EFFECT OF MODULATION INDEX ON TOTAL HARMONIC DISTORTION AND INDIVIDUAL HARMONICS IN A SINGLE-PHASE FIVE LEVEL SPWM BASED CHML INVERTER-A REVIEW

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Abstract.

An effort has been made to design a sinusoidal pulse width modulation based five-level inverter produced almost sinusoidal output waveform and to investigate how this inverter's other harmonics and overall harmonic distortion are affected by changes in the modulation index.

It is well known that commercial inverters, whether single-phase or three-phase, produce output voltage waveforms that are square waves or modified square waves, and as a result, contain harmonics of lower and higher orders. The effect of lower order harmonics in a commercial inverter may be eliminated or reduced by using suitable low-pass filter but, as the frequency is on the lower side of frequency spectrum, some portion of the fundamental also get filtered affecting the efficiency of the inverter. Besides, the use of low pass filter also increases the size of inverter as well as the cost.

Keywords. Cascaded H-bridge Multilevel Inverter; SPWM; Power Semiconductor Devices; Harmonic Factor (HF); Total Harmonic Distortion (THD); (CHMLI).

1. INTRODUCTION

A primary function of an inverter is to transform a DC input voltage into an AC output voltage with a sinusoidal waveform of the desired amplitude.

Commercial inverters, on the other hand, typically have waveforms that are square wave or quasi-square wave and contain lower and higher order harmonics. Inverter performance and lifespan are eventually impacted by this non-sinusoidal waveform. These inverters can be employed for low and medium power applications, while sinusoidal waveforms with less harmonics are needed for high power applications. Multilevel inverters (MLIs) are gradually replacing the old two level inverters. As staircase type voltage level (which looks like almost sine wave) can be synthesized with proper switching of the devices contained in numbers of H-bridges. More is the number of H-bridges, step level will be more and the waveform will look like sinusoidal. The introduction of high speed power semiconductor devices and the application of appropriate switching techniques allow for the elimination of lower and some higher order harmonics, improving fundamental component voltage and bringing total harmonic distortion (THD) of MLI inverters to an allowable level.

Amongst the different methods for systematically switching the power devices, space vector PWM and sinusoidal pulse width modulation (SPWM) techniques are frequently employed to regulate the output voltage waveform's amplitude and frequency.

This work uses simulation software matlab-simulink [18] with a unipolar switching scheme to examine the performance of a single-phase multicarrier based five level H-Bridge inverter employing SPWM (level shifting) approach with varied modulation indices. As mentioned, a multilayer inverter's voltage waveform is made up of numerous voltage steps that can be created by connecting various H-bridges in various ways, with each H-bridge having its own independent dc voltage source.

In general, multilayer inverters are helpful for high-power applications, and they are more efficient than traditional two-level inverters.

2. THEORETICAL BACKGROUND

2.1. Different PWM Techniques

Power electronics and drive systems have seen a rise in the use of switching utilising PWM approaches.

No single PWM technique can be used for all applications. Several pulse-width modulation (PWM) approaches have been created for diverse industrial applications in accordance with the advanced technology in solid state power electronic devices and microprocessors.

The PWM approaches have been the focus of extensive research since the 1970s for the aforementioned reasons.

PWM's primary goals are to lower the output voltage's harmonic content and adjust the inverter's frequency and its output voltage.

Phase displacement control, Sinusoidal pulse width modulation, Harmonic Injection modulation, Single pulse width modulation, Multiple pulse width modulation, and Space Vector are just a few of the numerous PWM techniques.

The presence of medium and higher order harmonics in inverters using other methods, such as SHEPWM, limits the improvement of THD. The two PWM schemes that are most commonly used for multi-level inverters are the carrier based PWM (Sinusoidal PWM or SPWM) techniques and the space vector based PWM techniques.

The SPWM systems require relatively tiny size filters and are more adaptable and straightforward to apply.

By comparing a sinusoidal waveform with the necessary frequency to a triangle wave (Carrier signal) with a relatively high frequency, many pulses per half cycle are produced using this technique. For example, for five-level inverter- 4 carrier signals are required which may be of same frequencies or with varying frequencies with level shifting or phase shifting of carriers. In our study, level shifting with fixed carrier frequency has been used for a five level inverter (Figure 1).

2.2. A Brief of Unipolar Switching

In contrast to bipolar switching, which switches the output between high and low, unipolar switching switches the output either from high (positive level) to zero or from low (negative level) to zero.

