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A PERFORMANCE ANALYSIS OF HYBRID SHE PWM VS. SHM PWM TECHNIQUES FOR HARMONICS CONTROL IN MULTILEVEL INVERTERS

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Abstract

A distinctive Multilevel Inverter arrangement has been meticulously designed to reduce the number of power electronic components. This inverter system emphasizes effective harmonic control by utilizing a technique which is Hybrid Modulation that integrates the SHE-PWM for Elimination Pulse Width Modulation and the SHM-PWM for Mitigation Pulse Width Modulation. Utilizing Fourier series expansion, the paper formulates six nonlinear equations. The proposed topology generates a quarter-wave odd symmetry output waveform, eliminating even harmonics and exclusively producing odd harmonics. For half-wave, specific harmonics are targeted for elimination or mitigation while maintaining the fundamental harmonic at its maximum. To resolve the six nonlinear equations, an objective function is designed and subjected to constraints, utilizing a Genetic Algorithm to determine optimal switching angles. This investigation will use a Genetic Algorithm (GA) to identify the best switching angles for the suggested topology and modulation strategy. Extensive simulation analyses and comparing indicate that this method works better than conventional multi-level inverters at similar levels. Particularly, compared to previous multi-level inverters operating at the same level, the suggested design achieves much reduced Total Harmonic Interference.

Keywords: Multi-level Inverter, SHE, SHM, PWM, Genetic Algorithm (GA).

INTRODUCTION

Increased demand for electricity has added to Pakistan's energy issue. The current power generation is not keeping up with the rising demand, which leaves a significant energy imbalance. The economy and companies of the nation have been harmed by this lack of supplies. The situation is made worse by the decrease in reliance on traditional energy sources [1]. Thankfully, Pakistan has a lot of potential for generating power utilizing renewable energy sources because of its fortunate geographic position. The increasing global need for energy has made renewable energy sources, such as solar and wind

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power, important for supplying that demand while reducing the damage that conventional fossil fuels to the environment do. The volatile nature of renewable energy sources—which are dependent on the weather and other external factors—is one of the main obstacles to their utilization Light availability has led to an increase in the requirement for power [2]. Inverters with several levels play an essential part in resolving this issue. With the help of these cutting-edge power electronics devices, electricity generated by solar panels and other direct current (DC) sources may be converted more efficiently into alternating current (AC) that is suitable with the grid. This is carried out by multiple-level inverters, which divide the output voltage into several levels. As a result, there is less distortion due to harmonics, better energy conversion, and increased efficiency all around [2, 3]. This technology is essential to the shift to a more environmentally friendly and sustainable energy future since it not only improves the stability and dependability of renewable energy systems but also clears the path for a more seamless integration of clean energy [4] into the grid [4]. Power electronic devices known as multi-level inverters have use in electric cars, renewable energy systems, and high-voltage direct current (HVDC) transmission, and other applications. Compared with traditional two-level inverters, these inverters have been designed to produce an output voltage of higher standards while showing less distortion due to harmonics. This can be done by multi-level inverters by synthesis the output voltage from several voltage levels. The reality that MLIs use a lot of power electronic switches might be a drawback [7–10]. The overall power inverter efficiency then decreases as an outcome of increased losses. Decreasing the number of switches and increasing the efficiency of the inverters are two ways that ongoing study in this area attempts to address these issues. In order to get around these difficulties, I proposed an MLI structure with a few power electronic components in the present investigation, along with a mix of methods: "The elimination pulse width modulation by using selective harmonics method (SHEPWM) and Prevention pulse width modulation by using selective harmonics method (SHMPWM) for the harmonic control of MLI [9, 12]." A comprehensive correlation has been performed with the various Multilevel Inverter topologies on the same level [6].

The primary objective is to build a new multilevel inverter topology (recommended) with fewer switches [5]. Applying a hybrid modulation technique Elimination Pulse Width Modulation using the selective harmonics method (SHEPWM) and Mitigation Pulse Width Modulation using the selective harmonics method (SHMPWM) to the MLI and comparing the results with those of other multilevel inverters with reduced switches [14, 15]. A diverse approach to improving power electronic inverters. First, the emphasis is on reducing total harmonic distortion (THD), which improves the overall quality of the output waveform. Second, the use of Hybrid SHE and SHM PWM modulation approaches aims to improve inverter performance. To enhance efficiency and operational simplicity, it is essential to include a reliable multi-level inverter architecture that simultaneously minimizes the number of power electronic components [16]. To lower in-system losses, which raises reliability and efficiency levels all around. To ensure economic viability, it also aims to lower the total cost of power electronic inverters. Another primary objective

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is obtaining a sine output waveform without the requirement for additional filters [17]. In order to establish standards and show gains in efficiency and performance, the produced power inverter is finally compared to the most recent iteration.

METHODOLOGY

The creative Multi-level inverter was designed and developed through an exhaustive procedure with several important turning points. To inform the design process, an in-depth examination of a number of multi-level inverter topologies was initially performed. Then, in order to find areas for improvement, an extensive contrast between the original Multi-level inverter topologies and their modern replacements was conducted. After then, the circuit design for the new Multi-level inverter that was proposed was carefully developed. A strategy combining SHE and SHM PWM modulation was used to increase its performance; input formulas and mathematical design were developed to help with implementation. Utilizing a Genetic Algorithm (GA) with a bioinspired design, the switching angles for this method were improved. MATLAB Simulink was then used to assess the produced Multi-level inverter's performance, providing an in-depth understanding of its behavior. In order to evaluate the efficacy of the indicated Multi-level inverter against the models that are now in use, an analysis of comparisons was conducted, which yielded important insights into the industry.

Multilevel Inverter Topologies:

An overview of power converters is given in this section, with a particular emphasis on power electronics inverters particularly within the structure of the thesis. A thorough analysis of the various types of inverters is provided, highlighting Multilevel Inverters (MLIs) as a significant subset [13]. The talk covers existing MLI inverter topologies, highlighting their merits and limitations. Furthermore, the chapter examines the modes of cascaded and suggested multi-level inverters, doing a comparative study using simulation findings. Notably, a multi-level inverter is defined as a power electronic device in electrical engineering that is typically used to convert direct current (DC) into alternating current (AC) at many voltage levels [14].Despite standard two-level inverters, which produce square-wave or pulse-width-modulated (PWM) sinusoidal outputs, multi-level inverters provide stepped or multi-level waveforms, which have a number of advantages in a range of systems. The next section outlines significant aspects to consider concerning multi-level inverters, laying the groundwork for future investigation [15].

Levels of Voltages:

Multiple levels inverters generate AC output waveforms with more than just two levels of voltage. These extra voltage levels are formed by combining multiple voltage sources or switching states. Inverters with three, five, or seven levels of voltage are common [16]. Levels of voltages are important in digital electronics because they represent binary data. A high voltage level (commonly labeled as '1') usually symbolizes logic "on" or "true," whereas a low voltage level (typically written as '0') represents logic "off" or "false" [17].

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Converters of Power:

A converter of power is a vital component in contemporary electrical and electronic systems that converts electrical energy from one form to another. Its major duty is to manage voltage, current, or frequency to ensure that the electrical power provided to a load or device meets its needs. A power converter is an electrical device that converts one type of energy into another (often AC to DC or DC to AC). Inverters are a key type of power electronics converter [18].

There are essentially several types of power converters: DC-DC converters, AC-DC converters, and DC-AC inverters. Each kind serves a distinct purpose, such as increasing or decreasing voltage levels or switching between alternating current (AC) and direct current (DC). Converters are essential parts of electrical systems, and they can be classified according to a number of factors, such as input, output, and specific parameters. The AC to AC converter, additionally referred to as a Cyclo converter, is one kind. With the support of this type of converter, you can change the output frequency by converting alternating current (AC) input to variable-frequency AC output. Direct current (DC) is produced from alternating current (AC) using a rectifier. In order to ensure that electrical current travels in a single direction, rectifiers are necessary for converting alternating current to direct current [19].

