A Unique Closed Loop Controller Based Advanced Multilevel Structure
Fed Induction Motor Drive System

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Abstract: Variable voltage and frequency supply to A.C drives is invariably obtained from a three-phase power conditioning units. Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance. Hence, different circuit configurations namely multilevel inverters have become popular and considerable interest by researcher are given on them. Variable voltage and frequency supply to A.C drives is invariably obtained from a three-phase voltage source inverter. Closed loop control action of H-Bridge Seven level inverter with SPWM fed The proposed topology is suitable for any number of levels. When the levels are increased the number of switches used is reduced compared to the conventional cascaded H-bridge multilevel inverter. This paper is particularly focused on the 7-level inverter with the requirement of low switching components. In the proposed topology only 7 switches were used. The harmonic reduction is achieved by selecting appropriate switching angles. It shows hope to reduce initial cost and complexity hence it is opt for industrial applications.

Keywords: Multilevel Inverter, MATLAB, THD and RV Technique.

I. INTRODUCTION

Power electronics devices are widely used in different fields and for different practical applications. The expansion of their field of applications is related to the knowledge of the device behaviour and of their performances. Large electric drives and utility applications require advanced power electronics converter to meet the high power demands. As a result, multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. Power electronic converters, especially dc/ac PWM inverters have been extending their range of use in industry because they provide reduced energy consumption, better system efficiency, improved quality of product, good maintenance, and so on. The most common initial application of multilevel converters has been in traction, both in locomotives and track-side static converters. More recent applications have been for power system converters for VAR compensation and stability enhancement, active filtering, high-voltage motor drive, high-voltage dc transmission, and most recently for medium voltage induction motor variable speed drives. Many multilevel converter applications focus on industrial medium-voltage motor drives, utility interface for renewable energy systems, flexible AC transmission system (FACTS), and traction drive systems.

The inverters in such application areas as stated above should be able to handle high voltage and large power. For this reason, two-level high-voltage and large-power inverters have been designed with series connection of switching power devices such as gate-turn-off thyristors (GTOs), integrated gate commutated transistors (IGCTs), and integrated gate bipolar transistors (IGBTs), because the series connection allows reaching much higher voltages. However, the series connection of switching power devices has big problems, namely, non equal distribution of applied device voltage across series-connected devices that may make the applied voltage of individual devices much higher than blocking voltage of the devices during transient and steady-state switching operation of devices. As alternatives to effectively solve the above-mentioned problems, several circuit topologies of multilevel inverter and converter have been researched and utilized. The output voltage of the multilevel inverter has many levels synthesized from several DC voltage sources. The quality of the output voltage is improved as the number of voltage levels increases, so the quantity of output filters can be decreased. A multilevel converter can be implemented in many different ways. The simplest techniques involve the parallel or series connection of conventional converters to form the multilevel waveforms. More complex structures effectively insert converters within converters.

The voltage or current rating of the multilevel converter becomes a multiple of the individual switches, and so the power rating of the converter can exceed the limit imposed by the individual switching devices. In this paper, a novel cascaded H-bridge multilevel inverter has been proposed using less number of switches. A standard cascaded multilevel inverter requires 4h number of switches for (2h +
1) levels whereas \( h \) is the number of dc sources. Multilevel inverters supplied from equal and constant dc sources almost don’t exist in practical applications. The variation of the dc sources affects the values of the switching angles required for each specific harmonic profile, as well as increases the difficulty of the harmonic elimination’s equations. The emergence of multilevel inverters has been in increase since the last decade. These new types of converters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum. Finally the proposed topology is implemented with SHE[7],[8]. The THD values for the Traditional, Conventional and Proposed inverters are compared and analyzed.

II. H-BRIDGE MULTILEVEL INVERTER

The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output waveform. Therefore, using the multilevel inverter as an alternative to traditional PWM inverters is investigated. In this topology the number of phase voltage levels at the converter terminals is \( 2N+1 \), where \( N \) is the number of cells or dc link voltages. In this topology, each cell has separate dc link capacitor and the voltage across the capacitor might differ among the cells. So, each power circuit needs just one dc voltage source as shown in Fig.1. The number of dc link capacitors is proportional to the number of phase voltage levels .Each H bridge cell may have positive, negative or zero voltage. Final output voltage is the sum of all H-bridge cell voltages and is symmetric with respect to neutral point, so the number of voltage levels is odd. Cascaded H-bridge multilevel inverters typically use IGBT switches. These switches have low block voltage and high switching frequency. Consider the seven level inverter; it requires 12 IGBT switches and three dc sources. A cascaded H-bridge multilevel inverter is simply a series connection of multiple H-bridge inverters. Each H-bridge inverter has the same configuration as a typical single-phase full-bridge inverter as shown in Fig.2. The cascaded H-bridges multilevel inverter introduces the idea of using Separate DC Sources (SDCSs) to produce an AC voltage waveform. Each H-bridge inverter is connected to its own DC source \( V_{dc} \). By cascading the AC outputs of each H bridge inverter, an AC voltage waveform is produced.