One such unipolar switching method is depicted in Figure 1. It employs the following switch controllers [4]:

When $v_{sine} > v_{tri}$, S1 is on, followed by

S2 when $-v_{sine} < v_{tri}$,

S3 when $-v_{sine} > v_{tri}$, and

S4 when $v_{sine} < v_{tri}$.

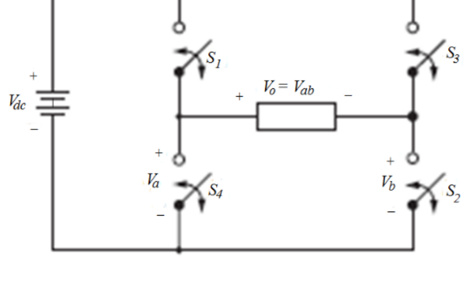

Figure 1 (a). H-bridge used for unipolar switching

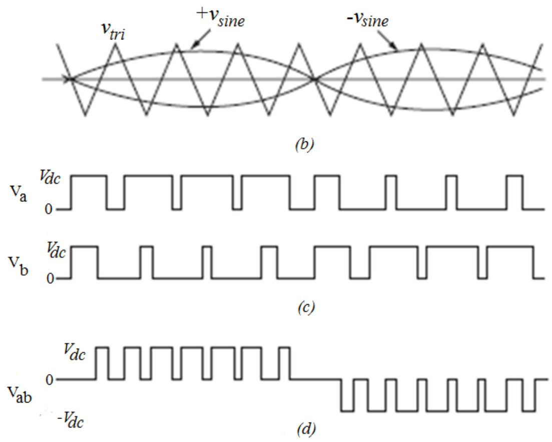

Figure 1. (b). PWM is created by comparing triangular carrier signals with a sinusoidal signal (the reference signal); (c) bridge voltages V_a and V_b; and (d) output voltage V_{ab}.

When one switch in a pair is closed, the other is open, which is how complementary switching is done with switch pairs (S1, S4) and (S2, S3).

In Figure 1(a), voltages V_a and V_b alternate between $+V_{dc}$ and zero.

Figure 1(d) depicts the output voltage $V_o = V_{ab} = V_a - V_b$.

2.3. Traditional Single-Phase Half-Bridge Inverter

Figure 2 (a) shows a traditional single phase half-bridge inverter with two levels that uses two MOSFETs and a single dc supply. Figure 2(b) displays the output voltage waveform for both resistive and inductive loads.

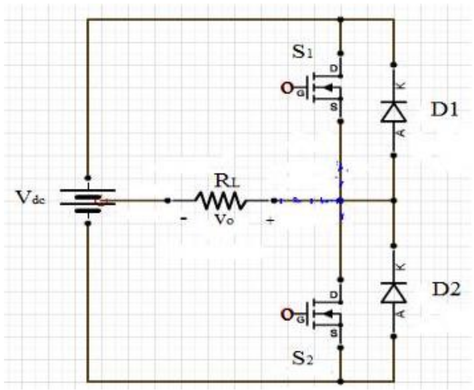

Figure 2(a). Traditional single phase half-bridge inverter with MOSFETs

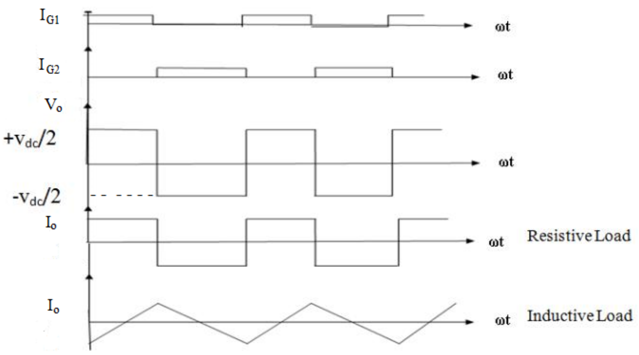

Figure 2 (b). Waveforms of voltage and current for resistive and inductive loads

In Figure 2(b), I_o represents the current flowing through the load, and I_{G1} and I_{G2} are the gate currents of MOSFETs 1 and 2, respectively.
The switching time period of the devices can be altered to alter the frequency of the inverter output voltage. Each semiconductor device S1 and S2 is considered to conduct for the time that its gate pulse is present while under a resistive load and to commutate as soon as this gate pulse is removed, i.e., each switch conducts for a 180^o conduction angle. The output wave patterns contain both lower order and higher order harmonics.
Even harmonic terms won't be present because of the waveform's quarter-wave symmetry; only odd harmonics will be present.
The following gives the formula for the instantaneous output voltage:

$$v_0(t) = \frac{2V_{dc}}{n\pi} \sin n\omega t, \quad \text{Where } n=1,3,5,\ldots \infty$$

The amplitude or peak of the nth component is,

$$V_n = \frac{2V_{dc}}{n\pi} = \frac{V_1}{n} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The term $V_1 = \frac{2V_{dc}}{\pi}$ is the amplitude of fundamental component and common to all expressions for harmonic voltages. The harmonic factor V_n/V_1 is used to all formulas for harmonic voltages to obtain percentage of harmonics with respect to V_1.