Alternatively, DC to DC conversion is carried out using a helicopter. By changing the input waveform's duty cycle, chopper circuits modulate the output voltage. DC to alternating current (AC) conversions is carried out by inverters. An essential function of inverters is to change direct current into alternating current so that a variety of devices can work simultaneously. Last but not least, the CYCLO CONVERTER is a specialized AC-to-AC converter that takes fixed-frequency AC power sources and outputs a variable-frequency output. Power converters come in several varieties, each with a specific function that contributes to the efficient and controlled transfer of electrical energy in various applications [20].

One kind of electronic power converter designed specifically to convert AC to AC current with varying frequencies is the cycloconverter. A cycloconverter only works in the AC domain, compared to traditional converters like rectifiers or inverters, which manage conversion from DC to AC or AC to DC. This unique device may be used for many different things, including as controlling the acceleration of induction engines and providing variable-frequency AC power to systems [21].

Inverter:

An essential part of power electronics is the inverter, which converts direct current (DC) electricity into alternating current (AC) with variable voltage and frequency properties. It is extremely common in modern company operations, where it is used for anything from small motor operation to large-capacity induction motor propelling. Furthermore, inverter utilization spans a wide range, from small residential power generation setups to the integration of micro-grids into the larger conventional grid infrastructure, aided notably by

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grid-tied inverters, which act as the linchpin in connecting decentralized power sources and micro-grids to the established grid network [22].

Energy which is renewable has evolved as an important power source due to its numerous advantages. This type of energy is not only ecologically benign, but also sustainable, cost-free, and infinite. Power converters, particularly inverters, greatly improve the efficacy of renewable energy systems and come with a lifetime warranty, demonstrating the systems' long-term stability. Because renewable energy systems rely on batteries for power storage, grid-tied inverters play an important role. Users may smoothly donate extra electricity to the national grid using this technique and reclaim it when renewable energy sources fail, a notion known as Net Metering. Advancements in power converters, particularly inverters, have had a significant impact on this capability, making renewable energy a feasible and efficient option for a greener, more sustainable future.

Each MLI topology has its advantages. The only drawback with MLIs is that they have a significant number of switches [3-4], which causes losses and reduces inverter efficiency. This thesis also focuses on reducing the quantity of power electronics.

Types of Inverter:

Inverters are classified according to the number of output levels, as shown in Figure 1, which depicts the many kinds and subcategories. There are three main types of inverters: two level, three level, and multilevel. These are further classified into distinct categories. Two and three-level inverters are classified as Square Wave Inverters, which generate a simple square waveform; Pulse Width Modulation (PWM) Inverters, which use varying pulse widths to approximate a sine wave; and Modified Square Wave Inverters, which refine the square wave output for better performance. With each output level classification focused on different applications and performance specifications, it offers an organized foundation for understanding and utilizing a range of inverter technologies.

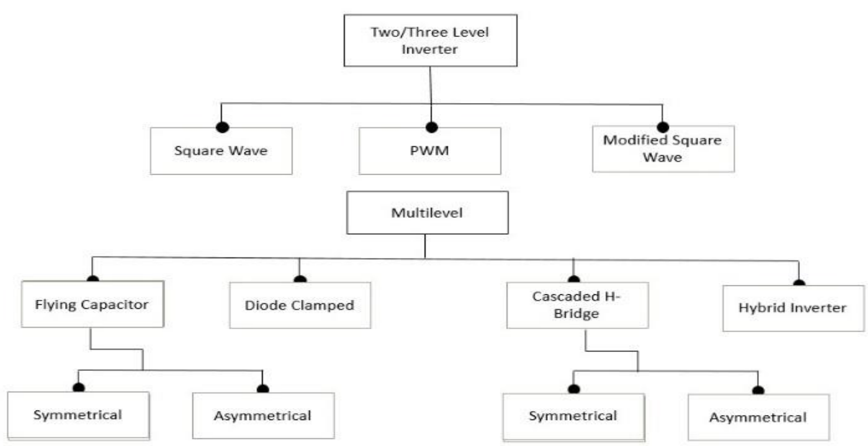

Fig 1: Subtypes & Inverter types

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Multi-Level Inverter (MLI)

Inverters that are multilevel are a sophisticated kind of power electrical equipment capable of converting direct current (DC) to alternating current (AC) at many voltage levels. Multilevel inverters employ a more challenging approach than standard two-level inverters, which are limited to outputting only two voltage levels of AC signals, typically +V dc and -V dc. These inverters provide multiple intermediate voltage levels by integrating capacitors and semiconductor switches, resulting in smoother and more accurate output waveforms [9, 12, 19]. This property makes them useful in many different applications, such as electric vehicles, renewable energy systems, and, and high-voltage AC gearbox systems, since it reduces harmonic distortion, improves efficiency, and improves overall power quality. Multi-level inverters play an important role in developing efficient and sustainable energy conversion solutions in various industries, creating output waveforms that resemble pure sine waves. The topologies of conventional Multilevel Inverters are commonly used in marketable applications, with numerous circuit simulations and results thoroughly documented in various research papers [2, 9] i.e. Flying Capacitor, Diode Clamp, Cascaded H-Bridge.

Flying Capacitor:

The flying capacitor multilevel inverter, shown in Figure 2, is made up of three capacitors, four switches, and a DC voltage supply. In order to divide a single DC power source into equal halves, capacitors are essential. However, issue comes because the voltage between these capacitors may fluctuate over time and based on the immediate load circumstances. This unpredictability causes a DC impact in the output voltage, which poses a major risk to inductive loads and motors. The main drawback of the flying capacitor multi-level inverter is that these capacitors must have proper voltage balancing for them to reduce their negative impact on connected devices. [4]. Furthermore, the converter confronts hurdles in terms of capacitor size and quantity, since increasing the voltage causes a significant rise in capacitor size and an increase in the quantity of capacitors rapidly, with higher output voltage levels.

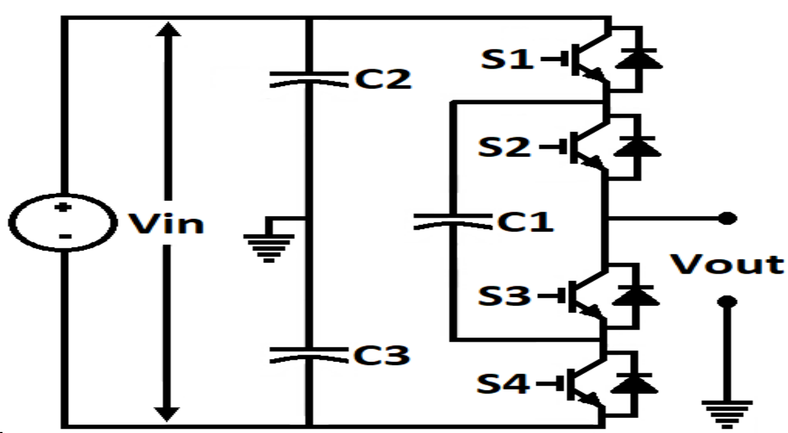

Fig 2: Inverter of 3- Level Flying Capacitor having Multi Level

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Formulae for estimating the switches and capacitors numbers in a "n" level flying capacitor Multilevel Inverter are as follows:

$$Switches\ number = 2(n-1) \qquad (1)$$

$$Capacitors\ number = \sum_{i=1}^{n-1}(n-1) \qquad (2)$$

Here, “n” denotes the flying capacitor multilevel inverter's level count; the formulas work for n = 3, 4, 5-----. Equation 2(n-1) can be used to determine the number of switches. Whereas the number of capacitors is computed by adding (n-1) from i=1 to n-1.

These equations help with the design and analysis of flying capacitor multilevel inverters by providing information on the components needed for a system with a specific voltage levels.

Diode Clamped:

In the Figure 3 it indicates the Multilevel Inverter Diode Clamp, which includes a voltage supply which is DC, two diodes, two capacitors, and switches.

