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Comparative Analysis of Various Multicarrier PWM Methods for Binary DC Source Inverter

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Abstract:
This paper focuses a new topology of an asymmetrical seven level inverter with binary DC sources. Multilevel inverter is triggered by using Unipolar Multicarrier Pulse Width Modulation (UMCPWM) method, sine and trapezoidal references with triangular carriers; it includes Phase Disposition (PD) method, Alternate Phase Opposition Disposition (APOD) method, Carrier Overlapping (CO) method and Variable Frequency (VF) method. The Performances measure like, Total Harmonic Distortion (THD), Fundamental V_{RMS} Crest Factor (CF), Form Factor (FF) and Distortion Factor (DF) are evaluated for various modulation indices. Simulation is carried out by using MATLAB-SIMUINK. It is observed that UMCVFPWM method provides lower THD, UMCCOPWM method provides higher fundamental V_{RMS} output voltage, and UMCAPODPWM method provides lower Distortion Factor.

***Key words**: APOD, CO, PD, PWM, UMCPWM, VF*

1. Introduction

Multilevel Inverter is introduced to reduce the switching stress and to obtain the output voltage with multiple steps to achieve the lowest total harmonic distortion (THD) and improved fundamental V_{RMS}. Juan and Moran [1] analysed high-level multistep inverter optimization using a minimum number of power transistors. Du et al [2] introduced active harmonic elimination for multilevel converters. Couge et al [6] presented parallel three-phase inverters: optimal PWM method for flux reduction in intercell transformers. Ewanchuk et al [7] proposed a five/nine-level twelve-switch neutral-point-clamped inverter for high-speed electric drives. Khoucha [8] made a comparison of symmetrical and asymmetrical three-phase h-bridge multilevel inverter for DTC induction motor drives. Yousefpoor [9] analyzed a THD minimization applied directly on the line-to-line voltage of multilevel inverters. Diong et al [10] developed a harmonic distortion optimization of cascaded h-bridge inverters considering device voltage drops and non integer dc voltage ratios. Taghizadch and Tarafdarhag [3] introduced harmonic elimination of cascade multilevel inverters with non equal dc sources using particle swarm optimization. Lu et al [4] proposed asymmetrical cascade multilevel converters with non integer or dynamically changing dc voltage ratios, concepts and modulation techniques. Hinago and Koizumi et al [5] presented of a single-phase multilevel inverter using switched series / parallel dc voltage sources. This paper proposed a single phase asymmetrical 7 level inverter with various UMCPWM switching methods. Simulations were performed using MATLAB SIMULINK.

2. Single Phase Asymmetric Multilevel Inverter

Figure. 1 shows a circuit configuration of a cascade half of the H- bridge multilevel inverter having binary DC input source. The half H-bridges are connected in series with different voltage ratings, in order to obtain the required seven level output. The voltage levels are $0V_{dc}$, V_{dc} $2V_{dc}$, $3V_{dc}$, $-V_{dc}$, $-2V_{dc}$, $-3V_{dc}$. The switches S_1, S_2, S_3 and S_4 operate at the higher frequencies to get the positive polarity output levels. The switches A_1, A_2 and B_1 B_2 are having at the fundamental frequency. The final output voltage levels become sum of the each terminal's of half H-bridges.

In the new topology circuit if n, number of half H-Bridges module has different DC sources in sequence of the power of 2, an required output voltage level is given as

$V_n = 2^{n+1}-1$, n = 1, 2, 4...

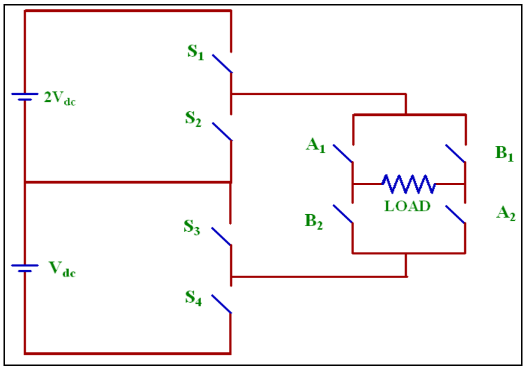

Figure 1: Single Phase 7 level MLI

3. Unipolar Multi Carrier PWM Methods

In proposed work a unipolar sine and trapezoidal references with triangle carrier is used to generate firing pulses for a 7 level inverter. For an m-level inverter using unipolar multi carrier technique, (m-1) /2 carriers with the same frequency f_c and same peak to peak amplitude A_c are used. The reference waveform has amplitude A_m and frequency f_m and it is placed at the zero reference. The sine wave is continuously compared with each of the triangle carrier. If the sine wave is more than a triangle carrier, then the active devices corresponding to that carrier are switched on. Otherwise, the device switches off.