By closing the appropriate switches, each H-bridge inverter can produce three different voltages: \(+V_{dc}\), 0 and \(-V_{dc}\).

![Fig.2. Output Voltage of cascaded H-bridge seven level inverter.](image)

It is also possible to modularize circuit layout and packaging because each level has the same structure, and there are no extra clamping diodes or voltage balancing capacitors. The number of switches is reduced using the new topology. This circuit is simulated using the MATLAB software. The results are shown in the later sections in detail.

III. PROPOSED TOPOLOGY

The main objective is to improve the quality output voltage of the multilevel inverter with reduced number of switches. An important issue in multilevel inverter design is that to generate nearly sinusoidal output voltage waveform and to eliminate lower order harmonics as shown in Fig.3. A key concern in the fundamental switching scheme is to determine the switching angles in order to produce the voltage with fundamental frequency.

![Fig 3 Proposed Power circuit for 7-level output.](image)

There are three modes of operation for the proposed 7-level multilevel inverter. These modes are explained as below.

**Powering Mode:** This occurs when both the load current and voltage have the same polarity. In the positive half cycle, when the output voltage is \( V_{dc} \), the current pass comprises; the lower supply, \( D_6, Q_1, \) load, \( Q_4, \) and back to the lower supply. When the output voltage is \( 2V_{dc} \), current pass is; the
lower source, Q5, the upper source, Q1, load, Q4, and back to the lower source. When the output voltage is 3Vdc, the current pass comprises: upper supply, Q1, load, Q4, Q7, lower supply. In the negative half cycle, Q1 and Q4 are replaced by Q2 and Q3 respectively. Free-Wheeling Mode
Free-wheeling modes exist when one of the main switches is turned-off while the load current needs to continue its pass due to load inductance. This is achieved with the help of the anti-parallel diodes of the switches, and the load circuit is disconnected from the source terminals. In this mode, the positive half cycle current pass comprises; Q1, load, and D2 or Q4, load, and D3, while in the negative half cycle the current pass includes Q3, load, and D4 or Q2, load, and D1. Regenerating Mode
In this mode, part of the energy stored in the load inductance is returned back to the source. This happens during the intervals when the load current is negative during the positive half cycle and vice-versa, where the output voltage is zero.

The positive current pass comprises; load, D2, Q6, the lower source, and D3, while the negative current pass comprises; load, D1, Q6, the lower source, and D4. From the fig.4 switching pattern for the various switches are explained. In this paper fundamental frequency switching scheme is employed which reduces the switching losses. Because the switching frequency is less in this method when compared to the other methods. Switching losses are directly proportional to the switching frequency.

![Waveforms of the proposed seven level inverter.](image)

**IV. SELECTIVE HARMONICS ELIMINATION**

The Selective Harmonic Elimination Stepped-Waveform (SHESW) technique is very suitable for a multilevel inverter circuit. Employing this technique along with the multilevel topology, the low Total Harmonic Distortion THD output waveform without any filter circuit is possible.

**A. Fourier Series and Harmonics Elimination Theory**

After applying Fourier theory to the output voltage waveform of multilevel converters, which is odd quarter-wave symmetric, we can find the Fourier expression of the multilevel output voltage as (1). If the DC voltages are equal in the multilevel converter, the equation for the fundamental frequency switching control method can be expressed as:

\[
V(t) = \sum_{n=1\text{odd}}^{\infty} \frac{4V_{dc}}{n\pi} \left( \cos(n\theta_1) + \cos(n\theta_2) + \cdots + \cos(n\theta_s) \right) \sin(n\omega t)
\]

(1)

From the equation, it can be seen that the output voltage has no even harmonics because the output voltage waveform is odd quarter-wave symmetric. It also can be seen from (2) that the peak values of these odd harmonics are expressed in terms of the switching angles \( \theta_1, \theta_2, \) and \( \theta_s \). Furthermore, the harmonic equations produced from (2) are transcendental equations. Based on the harmonic elimination theory, if one wants to eliminate the nth harmonic, then

\[
\cos(n\theta_1) + \cos(n\theta_2) + \cdots + \cos(n\theta_s) = 0
\]