Voltage across these capacitors varies and depends on the instantaneous load circumstances, making it difficult to maintain equality and stability over time.

This variance causes a worrying DC impact in the output voltage, which is especially harmful for inductive loads and motors [3-4].

The principal disadvantage of the Multilevel Inverter (diode clamped) is the need for voltage balancing of the capacitors, as uneven voltage distribution might be detrimental.

Although the capacitor voltage of this inverter type is rather constant, the voltage balancing problem remains, albeit to a lower amount than in the Multilevel Inverter (flying capacitor).

Furthermore, an important problem emerges from the growing number of diodes, which grows dramatically as the voltage levels number increases [1].

The formulas for calculating the switches, diodes, and capacitors numbers at "n" levels these equations provide the multilevel inverter (diode clamped):

Switches number=2(n-1) (3)
Number of diodes = (n-1)(n-2) (4)
Number of capacitors = (n-1) (5)

Here “n”, denotes the number of level that are n = 3, 4, 5…

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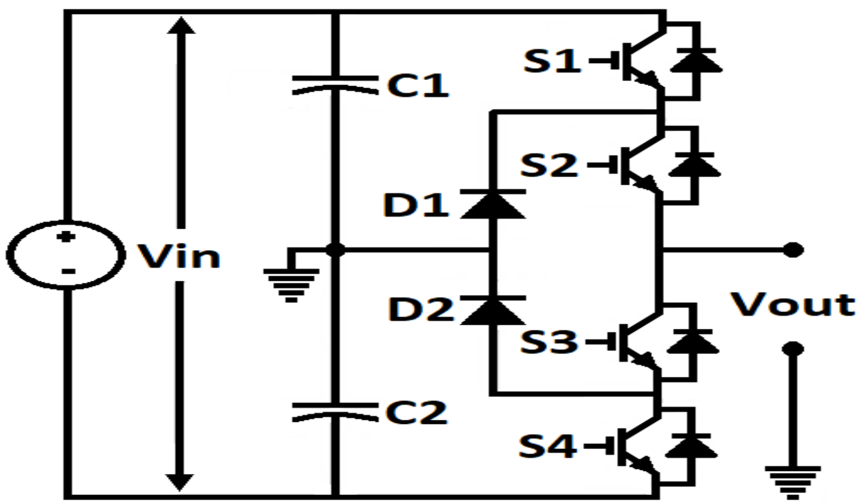

Fig 3: Diode Clamped MLI with three level

H-Bridge Cascaded:

Figure 4 indicates the Multilevel Inverter Cascaded, which has two separate voltage sources of DC voltage and round about eight switches. Unlike diode clamped and flying capacitor Multilevel Inverters, architecture does not use capacitors or diodes. Notably, the Cascaded Multilevel Inverter distinguishes itself by eliminating voltage balance difficulties. The underlying issue arises in developing different DC voltage sources for the multilevel inverter with cascading H bridge [11]. To overcome this, for a "n" level cascaded Multilevel Inverter, the switch number and voltage of a single, isolated DC source are determined using the following equations:

$$Number\ DC\ Sources = \frac{(n-1)}{2} \qquad (6)$$

$$Number\ Switches = 2(n-1) \qquad (7)$$

Here “n”, indicates levels with number and are n = 3, 4, 5…

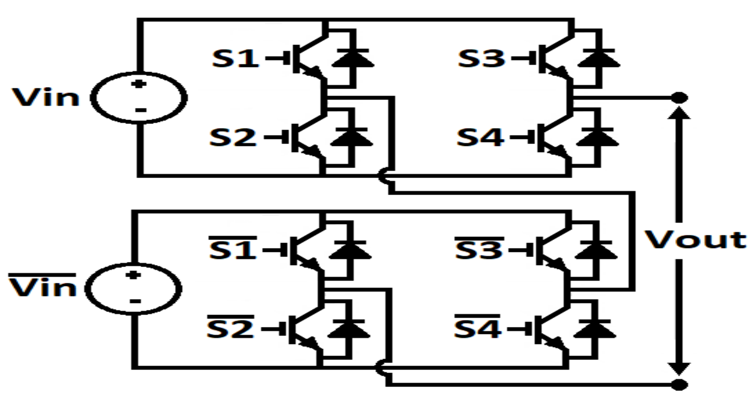

Fig 4: Cascaded Multilevel Inverter with five levels.

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Design of Multilevel Inverter:

The research is thoroughly describes the proposed Multilevel Inverter, diving into its switching scheme and offering a complete description of its operating principle. Furthermore, the Fourier series analysis and mathematical modeling of the suggested Multilevel Inverter are thoroughly described [20]. The inclusion of a case study improves comprehension of the inverter's practical use by providing insights into its operating dynamics and performance parameters.

Multilevel Inverter Design:

The circuit arrangement for the indicated multilayer inverter with seven output levels is shown in Figure 5. Suitable for use with two DC sources and six switches in a single phase, seven-level inverter [2, 6, 22].

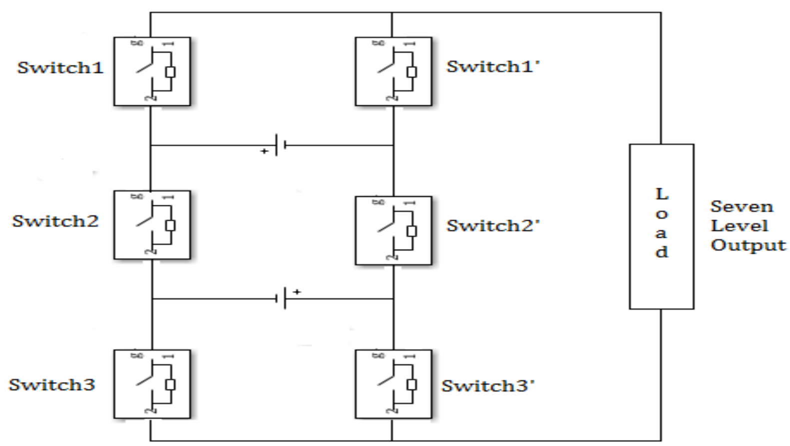

Fig 5: The proposed Seven Level Inverter

Figure 6 displays the waveform that results from the proposed seven-level inverter.

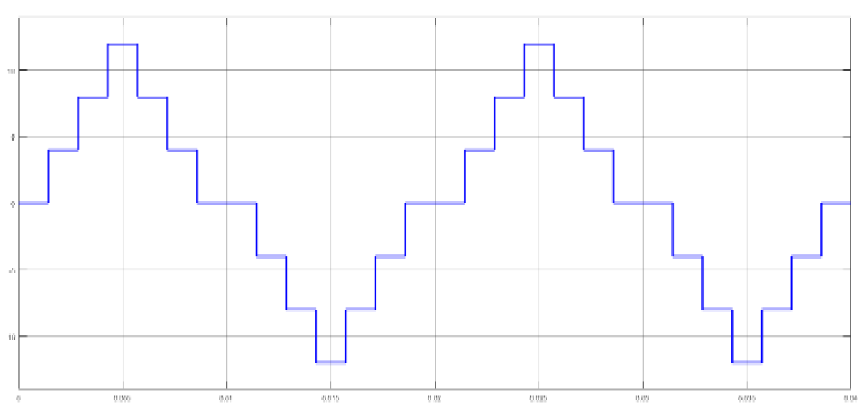

Fig 6: Seven Level Inverter waveform.

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Furthermore, the suggested solution's adaptability is demonstrated by its capacity to scale up to higher-level Multilevel Inverters. The suggested multi-level inverter produces significantly higher output levels than cascaded multi-level inverters by merely adding one cell, which consists of two switches and one battery. This scalability is useful since it requires little hardware adjustments for significant performance improvement. The option of employing JFET or MOSFET switches increases the design's versatility, allowing for optimisation depending on unique application needs and efficiency concerns.