There are many alternative methods are possible, some of them are tried in this paper and they are:

- Unipolar Multicarrier Phase Disposition PWM method (UMCPDPWM).
- Unipolar Multicarrier Alternative Phase Opposition Disposition PWM method (UMCAPODPWM).
- Unipolar Multicarrier Carrier Overlapping PWM method (UMCCOPWM).
- Unipolar Multicarrier Variable Frequency PWM method (UMCVFPWM)

The frequency ratio m_f is as follows:

$m_f = f_c / f_m$

The formula is to be finding the amplitude modulation indices for except UMCCOPWM as follows:

$m_a = 2A_m / (m-1)A_c$

The formula is to be finding the amplitude modulation indices for UMCCOPWM as follow:

$m_a = A_m / (2*A_c)$

3.1. Unipolar Multicarrier Phase Disposition PWM (UMCPDPWM)

Three carriers are in phase with the same frequency and same amplitude. The carrier arrangement for asymmetrical 7 level multilevel inverter having sinusoidal reference and trapezoidal references are shown in figures 2 and 3 respectively.

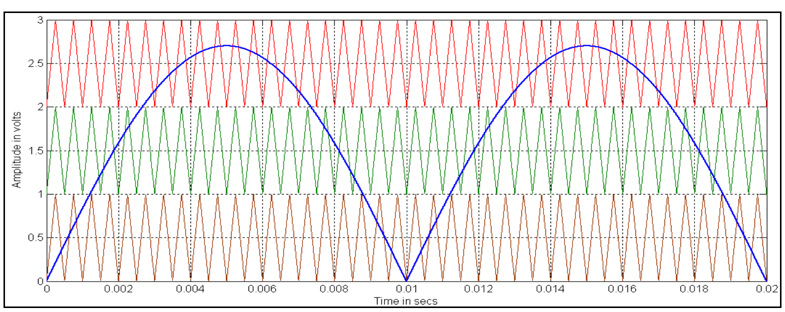

Figure 2: Unipolar Multicarrier Arrangement for PDPWM method with sinusoidal reference *(m_a=0.9 and m_f=40)*

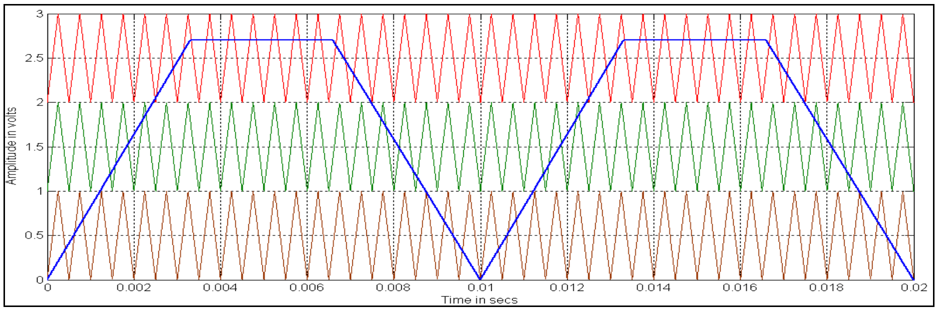

Figure 3: Unipolar Multicarrier Arrangement for PDPWM method with trapezoidal reference (m_a=0.9 and m_f=40)

3.2. Unipolar Multicarrier Alternative Phase Opposition Disposition PWM (UMCAPODPWM)

In that the three carriers is in out of phase with its neighbor by 180 degree. The carrier arrangement for asymmetrical multilevel inverter having sinusoidal reference and trapezoidal references are shown in figures 4 and 5 respectively.

