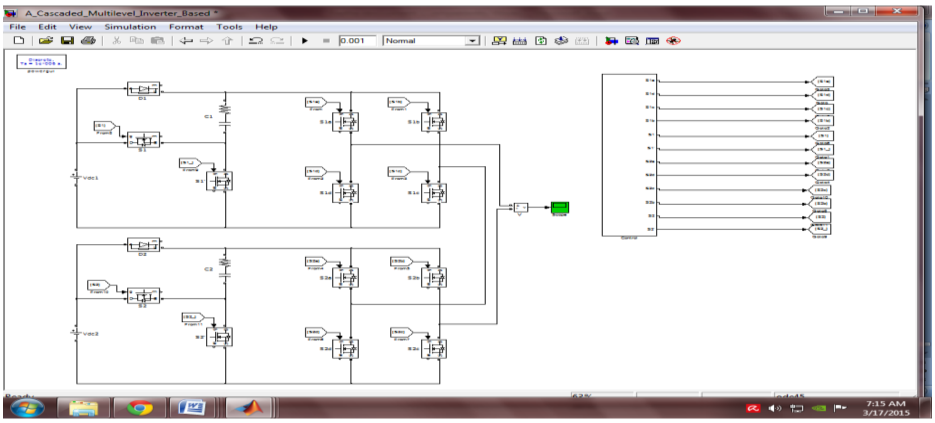

Fig 9: Existing modal

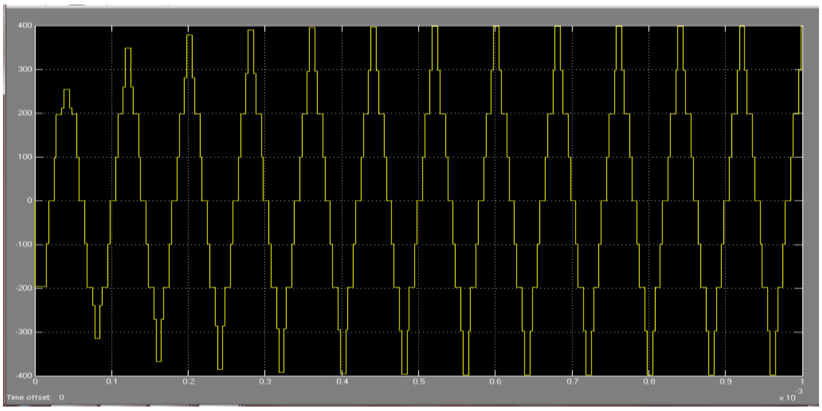

Fig 10: Nine level output wave form Pulse Controlling

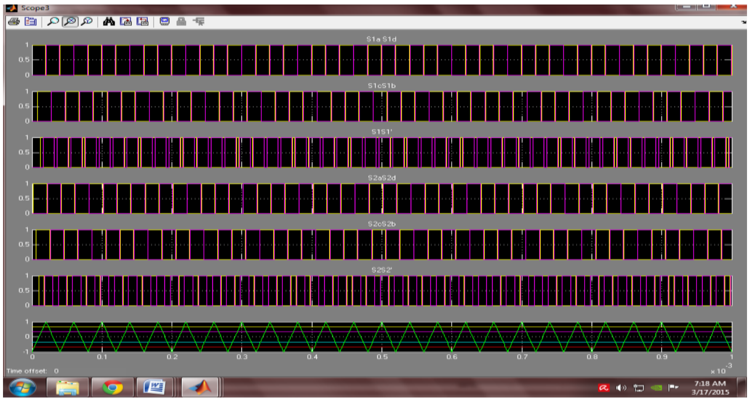

Fig 11: Pulse Controlling Extension results

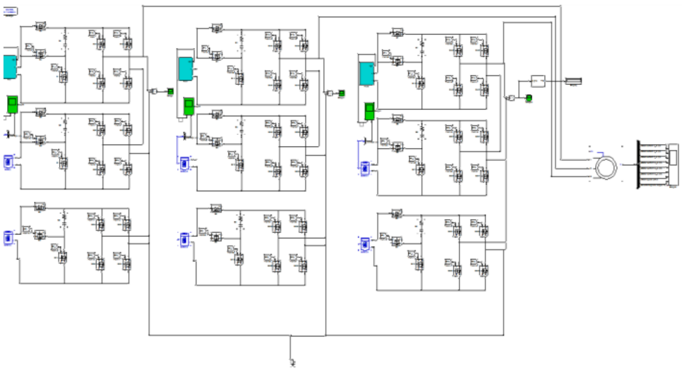

Fig12: Extension of cascaded nine-level inverter output fed to induction motor

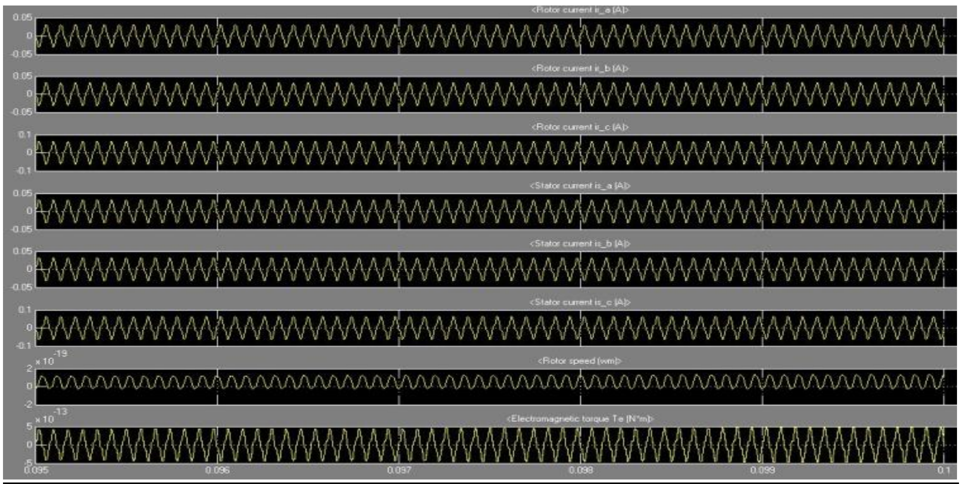

Fig 13: Simulation output results for 3-phase inverter fed to induction motor drive

7. Conclusion

This proposal demonstrates a novel approach to designing high-frequency inverters for AC power distribution systems. We propose asymmetric triangular waveform modulation for its simple analog implementation and lower modulation frequency compared to traditional multicarrier modulation techniques. By utilizing this modulation technique, we can achieve precise control over the output waveform while minimizing complexity and computational overhead. By integrating techniques from cascaded multilevel inverters and employing asymmetric triangular waveform modulation, we can create efficient, compact, and high-performance inverters suitable for various energy applications. This research paves the way for the development of advanced power distribution systems capable of meeting the evolving demands of modern energy infrastructure.

Future Scope

The suggested multilayer inverter's pulse width modulation and straightforward circuit topology lower harmonics in the staircase output. It can function as a controlled-magnitude high-frequency power source. Electrical networks and photovoltaic systems connected to the grid could benefit from the use of inverters. Additional investigation may enhance design and control algorithms.

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