Proposed Terminalogy:

The proposed Multilevel Inverter function essentially in a way that's similar to that of the cascaded H-bridge Multilevel Inverter, in which multiple voltage levels are achieved by arranging the switches suitably [5, 9]. Each voltage level correlates to a certain switching configuration, indicating a consistent link between the inverter's output and the switch arrangement used. Table 1 summarises all of the switching combinations applicable to the recommended 7-level inverter. It is important to remember that switches S1, S2, and S3 have complements, which are S1', S2', and S3' switches, respectively [3, 4]. Analysis the suggested inverter's behaviour under each switching configuration indicates its potential to create certain output levels. The quarter-wave symmetry of a multi-level inverter's output restricts the analysis to a 90° waveform. Symmetry indicates that examining the first quarter-wave reveals insights into the complete waveform, while the subsequent three quarters are simply reflections of the original section [1]. Understanding these key properties is critical for effectively applying the proposed Multilevel Inverter's capabilities in a variety of applications.

Table 1: The Configurationof switching for proposed Seven Level Inverter for the half cycle (180°)

S1	S2	S3	S1’	S2’	S3’	Output	Angle
OFF	OFF	OFF	ON	ON	ON	0	α1
OFF	OFF	ON	ON	ON	OFF	Vdc2	α2
ON	OFF	OFF	OFF	ON	ON	Vdc1	α3
ON	OFF	ON	OFF	ON	OFF	Vdc1+Vdc2	180°-α3
ON	OFF	OFF	OFF	ON	ON	Vdc1	180°-α2
OFF	OFF	ON	ON	ON	OFF	Vdc2	180°-α1
OFF	OFF	OFF	ON	ON	ON	0	180°

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Output Level 1 of Switching:

In the Figure 7 indicates that the circuit diagram in which the current direction is included, switch states, and output level. As long as switching setup is continued, output will remain at level 1, as seen in the figure below.

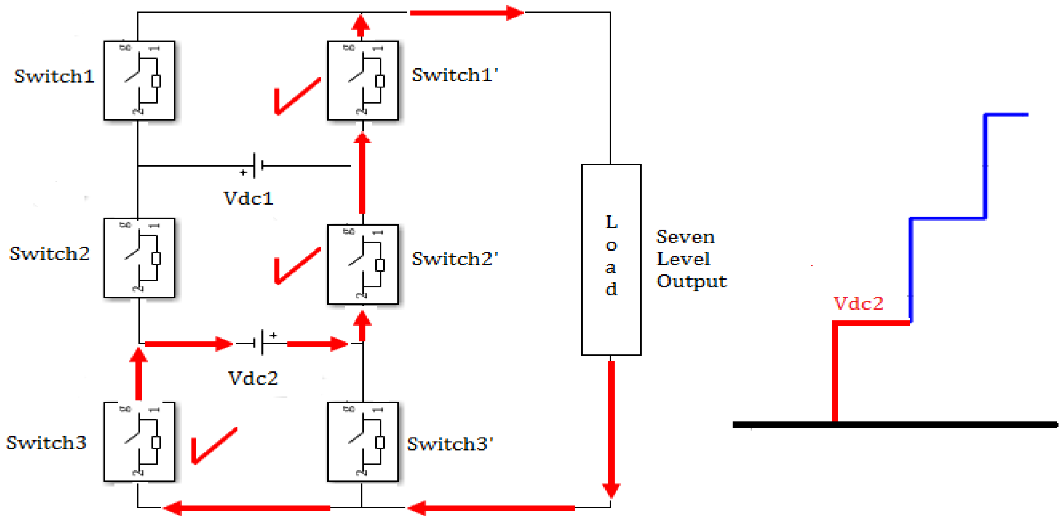

Fig 7: Configuration & Current direction for Output level of Switching

Output Level 2 of Switching:

Figure 8 illustrates the circuit diagram in depth, including the direction of current, state of the switching, and level of output. The output will always be level 2 when this switching arrangement is used, as seen in the figure below.

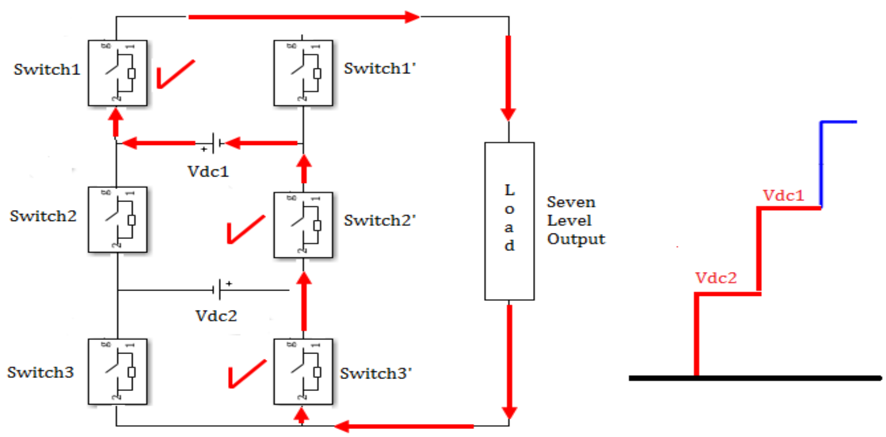

Fig 8: Configuration & Current direction for Output level 2 of Switching

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Output Level 3 of Switching:

Figure 9 illustrate the output level, switch condition, and current direction are shown in the circuit schematic. The output will always be level 3 in this switching setup, as seen in the figure below:

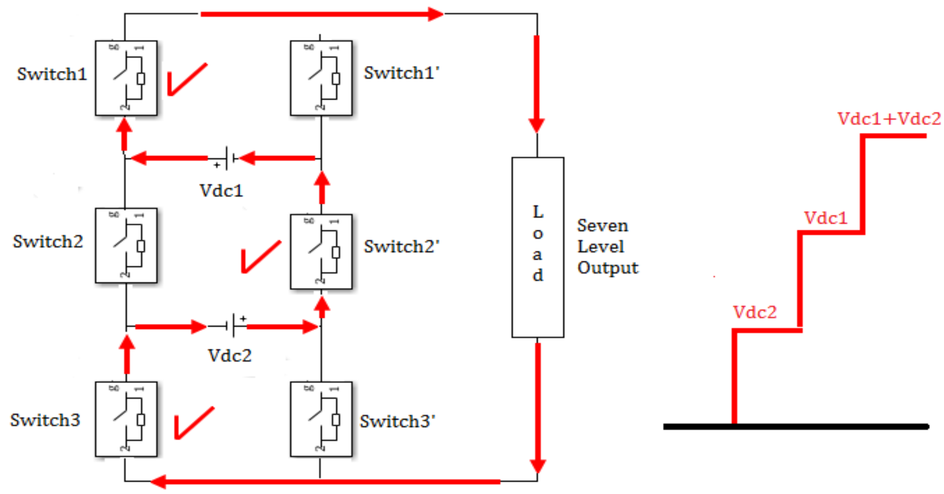

Fig 9: Configuration & Current direction for Output level 3 of Switching

Because of the quarter-wave symmetry, we only presented a quarter of the output waveform in the preceding working concept. The quarter waveform can be reflected to gain the balance of the waveform. It is possible to enhance the previously proposed 7-Level Inverter to create a higher-level inverter.

Number of components comparison

Table 2 shows the Diode Clamped Multilevel Inverter for a 7-level output and the proposed Multilevel Inverter components. The comparison chart clearly illustrates proposed 7-Level Inverter which is superior than the other 7-Level Inverters since it requires fewer components.