(2)

That means to choose a series of switching angles to let the value of the nth harmonic be zero. Therefore, an equation with s switching angles will be used to control the s different harmonic values. Generally, an equation with s switching angles is used to determine the fundamental frequency value, and to eliminate s-1 low order harmonics. For an equation with three switching angles, (2) becomes

\[
V(t) = \sum_{n=1\text{odd}}^{\infty} \frac{4V_{dc}}{n\pi} \left( \cos(n\theta_1) \cos(n\theta_2) + \cos(n\theta_3) \sin(n\omega t) \right)
\]

(3)

**B. Transcendental Equations to Solve**

In this paper we derived harmonic equations for eliminating the 3rd and 5th order harmonics. The resulting harmonic equations are:

\[
\cos(3\theta_1) + \cos(3\theta_2) + \cos(3\theta_3) = 0
\]

(4)

\[
\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0
\]

(5)

To simplify the expression, (4) can be written as

\[
\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) = m
\]

(7)

Where

\[
M = \frac{4V_{dc}}{3V_{dc}}
\]

(8)

These harmonic equations (4)-(6) are transcendental equations. They are difficult to solve without using some sort of numerical iterative technique. Here Newton Raphson method is employed for solving these equations.

**C. Solving the Harmonic Equations using Newton Raphson Method**

To solve the harmonic equations by resultant theory, they must be changed into polynomials. First, change the variables,

\[
X_1 = \cos(\theta_1)
\]

(9)

\[
X_2 = \cos(\theta_2)
\]

(10)

And

\[
X_3 = \cos(\theta_3)
\]

(11)

Also, use the following trigonometric identities:

\[
\cos(3\theta) = 4\cos^2(\theta) - 3\cos(\theta)
\]

(12)
\[
\cos(3\theta) = 3\cos(\theta) - 20\cos^2(\theta) + 10\cos^3(\theta) \tag{13}
\]

Then, apply them to the transcendental harmonic equations above, and the following polynomial harmonic Equations can be found. For the fundamental frequency harmonic:

\[
P_1(x_1, x_2, x_3) = \sum_{n=1}^{5} X_n - m = 0 \quad \tag{14}
\]

For the 3rd harmonic:

\[
P_1(x_1, x_2, x_3) = \sum_{n=1}^{5} (4X_n^2 - 3X_n) = 0 \quad \tag{15}
\]

For the 5th harmonic:

\[
P_1(x_1, x_2, x_3) = \sum_{n=1}^{5} 3X_n^2 - 20X_n^2 + 20X_n = 0 \quad \tag{16}
\]

The polynomial equations can be solved by using the Newton Raphson method. The following are steps for solving the equations. Substitute the initial guesses for variables. Then form the jacobian matrix with Newton’s formula. Repeat the same steps until the solutions to converge. Thus the solutions obtained are given below:

\[
\theta_1 = 8.70033^0 \\
\theta_2 = 28.0880^0 \\
\theta_3 = 34.9895^0
\]

IV. SEVERAL MODULATION SCHEMES

Many PWM techniques were developed to control the power inverter gain, and tried to improve the inverter operation, based on minimum harmonic contents in the output voltage. They are quite popular in industrial applications. In that PSPWM and LSPWM methods are merely preferred by many industrial applications.

A. Phase Shifted Pulse Width Modulation Scheme (PSPWM)

Phase shifted PWM (PS-PWM) is used with cascaded H-bridge (CHB) and flying capacitor (FC) inverters, since each cell is modulated independently using sinusoidal unipolar PWM and bipolar PWM, respectively, providing an even power distribution among the cells. A carrier phase shift of 180°/m for the CHB and of 360°/m for the FC is introduced across the cells to generate the stepped multilevel output waveform with lower distortion (where m is the number of cells). The difference between the phase shifts and the type of PWM (unipolar or bipolar) is because one CHB cell generates 3-level outputs, while one FC cell generates two level outputs and also used for many levels as shown in Fig.5.