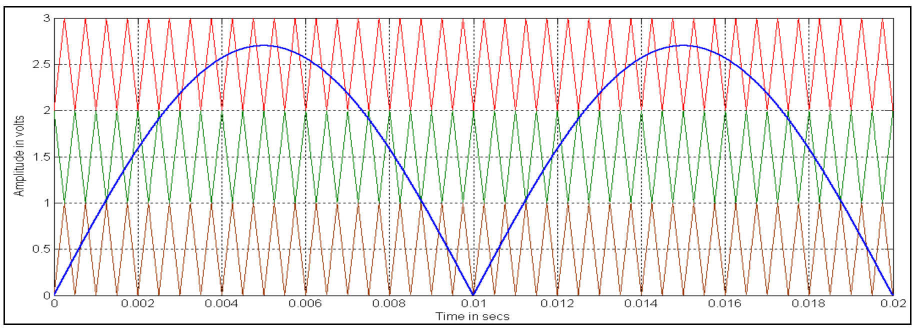

Figure 4: Unipolar Multicarrier Arrangement for APODPWM method with sine reference (m_a=0.9 and m_f=40)

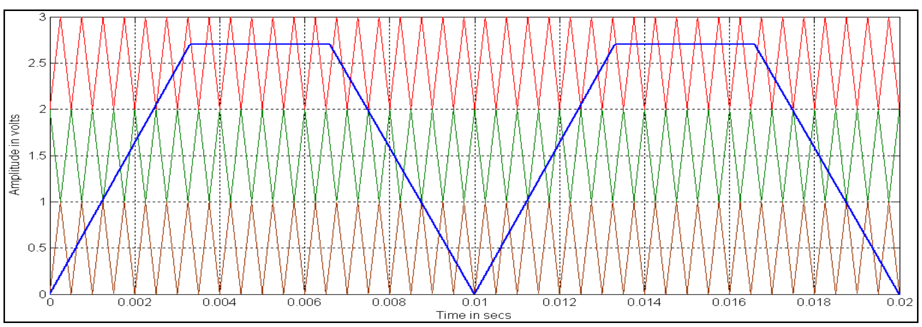

Figure 5: Unipolar Multicarrier Arrangement for APODPWM method with trapezoidal reference (m_a=0.9 and m_f=40)

3.3. Unipolar Multicarrier Carrier Overlapping PWM (UMCCOPWM)

The carriers are disposed such that the bands they occupy overlap each other, the overlapping vertical distance between each carrier is half of the peak to peak amplitude (A_C/2). The carrier arrangement for asymmetrical 7 level multilevel inverter having sinusoidal reference and trapezoidal references are shown in figures 6 and 7 respectively.

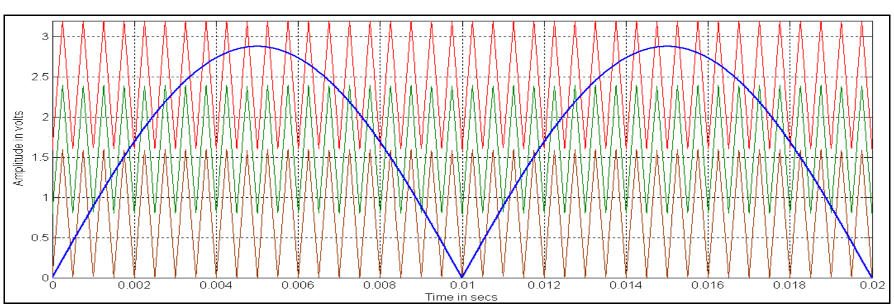

Figure 6: Unipolar Multicarrier Arrangement for COPWM method with sine reference (m_a=0.9 and m_f=40)

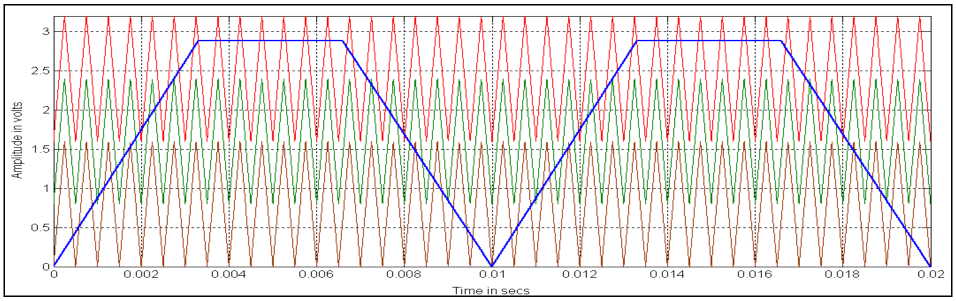

Figure 7: Unipolar Multicarrier Arrangement for COPWM method with trapezoidal reference (m_a=0.9 and m_f=40)