Table 2: Porposed Multilevel inverter comparison with other Multilevel Inverter for seven level output

Components Multilevel Inverter	No. of Switches	No. of (Clamping-diodes)	No. of (Clamping – capacitors)	No. of dc bus capacitors	No. of dc sources	No. of driver circuits	Total
Diode-Clamped	12	30	3	3	6	12	66
Flying-Capacitor	12	0	12	3	6	12	45
Cascaded	12	0	0	3	3	12	27
Proposed	6	0	0	0	2	6	14

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Modulation Techniques Used:

Modulation methods are inherent control mechanisms for the exact switching of power electronic devices, mainly semiconductor switches such as MOSFETs or IGBTs, within inverters. The process of converting an alternating current (AC) output from a direct current (DC) input is made simpler by this method. Utilizing modulation techniques properly is vital for defining how these switches are turned on and off, and so structuring the waveform at the output [4-5]. Inverter applications use a variety of modulation techniques, with the choice determined by factors including as efficiency, output quality, and application specific needs The modulation methods used have an important impact on how well inverters function and perform overall in different situations.

Multilevel inverters, which are intended to overcome harmonic control difficulties, add a layer of complexity to modulation schemes. Several modulation approaches are especially designed for the harmonic control of multilevel inverters [6-8]. These strategies help to refine the output waveform and reduce undesired harmonics, meeting the severe criteria of contemporary power systems. The continuing development and adaption of modulation techniques demonstrates the dynamic character of power electronics, where innovation is shaping the landscape of efficient and dependable energy conversion systems i.e. SPWM, SHEPWM, and SHMPWM.

The Sinusoidal Pulse Width Modulation Technique:

PWM:

One of the least popular modulation techniques for inverters is PWM. It works by maintaining a steady frequency while varying the pulse width over a predefined period of time. You can modify by adjusting the duty cycle, which is the ratio of on-time to total period the output waveform frequency and effective RMS voltage [13]. PWM methods consist of. A high-frequency modulation method called sinusoidal pulse width modulation (SPWM) shifts lower-order harmonics to a higher frequency where a small filter can readily eliminate them. [21]. this modulation scheme compares the carrier wave to a reference sine wave. The triangle wave indicates the switching frequency, and the reference sine wave represents the required elementary frequency at the output [4, 5]. Phase-shifted or level-shifted SPWM can be categorized. A common technology in power electronics and motor control applications is PS-PWM. This modulation technique successfully adapts an inverter's current, output voltage, or switch-mode power supply by modulating the phase connection among several carrier signals and changing pulse width over an identified switching period [11]. High-order harmonics are decreased by using sinusoidal pulse width modulation, or SPWM.

The SPWM waveform is seen in Figure 10 [7, 8]

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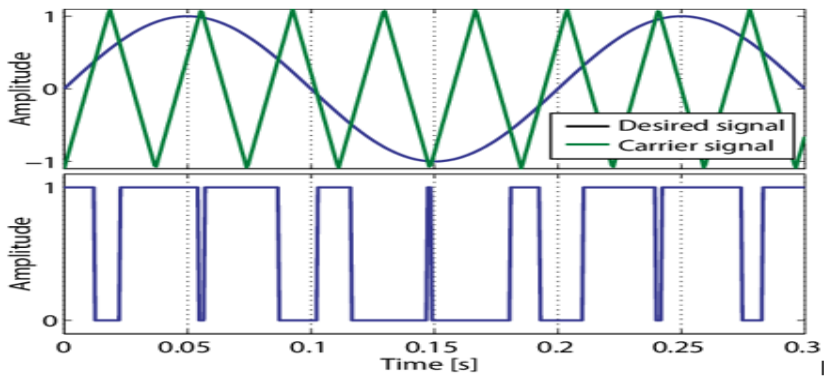

Fig 10: PWM (Sinusoidal)

Since PWM Level-Shifted make it possible to create variable current or voltage waveforms with various duty cycles, it is an essential technology in power electronics and motor control. Applications that need accurate power management for loads, such as electric motors or LEDs, frequently use this modulation technique. It involves using a particular level-shifting circuit to transfer the bus voltage. This circuit is necessary to altering the voltage waveform before to using the PWM process. It accomplishes so by utilizing a number of components, including transformers and capacitors. By allowing for slight modifications to duty cycles, level-shifted PWM facilitates efficient power distribution management and fulfills the dynamic requirements of applications requiring accurate and adaptable voltage or current control.

Using SH Method to Eliminate PWM:

A SHEPWM modulation approach removes certain lower-order harmonics. By setting optimum switching angles, this technique guarantees that all intended harmonics are removed, which can be made easier by the application of heuristic algorithms [9-13]. Shepardized Hierarchical Power Management (SHEPWM) is widely utilized in pulse-width modulation (PWM) inverters and VFDs for motor control, uninterruptible power supplies, and renewable energy systems, among other applications. Compact filters are used to attain the desired removal of lower-order harmonics, which facilitates the ensuing elimination of higher-order harmonics [7].

However, but while SHEPWM is good at controlling harmonics, it has a big drawback. The total efficiency of the inverter is lost as the basic component's magnitude falls in all its components [3, 6]. This trade-off highlights the necessity of considering the impact on basic components as well as harmonic elimination goals when selecting modulation schemes for particular applications.

Using SH method for Mitigation Pulse Width Modulation:

Pulse Width Modulation (SHMPWM), also known as the SH approach for reduction, is a modulation scheme that keeps lower-order harmonics within established bounds set by IEEE standards, rather than eliminating them completely. In order to make sure that the

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selected harmonics correspond to these established limits, it is essential to optimize the switching angles using heuristic approaches [22]. After reducing lower-order harmonics, a compact filter may efficiently eliminate higher-order harmonics. SHMPWM has a particular benefit in that it can preserve the size of fundamentals without reducing them, making it a useful approach for situations where keeping fundamental components is crucial.

SHM appears critical technology in the field of energy management and power quality, directed at reducing the distortions of harmonic in systems of electrical. Harmonic Distortions of harmonics, demarcated as variations from the ideal sinusoidal waveform in electrical currents and voltages, can cause a variety of problems, including greater losses, shorter tackle lifespan, and the interference with sensitive electronic devices. While SHMPWM effectively reduces lower-order harmonics, it is crucial to note that increased amplitudes of higher-order harmonics might raise Total Harmonic Distortion, offering a trade-off that must be carefully considered in the context of specific application needs [4, 21].

Proposed Hybrid Modulation Technique:

During my research, I presented a unique methodology for harmonic control in multilevel inverters called Hybrid "Using SHEPWM and SHMPWM". The innovative approach combines components of elimination and mitigation to provide a comprehensive harmonic control strategy. The Hybrid Elimination Pulse Width Modulation completely removes some lower-order harmonics using the selective harmonics approach, and the Mitigation Pulse Width Modulation mitigates other harmonics in compliance with IEEE standards. In increasing Fundamental Amplitude and decreasing Total Harmonic Distortion (THD), this hybrid strategy seeks to deliver a balanced solution that increases inverter performance while minimizing harmonic effect [5]. When this strategy is used, the harmonic control challenge becomes an optimization problem. Finding the ideal switching angles necessitates a thorough examination of how to maximize fundamental amplitude while minimizing Total Harmonic Distortion (THD). This optimization-driven technique demonstrates a careful and complete approach to multilevel inverter harmonic control, assisting in the creation of effective and high-performance power electronics systems.

The Fourier Series Representation:

Before going into the intricate details of the method for calculating optimal switching angles, it is essential to have an in-depth understanding of the concept of Fourier series. By dividing the Fourier series into sine and cosine functions, or complex exponential functions, it shows a periodic function. Numerous fields, including mathematics, physics, engineering, and signal processing, depend heavily on Fourier series. They provide a robust method for the analysis and approximation of complex periodic functions. Now that we're in the specific context of inverter analysis, Figure 11 shows the output waveforms of the seven inverters, which is a crucial first step towards understanding the analysis of the inverter output waveform that has been proposed.