According to Equation (1), the output voltage waveform contains harmonic frequencies that mostly affect the shape of the output voltage and are very challenging to filter out because they are close to the fundamental frequency. These frequencies include the third harmonic at 33.33%, the fifth harmonic at 20%, the seventh harmonic at 14.3%, and the ninth harmonic at 9.1%.

2.4. A Brief of Five-level Inverter and generation of PWM

A five-level inverter is shown in Figure 3 [1, 5, 6, 7]. It uses two H-bridges connected in cascade. For generation of switching pulses using SPWM technique, a 50 Hz sinusoidal signal is compared with (m-1) i.e., four numbers triangular waves (Here m=5 for five level inverter) after level shifting of each carrier as shown in Figure 4. The switching pulses so generated are applied for switching on and switching off each power semiconductor devices (Here MOSFETs) in the H-bridges using unipolar switching scheme as mentioned above.

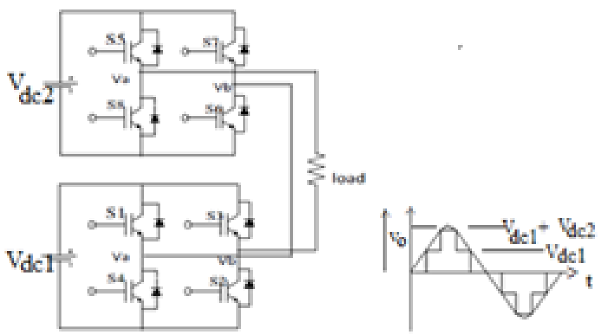

Figure 3. Cascaded five level H-bridge inverter

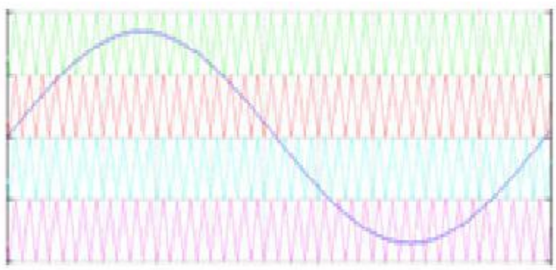

Figure 4. Level Shifted and In Phase Disposition (IPD) technique to generate switching pulses.

The output voltage's rms value is represented by

$$V_{rms} = V_{dc1}\left(\sum_{m=1}^{N_{p1}} \frac{P_{m1}}{\pi}\right)^{\frac{1}{2}} + V_{dc2}\left(\sum_{m=1}^{N_{p2}} \frac{P_{m2}}{\pi}\right)^{\frac{1}{2}},$$

Where,

V_{dc1} and V_{dc2} are respectively the dc source voltages of the two H-bridges,

N_{p1} and N_{p2} represent respectively the number of pulses per half cycle of the H-bridges, and

P_{m1} and P_{m2} represent respectively the width of the m^{th} pulses of the H-bridges.

The output voltage of five level inverters employing the SPWM technique's harmonic analysis reveals that SPWM has the following significant characteristics.

1) The greatest harmonic amplitudes in the output voltage for modulation indices smaller than one are connected to harmonics of orders mf 1, where mf is the frequency modulation ratio.
   As a result, by increasing the number of pulses per half-cycle, it is possible to shift the main harmonic frequency's order to the higher side, where it may then be readily removed by a smaller filter.

   If mf is chosen even (unipolar switching), the other higher order harmonics with reduced amplitude associated with the output voltage waveform are mf $\pm$3…, 2mf $\pm$1, 2mf $\pm$3…, 3mf $\pm$ 3…, etc.; if mf is chosen odd (bipolar switching), the other higher order harmonics are mf $\pm$2, mf$\pm$ 4…, 2 mf $\pm$1, 2mf $\pm$3…, 3mf $\pm$2, etc.
2) Lower order harmonics become visible for modulation indices greater than 1, as the pulse width is no longer a sinusoidal function of the pulse's angular position.