3.4. Unipolar Multicarrier Variable Frequency PWM (UMCVFPWM)

The number of switching for upper and lower devices of chosen MLI is much and more than that of intermediate switches in PDPWM using constant frequency carrier. In order to equalize the number of switching for all the switches, variable frequency PWM method is used a illustrated in which the carrier frequency of the intermediate switches is properly increased to balance the number of switches for all the switches.

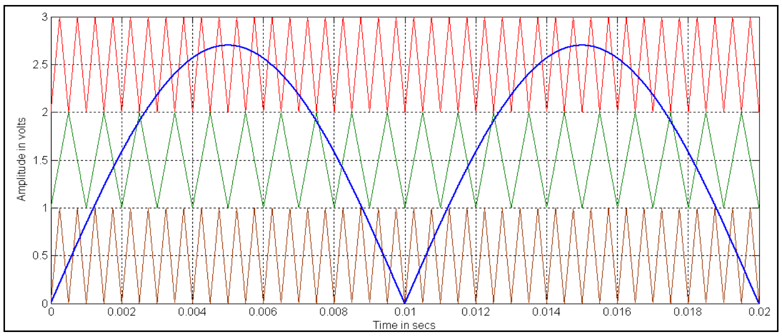

Figure 8: Unipolar Multicarrier Arrangement for VFPWM method with sine reference (m_a=0.9, m_{f1}=20, m_{f2}=40)

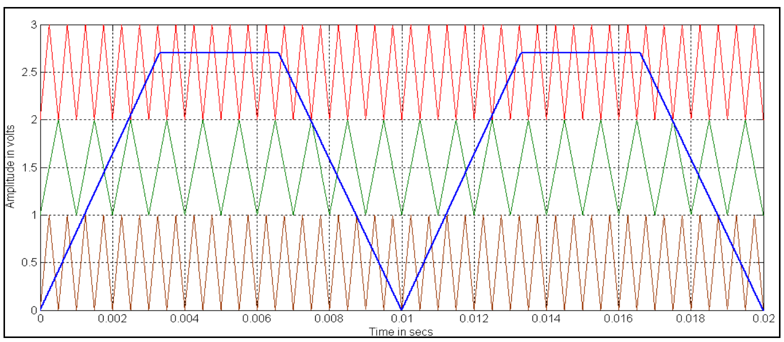

Figure 9: Unipolar Multicarrier Arrangement for VFPWM method with trapezoidal reference (m_a=0.9, m_{f1}=20, m_{f2}=40)

4. Simulation Result

A single phase asymmetrical seven level inverter is modeled in SIMULINK using power system block set. Switching signals for binary multilevel inverter using Unipolar Multicarrier Pulse Width Modulation methods are simulated. Figure. 10 (a) and (b) respectively shows the seven level output voltage generated by UMCPD method with sine reference and its FFT plot. Figure 11 (a) and (b) respectively shows the seven level output voltage generated by UMCPD method with trapezoidal reference and its FFT plot. Next Figure. 12 (a) and (b) respectively shows the 7 level output generated by UMCAPOD method with sine reference and its FFT Plot. Then Figure. 13 (a) and (b) respectively shows the 7 level output voltage generated by UMCAPOD method with trapezoidal reference and its FFT plot. Next Figure 14 (a) and (b) represents the seven level output voltage generated by UMCCOPWM method with sine reference and its FFT plot. Then Figure 15 (a) and (b) represents the seven level output generated by UMCCOPWM method with trapezoidal reference and its FFT plot. Next Figure. 16 (a) and (b) represents the 7 level output voltage generated by UMCVF method with sine reference and its FFT plot. Then the Figure 17 (a) and (b) represents the 7 level output voltage generated by UMCVF method with trapezoidal reference. The following parameters values are used for simulation: V_{DC}=100, R (load) = 100, f_c=2000 Hz and f_m=50 Hz.