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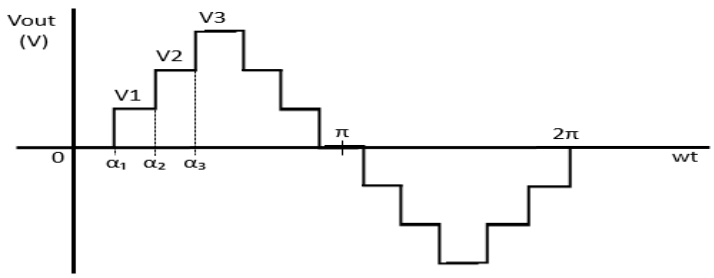

Fig 11: Proposed 7-Level Inverter's output waveform complete cycle

The waveform output shows a balanced waveform with V1 at 6V and V2 at 12V. This research project's major focus is on the fourier series representation of balanced seven-level inverter performance. The systematic fourier series formula for an output waveform at the "n" level is shown below:

$$F(wt) = a_0 + \sum_{n=1}^{\infty}(a_n \cos(nwt) + b_n \sin(nwt) \qquad (8)$$

OR

$$F(wt) = \alpha o + \sum_{n=1}^{\infty} [ancos(T2\pi nt) + bnsin(T2\pi nt)] \qquad (9)$$

"a_0" the dc is is offset, "a_n" & "b_n" are the coefficient of the nth harmonic O/P. The "DC component" (a_0) represents the average value of the f(t) function over a certain time period. The coefficients "a_n" and "b_n" adjust the amplitude and phase of the cosine and sine terms, respectively.

Harmonic number is denoted by the integer "n".

The function's “T” is a period.

When evaluating real-world scenarios, numerical techniques or reference integral tables are often employed to identify these function-specific coefficients. In order to express periodic functions using a range of basic sinusoidal components, the Fourier series is a helpful tool that facilitates analysis and modification in a variety of situations. Its importance and diversity are demonstrated by the signal processing, image compression, and partial differential equation resolution applications it has [7].

Calculating coefficients “a_n” & “b_n”, normally the following formulae is using:

$$a_n = 2/T\int_0^T f(t)\cos(2\pi nt/T)dt \qquad (10)$$

So, O/P waveform has odd symmetry of quarter-wave, it means that $a_0 = a_n = 0$, therefore, all even harmonics are zero and only odd harmonics will be present. Equation [8] gives the Fourier series expansion for the general multi-layer stepped O/P voltage:

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$$v(wt) = \sum_{n=1}^{\infty} b_n \sin(nwt) \qquad (11)$$

As, $b_n = v_n$ given by the following equation:

$$v_n = \begin{cases} \frac{4}{n\pi}\sum_{i=1}^{p} V_{dc} \cos(n \propto_j) & for\ odd\ n; \\ 0 & for\ even\ n; \end{cases} \qquad (12)$$

"n" is the harmonic number, α_j is the switching angle, p is number of voltage level and Vdc is DC source.

In the case Vdc = V1 + V2 = 18V, and P = 3. Therefore, the following equation provides the fourier series expansion of the output waveform of the recommended seven-level inverter:

$$V_{out}(wt) = \begin{cases} \sum_{n=1}^{\infty} \sin(nwt) \times (\frac{4}{n\pi}\sum_{i=1}^{3} V_{dc} \cos(n \propto_j)) & for\ odd\ n; \\ 0 & for\ even\ n; \end{cases} \qquad (13)$$

Simplifying the above equation gives

$$V_{out}(wt) = \begin{cases} \sum_{n=1}^{\infty} \frac{4V_{dc}}{n\pi} \sin(nwt)\,(cosn\alpha_1 + cosn\alpha_2 + cosn\alpha_3) & for\ odd\ n; \\ 0 & for\ even\ n; \end{cases} \qquad (14)$$

The switching angles α_j can have any value constrained by the following limit equation:

$$0 < \alpha_1 < \alpha_2 < \alpha_3 < \frac{\pi}{2}$$

The modulation index (MI), the ratio od the fundamental amplitude to that of the harmonic is given by the following equation[10]:

$MI = \frac{4}{\pi}\frac{v1}{p \times Vdc}$ (15)

Mathematical Modeling of Proposed Technique:

Within my research, I explore a novel modulation approach integrating Hybrid Harmonic distortion can be efficiently managed by employing the Selective Harmonics Method (SHM) in both Elimination Pulse Width Modulation (HEPWM) and Mitigation Pulse Width Modulation (MPWM).

This innovative technique combines both elimination and mitigation strategies wherein specific harmonics are targeted for elimination while others undergo mitigation [7, 8]. The

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residual higher-order harmonics can be efficiently suppressed using compact filters. To confirm the protection of the diminish lower order and fundamental component and diminish lower-order odd harmonics, the formulation of six nonlinear equations are:

$$H_1 = \frac{4V_{dc}}{\pi}[cos\alpha_1 + cos\alpha_2 + cos\alpha_3] = p \times MI \quad (16)$$

$$H_3 = \frac{4V_{dc}}{3\pi}[cos3\alpha_1 + cos3\alpha_2 + cos3\alpha_3] = 0 \quad (17)$$

$$H_5 = \frac{4V_{dc}}{5\pi}[cos5\alpha_1 + cos5\alpha_2 + cos5\alpha_3] < L_5 \times MI \quad (18)$$

$$H_7 = \frac{4V_{dc}}{7\pi}[cos7\alpha_1 + cos7\alpha_2 + cos7\alpha_3] < L_7 \times MI \quad (19)$$

$$H_9 = \frac{4V_{dc}}{9\pi}[cos9\alpha_1 + cos9\alpha_2 + cos59] < L_9 \times MI \quad (20)$$

$$H_{11} = \frac{4V_{dc}}{11\pi}[cos11\alpha_1 + cos11\alpha_2 + cos11\alpha_3] = 0 \quad (21)$$

The L_5, L_7, & L_9 are the extenuation limits for the 5th, 7th, and 9th harmonics respectively, according to IEEE Standards [3, 7, 8]. The 3rd & 11th harmonics are chosen to eliminate, to moderate the 5th, 7th, and 9th harmonics, and keep the 1st harmonic at its maximum [7]. The hybrid approach allows for a wide variety of combinations. However, this combination provides the best outcomes.

Objective Function:

To solve the following equations, we must first define an objective function. The goal function will be subjected to limitations, and we will use Genetic Algorithm to identify optimal switching angles. We may also utilize various heuristic techniques to discover optimal switching angles, such as PSO (particle swarm optimization), DE (Differential Evolution), and so on. Using the preceding six nonlinear equations, to construct the goal function as follow:

$$F = (H_1 - p * mi)^2 + (H_3 - 0)^2 + (H_5 - L_5 * mi)^2$$

$$+(H_7 - L_7 * mi)^2 + (H_9 - L_9 * mi)^2 + (H_{11} - 0)^2$$

The impartial function is to be diminished by using GA (Genetic Algorithm) to control the optimal switching angles $\alpha_{1,}\ \alpha_{2,}\alpha_3$ such that THD is to be minimum and Harmonics are under minimum level as per IEEE Standards.

By calculating the optimal switching angles, the following formula is used in order to convert the angles to time.

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$$t = \frac{Time\ Period \times angle}{360°}$$

Angle must be in degrees.

$$Time\ Period = \frac{1}{frequency}$$

Frequency is 50Hz

Genetic Algorithm (GA):

Genetic algorithms, sometimes known as innovative algorithms, are commonly used for search reasons. While not intrinsically clever, these algorithms are remarkably sensitive to changes. They have a particular advantage over gradient approaches, which frequently become trapped in local minima, since genetic algorithms are efficient at detecting maxima. Natural selection-based genetic algorithms are effective optimization methods applied in computer science, biology, engineering, and finance [3, 12–13]. These algorithms use methods of evolution to produce a population of potential solutions frequently for a specific problem. All solutions are composed of a collection of genes or parameters that experience genetic processes such as crossover and mutation in order to produce new generation. Then, these offspring are assessed according on their fitness level, which indicates how well they will deal with the situation at hand [6, 7].