Amplitude of fundamental is given by

V1 = mi. S.Vdc = 2mi.Vdc [S= no of H-bridges = 2 for five-level inverter and mi is the modulation index or amplitude modulation ratio]

Hence, mi controls the amplitude of the output voltage's fundamental frequency and is linearly proportional to mi as long as mi is less than 1.The amplitude of the fundamental increases with mi, but not linearly, if mi is bigger than 1.

3. SIMULATION RESULT

The MATLAB-SIMULINK simulation software [18] was used to simulate a single-phase five-level voltage source inverter circuit with two H-bridges similar to Figure 3. The carrier frequency was set to 1000 KHz, the modulating signal frequency to 50 Hz, and each voltage source was taken into consideration as being 100 V DC.

To determine the outcomes of the rms output voltage, fundamental voltage, harmonic voltages, and total harmonic distortion (THD), simulation has been done for various modulation indices. Figures 5, 6, and 7 display the MATLAB-SIMULINK simulation circuits. Figure 8 depicts the method for producing PWM pulses during simulation.

For various values of the modulation index mi, the values of the rms voltage, THD (In proportion with fundamental), fundamental, and other harmonic voltages are shown in Table I. Figures 9, 10, and 11 show visually how the rms voltage, fundamental voltage, THD, and other harmonic voltages vary for various values of the modulation index.

In Figures 12 and 13, the output voltage waveform for mi=0.8 is depicted without and with a filter, respectively.