B. Level Shifted PWM Scheme (LSPWM)

Level shifted PWM (LS-PWM) is used for controlling voltage of a diode clamped multilevel inverter as shown in Fig.6. The control principle of the level shifted SPWM is to use several triangular carrier signals keeping only one modulating sinusoidal signal. For a three level inverter two carriers and for a five level inverter, four triangular carriers are needed. In general if an m-level inverter is employed, (m-1) carriers are needed. The carriers have the same frequency f_c and the same peak-to-peak amplitude A_c. The zero reference is placed in the middle of the carrier set. The modulating signal is a sinusoid of frequency f_m and amplitude A_m. At every instant, each carrier is compared with the modulating signal. Each comparison switches the switch “on” if the modulating signal is greater than the triangular carrier assigned to that switch.

Fig.6. LSPWM Scheme.

V. MATLAB/SIMULINK RESULTS

Here simulation is carried out in different cases in that 1). Conventional Cascaded H-Bridge Multilevel Inverter 2). Proposed Symmetrical H-Bridge Multilevel Inverter 3). Proposed Symmetrical H-Bridge Multilevel Inverter with closed Loop Controller Using Sinusoidal Modulation Scheme.

Case1: Conventional Cascaded H-Bridge Multilevel Inverter

Fig.7. Matlab/Simulink Model of Conventional Cascaded H-Bridge Multilevel Inverter.
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Fig.7 shows the Matlab/Simulink Model of Conventional Cascaded H-Bridge Multilevel Inverter using Matlab/Simulink platform.

Fig.8 Seven Level Output Voltage.

Fig.8 shows the Seven Level Output Voltage of Conventional Cascaded H-Bridge Multilevel Inverter.

Fig.9 FFT Analysis of 7-Level Output Voltage.

Fig.9 shows the FFT Analysis of 7-Level Output Voltage of Conventional Cascaded H-Bridge Multilevel Inverter, attains 16.89%.

Case2: Proposed Symmetrical H-Bridge Multilevel Inverter

Fig.10 shows the Matlab/Simulink Model of Proposed Symmetrical H-Bridge Multilevel Inverter Fed Induction machine Drive application by using Matlab/Simulink platform.

Fig.10. Matlab/Simulink Model of Proposed Symmetrical H-Bridge Multilevel Inverter.

Fig.11. Seven Level Output Voltage.

Fig.11 shows the Seven Level Output Voltage of Proposed Symmetrical H-Bridge Multilevel Inverter.

Fig.11 Seven Level Output Voltage.

Fig.12 Speed & Torque.

Fig.12 Speed & Torque of Proposed Symmetrical H-Bridge Multilevel Inverter Fed Induction machine Drive application.

Fig.12 Speed & Torque.

Fig.13 FFT Analysis of 7-Level Output Voltage.

Fig.13 FFT Analysis of 7-Level Output Voltage.
Fig.13 shows the FFT Analysis of 7-Level Output Voltage of Proposed Symmetrical H-Bridge Multilevel Inverter, attains 16.89%. Here THD response is near to formal one, but operating under low active switches, commercially so perfect.

Case 3: Proposed Symmetrical H-Bridge Multilevel Inverter with closed Loop Controller Using Sinusoidal Modulation Scheme.

Fig.14 shows the Matlab/Simulink Model Proposed Symmetrical H-Bridge Multilevel Inverter with closed Loop Controller Using Sinusoidal Modulation Scheme. application by using Matlab/Simulink platform.

Fig.15 shows the 7-Level Output Voltage of Proposed A-Symmetrical H-Bridge Multilevel Inverter with closed Loop Controller Using Sinusoidal Modulation Scheme.

VI. CONCLUSION

This proposed model is implemented using Matlab Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the closed loop performance of multilevel inverter has been established. The multilevel converters achieve high-voltage switching by means of a series of voltage steps, each of which lies within the ratings of the individual power devices. In this paper, a new inverter topology has been proposed which has superior

![Fig.16 Speed & Torque and Stator Current.](image)

![Fig.17 FFT Analysis of 7-Level Output Voltage.](image)
features over conventional topologies in terms of the required power switches and isolated dc supplies, control requirements, cost, and reliability. This will add up to the efficiency of the converter as well as reducing the size and cost of the final prototype. The closed loop control action fed by SPWM method is used to drive the inverter. The PWM for this topology has fewer complexities since it only generates positive carriers for PWM control. So, these new technologies of semiconductor are more suited to high power applications and they enable the design of multilevel inverters. Compared to typical PWM switching schemes, multilevel fundamental switching will lead to lower switching losses. As a result, using the multilevel fundamental frequency switching scheme will lead to increased efficiency. This paper presents a procedure for selectively eliminating certain harmonics in a multilevel inverter utilizing the high switching frequency, attains low THD with in IEEE standards.

VII. REFERENCES