RESULTS AND ANALYSIS

This section of the study goes into a review that is software-driven and aims to simplify and improve multilevel inverter technology. The objective of the research is to identify methods for simplifying and maximizing multilayer inverter operation, which will reduce complication and increase efficiency. The study looks at different configuration and control mechanisms using analytical tools and algorithms in an effort to find new approaches that increase performance while requiring few switches. The present work, which is software-driven, provides an in-depth overview of the basic principles governing multilevel inverters and sheds light on their potential applications and advancements in power electronics systems.

Software Implementation of Proposed Design:

Figure 12 displays the construction of a seven-level, single-phase multilevel inverter meant only for resistive load applications. MATLAB Simulink is used for carrying out the concept with accuracy, drawing on findings from the previously described investigations [3, 4, 8]. This configuration shows an advanced combination of technology and control techniques designed to deliver optimal performance and effective power conversion. MATLAB Simulink simulation enables a comprehensive assessment of the features and effectiveness of the suggested design, providing important insights into its operational characteristics and potential real-world applications.

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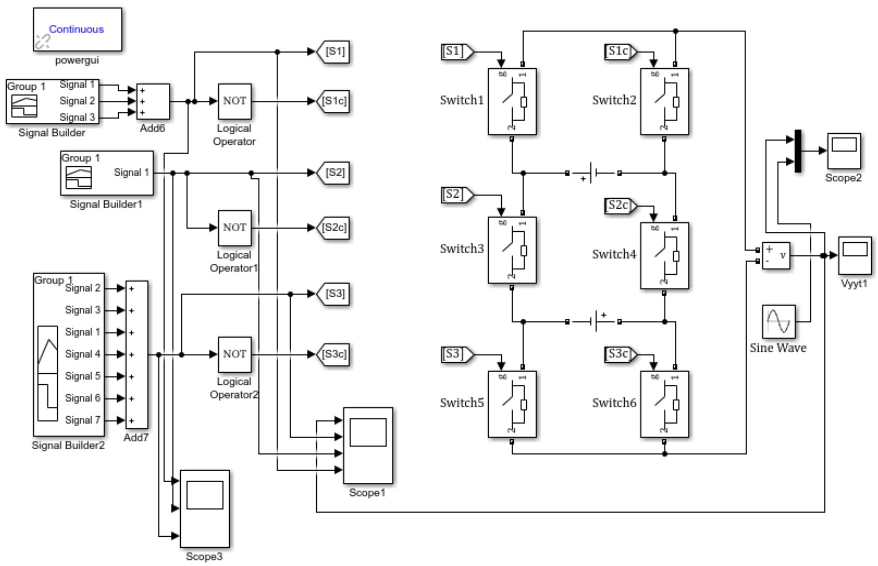

Fig 12: Proposed Seven Level Inverter Simulation model.

Figures 13 & 14 illustrate how a signal builder generates switching sequence for angles α_1 and α_3. Therefore, switching sequence for angle α_2 is modest which is easily created using a pulse generator. The GS (Genetic Algorithm) Tool, which is incorporated into MATLAB [8], is used to calculate these angles and solve the objective function. This technique allows for effective switching sequence optimisation, guaranteeing that the multilevel inverter system performs and functions properly. Using the GA Tool's capabilities streamlines the design process, allowing for the synthesis of optimal control schemes adapted to the application's unique requirements.

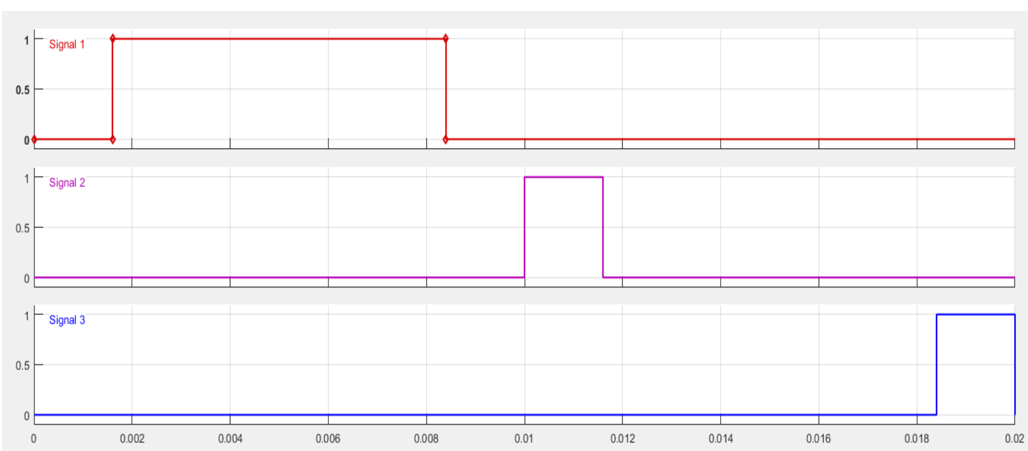

Fig 13: Switching sequence 1 produced by Signal builder 1.

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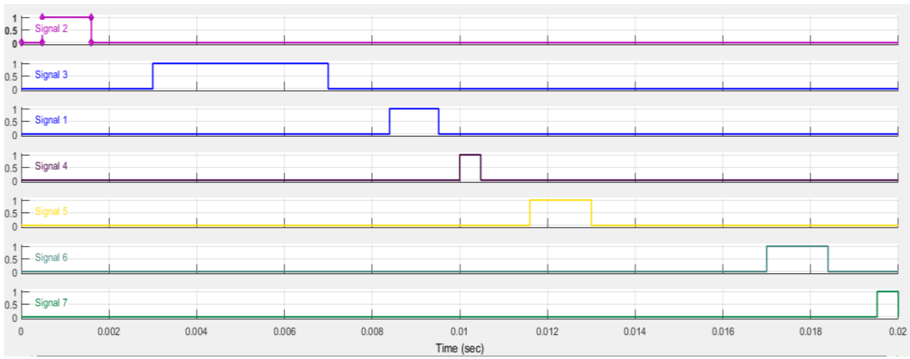

Fig 14: Switching sequence 3 porduced by Signal builder 2.

Figure 15 illustrates the O/P waveform of the 7- level inverter with resistive load (Proposed).

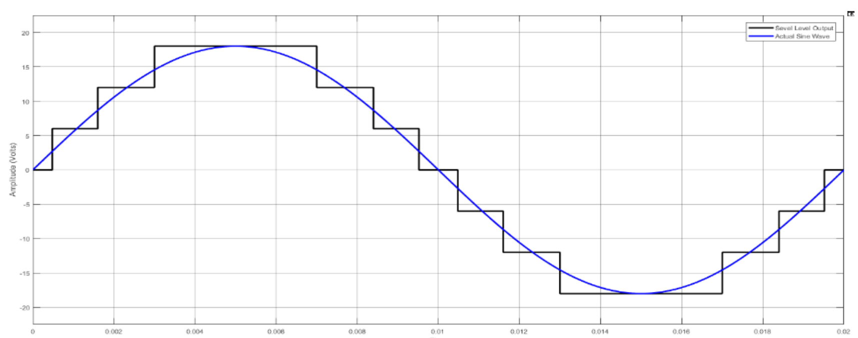

Fig 15: 7-Level Inverter O/P waveform with resistive load (Proposed)

Figure 16 displays the switching order for the S1, S2, and S3 switches based on the optimal angles α_1 = 8.7498°, α_2 = 28.7463°, and α_3 = 54.4681° that were discovered by utilizing the GA Tool to minimize the objective function. The approval of S1, S2, and S3 switches determines the switching order for the remaining S1', S2', and S3' switches.