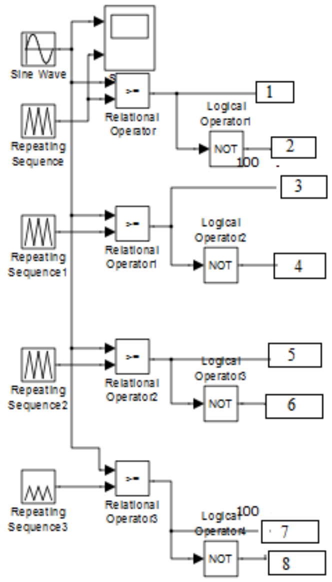

Figure 5. PWM Generation Circuit

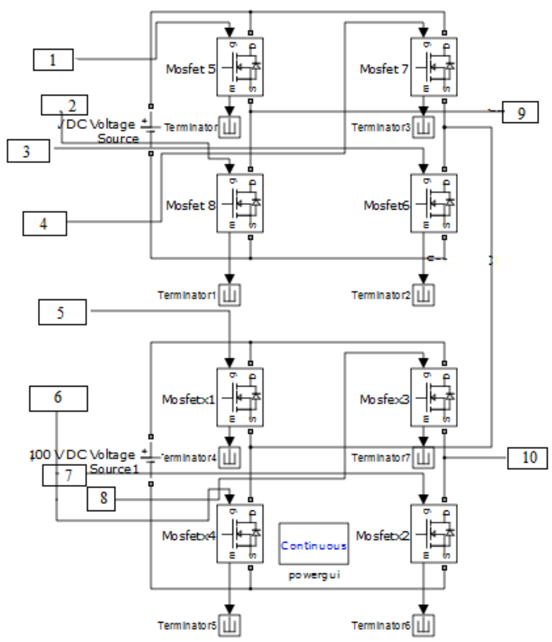

Figure 6. Main Inverter Circuit

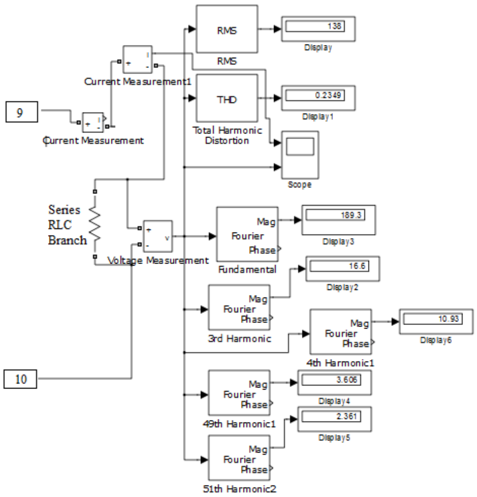

Figure 7. Different Parameter measurement Circuit

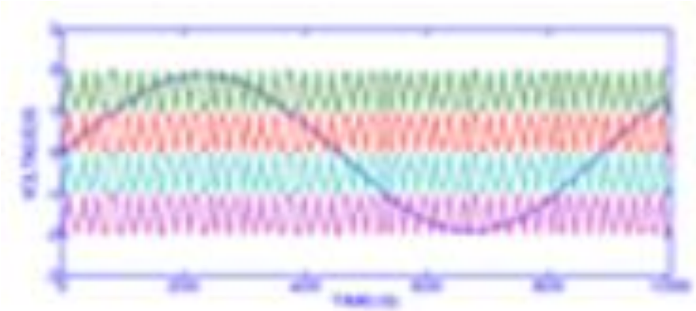

Figure 8. A Sinusoidal Signal is compared with different level shifted Carriers to generate PWM.

Table I**.** Showing effect of modulation index on THD and Harmonics.

Mod Index	Value of different parameters							
	RMS Output Voltage (V)	Total Harmonic Distortion w.r.to Fundamental (%)	RMS Voltage of Fundamental (V)	RMS Voltage of 3rd harmonic (V)	RMS Voltage of 4th harmonic (V)	RMS Voltage of 49th harmonic (V)	RMS Voltage of 51st harmonic (V)	
0.1	13.14	604.3	3.035	0.7884	0.1822	1.36	0.5179	Without filter and only R load
0.2	39.42	165.8	28.79	11.31	0.9083	9.645	7.071	
0.3	56.42	105.6	54.86	6.387	0.9706	5.853	5.269	
0.4	70.33	59.63	85.41	11.24	2.243	10.12	8.137	
0.5	78.13	40.89	102.3	2.059	0.9633	3.747	5.87	
0.6	82.79	35.31	110.4	7.926	0.4363	3.131	1.835	
0.7	99.12	37.27	131.3	5.203	0.9864	9.024	8.377	
0.8	114.4	33.73	153.3	1.91	1.525	5.675	10.5	
0.9	131.5	26.72	179.6	6.293	1.558	1.511	2.739	
1.0	141.3	21.72	195.2	3.34	1.837	2.457	3.597	
0.8	186.4	0.01	263.5	0.3583	0.228	0.103	0.1035	With LC Filter and R load
0.9	211.8	0.907	299.6	2.47	1.022	0.426	0.422	
1.0	232.7	0.8	329.1	2.247	0.4935	0.2816	0.284	