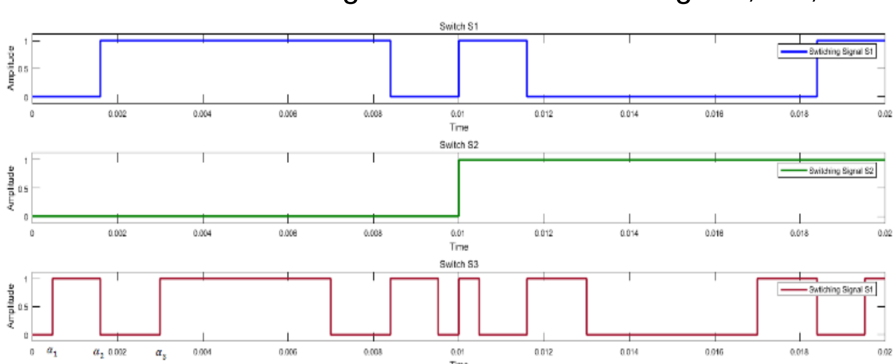

Fig 16: S1, S2, & S3 switches in switching order.

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Analysis of fast fourier transfrom:

FFT (Fast Fourier Transform) examination of the O/P voltage, Figure 17 shows the proposed Multi-Level Inverter.

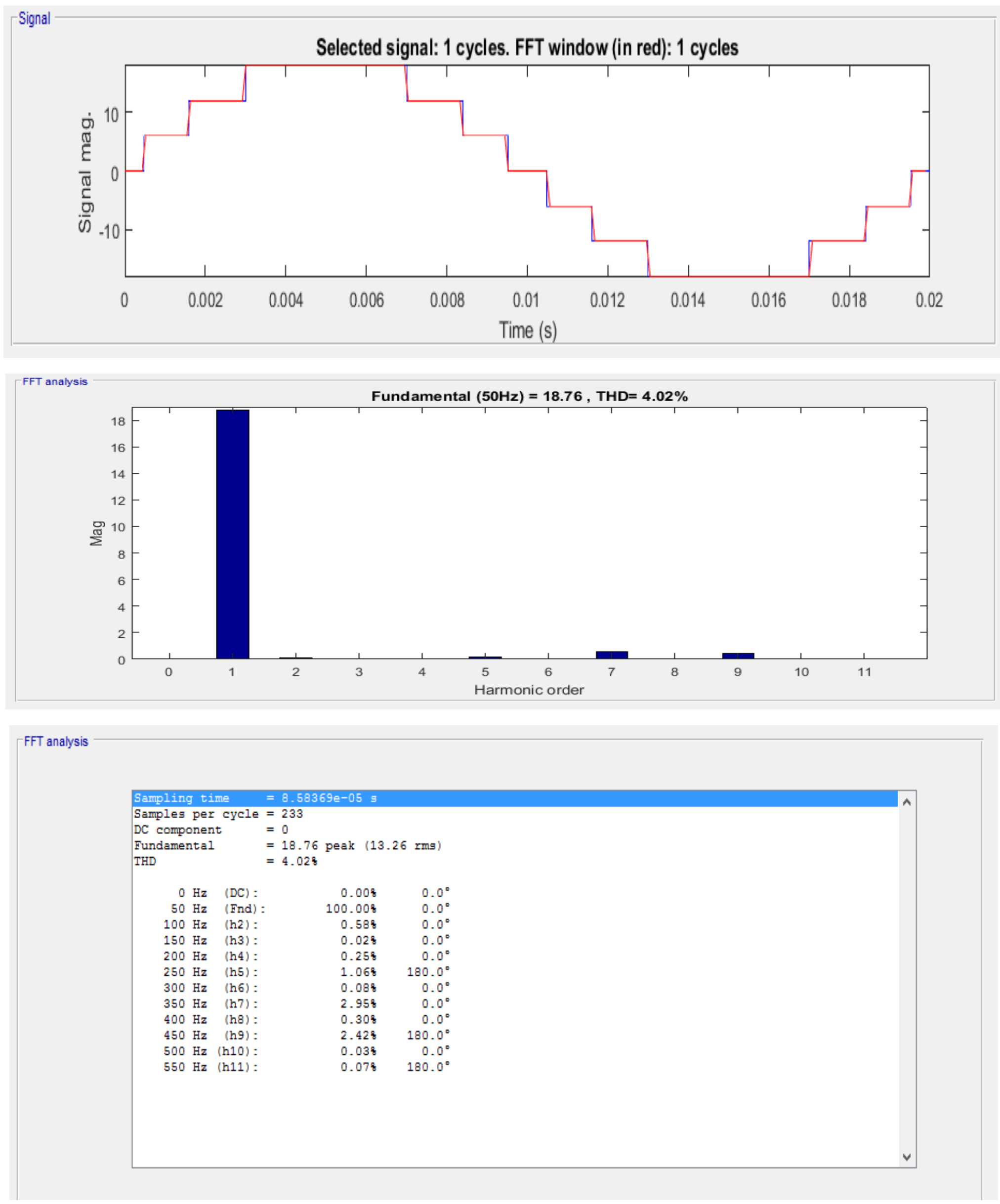

Fig 17: Proposed Output voltage 7- level Inverter.

The implied thirty-one-level Multi-Level Inverter (MLI) achieves a surprisingly low total harmonic distortion (THD) in its output voltage, registering at 4.02%, with a minor amount falling below the 5% THD threshold. Prior studies [3-4] shown a significant reduction in overall

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harmonic distortion with the inclusion of just a single H-bridge unit in the proposed multi-level inverter.

Efficiency and Cost Effectiveness:

Harmonic Distortion (THD) and cost in contrast to other conventional MLIs [4,10]. Table 4.1 summarises the significant differences in %THD between the suggested Multilevel Inverters and their traditional counterparts.

Table 3: Proposed 7-level inverter of the half cycle (180°)

Techniques of Modulations & Results	SHE controlled MLI1	SHMPWM 2	Hybrid SHE &SHM
% THD	12.93%	10.28%	4.02%
Levels of Multilevel inverter (MLI)	7 Level MLI	7 Level MLI	7 Level MLI

This Table 3 gives a clear contrast, emphasizing the considerable reduction in %THD achieved by the proposed Multilevel Inverter by including a Hybrid SHE and SHM modulation approach.

CONCLUSION

This work presents a detailed analysis of harmonic control inside a proposed Multilevel Inverter (MLI), adopting a Hybrid Pulse Width Modulation technique that combines the Selective Harmonics Method and Pulse Width Modulation with Selective Harmonics Mitigation. Notably, the Genetic Algorithm (GA) is used to optimise switching angles (a1, a2, and a3), resulting in a successful decrease in the number of switches in the MLI. The hybrid technique successfully removes the third and eleventh harmonics while also reducing the fifth, seventh, and ninth harmonics, which is consistent with the IEEE standards. The MLI structure, utilising six switches and two DC voltage sources, resulting in a 7-level output voltageso increasing the output waveform's quality and reducing the multilayer inverter's size and expense at the same time.

In addition, the findings for the seven-level MLI are improved by employing the Hybrid SHEPWM and SHMPWM techniques, which result in a significant reduction in Total Harmonic Distortion (THD) as compared to normal multilevel inverters. Running switches at their fundamental frequency reduces switching losses significantly. This combined benefit of lower switching losses and improved harmonic control highlights the potential applications of the proposed MLI, providing a realistic way to increasing the efficacy and economy of multilayer inverter systems in a variety of electrical power applications.

Future work:

The MATLAB/Simulink software suite was quite useful in aiding with data collecting during this project. A complicated computational tool known as MATLAB/Simulink makes it easy to design and analyze the proposed Hybrid SHEPWM. A seven-level inverter employs two forms of pulse width modulation:

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SHEPPWM (selective harmonic elimination pulse width modulation) and SHMPWM. This software framework not only streamlined the process, but it also provided a comprehensive platform for assessing the feasibility and performance of the proposed inverter designs.

Author's Contribution: M. Ali, Conceived the idea; K. Rehma, and J. Miraj, Designed the simulated work, K. Rehman, J. Miraj and M. Ali did the acquisition of data; K. Rehman, J. Miraj and M. Ali Executed the simulated work, data analysis or analysis and interpretation of data and wrote the basic draft; K. Rehman, did the language and grammatical edits or Critical revision.

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