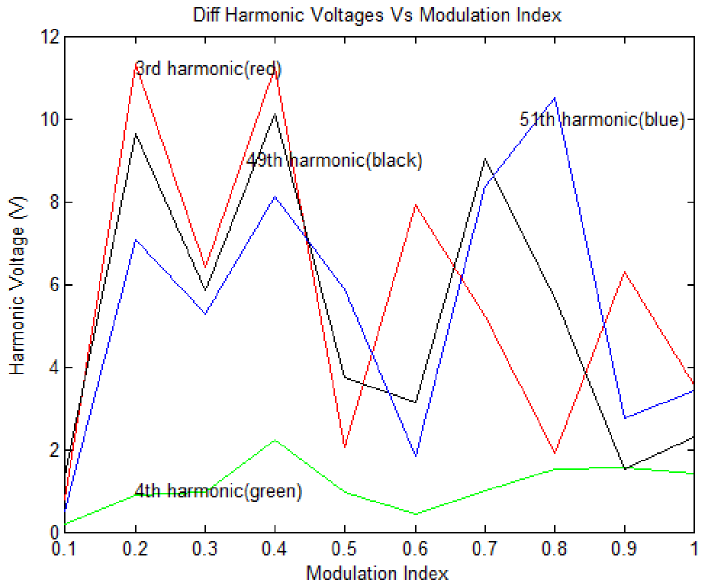

Figure 9. Different harmonic voltages with respect to different mi

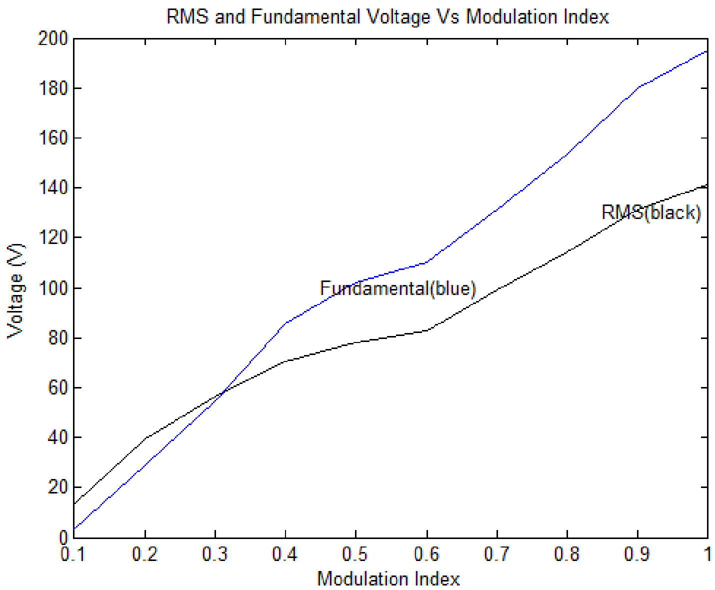

Figure 10. RMS and Fundamental Voltages.

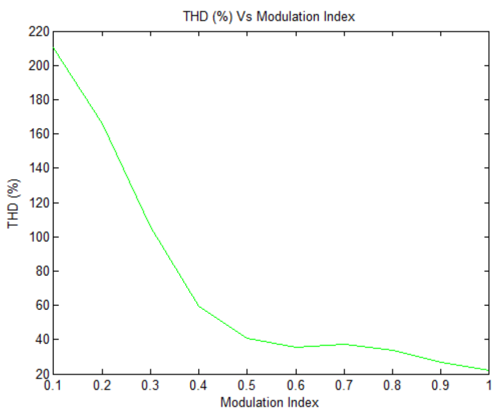

Figure 11. THD versus different modulation index

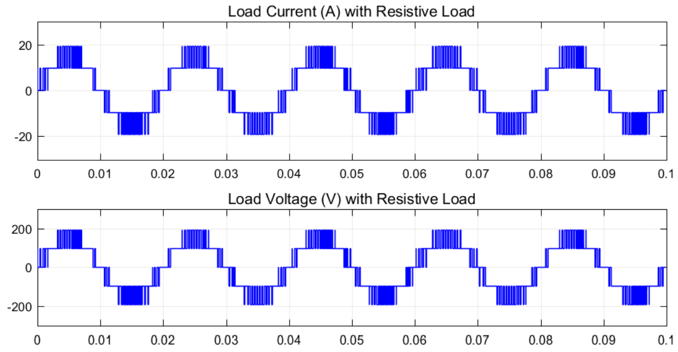

Figure 12. Load current and voltage waveform without filter

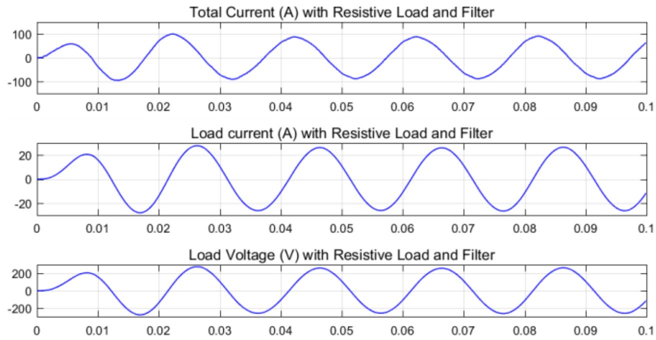

Figure.13. Load current and voltage waveform with filter

4. CONCLUSION

In order to reduce total harmonic distortion (THD), a single-phase, five-level cascaded H-Bridge inverter was designed. This research also examines the impact of modulation index on THD and the various harmonics present in the output voltage waveform.

According to the simulation results displayed in Figures 8, 9, and 10, the third harmonic has been dramatically reduced for mi=0.8, 0.9, and 1.0 from 33% (in the case of a typical two-level inverter) to 0.12%, 1.12%, and 0.8%, respectively. The THD decreased from 48.43% (in the case of a traditional two-level inverter) to 0.01%, 0.907%, and 0.8% for mi=0.8, 0.9, and 1.0, respectively. The current and voltage waveforms for resistive load and with low pass filter are almost sinusoidal. The fundamental voltage varies almost linearly as modulation index increases from 0.1 to 1.0.

5. ACKNOWLEDGMENT

The authors would like to express their gratitude to professors (Dr.) P.K. Sinha Roy and (Dr.) K. K. Ghosh of the Institute of Engineering and Management in Kolkata for their unfailing assistance and direction in advancing this research endeavor.

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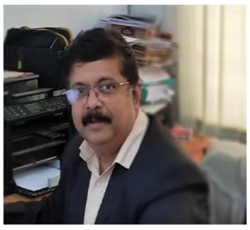

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