For m_a=0.9 it is observed from the figures [10(b), 11(b), 12(b), 13(b), 14(b), 15(b), 16(b) and 17(b)] the harmonic energy is dominant in: 10 (b) 25^{th}, 27^{th}, 29^{th}, 33^{rd}, 35^{th}, 37^{th}, 39^{th} orders in UMCPD method with sine reference and triangular carrier. 11(b) 5^{th}, 27^{th}, 39^{th} orders in UMCPD method with trapezoidal reference. 12(b) 31^{st}, 33^{rd}, 35^{th}, 37^{th}, 39^{th} orders in UMCAPOD method with sine reference and triangular carrier. 13(b) 5th, 31st, 33rd, 37th, 39th orders in UMCAPOD method with trapezoidal reference. 14(b) 3rd, 5th, 7th, 35th, 37th, 39th orders in UMCCO method with sine reference and triangular carrier.15 (b) 5th, 37th, 39th orders in UMCCO method with trapezoidal reference. 16(b) 7th, 11th, 13th, 17th, 19th, 21st, 23rd, 25th, 27th, 29th, 33rd, 35th, 37th, 39th orders in UMCVF method with sine reference and triangular carrier. 17(b) 5th, 17th, 21st, 27th, 31st,33rd, 39th orders in UMCVF method with trapezoidal reference.

Simulations were performed for different values of m_a ranging from 0.8 to 1 and the corresponding %THD is measured using the FFT block and their values are shown in the Table 1. Compare to all PWM methods, UMCVFPWM method with trapezoidal reference provides low %THD. Table 2 shows the V_{RMS} of the inverter output for same modulation indices. In that UMCPWM method with trapezoidal provides higher fundamental RMS voltage. Table 3 and Table 4 shows respectively the corresponding Crest Factor (CF) and Form Factor (FF) of the output voltage. CF and FF are almost same for all the methods. Table 5 shows the Distortion Factor (DF) of the output voltage. In that UMCAPODPWM method provides less DF with sine reference with triangular carrier.

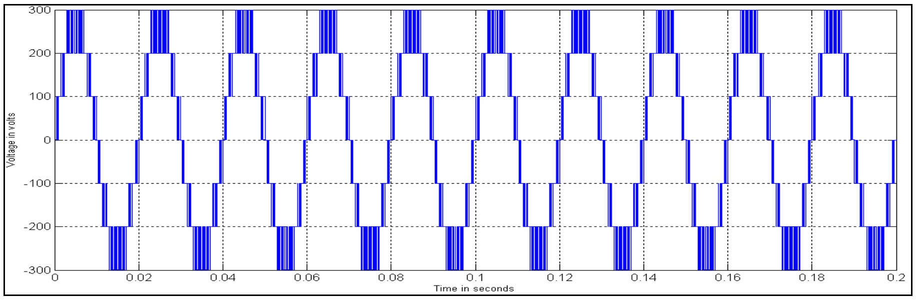

Figure 10 (a): Output Voltage generated by UMCPDPWM method with sine reference

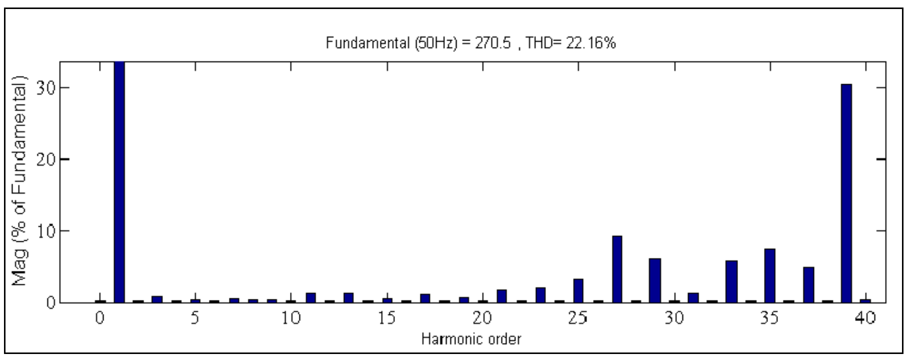

Figure 10 (b): FFT Plot for output voltage of UMCPDPWM method with sine reference

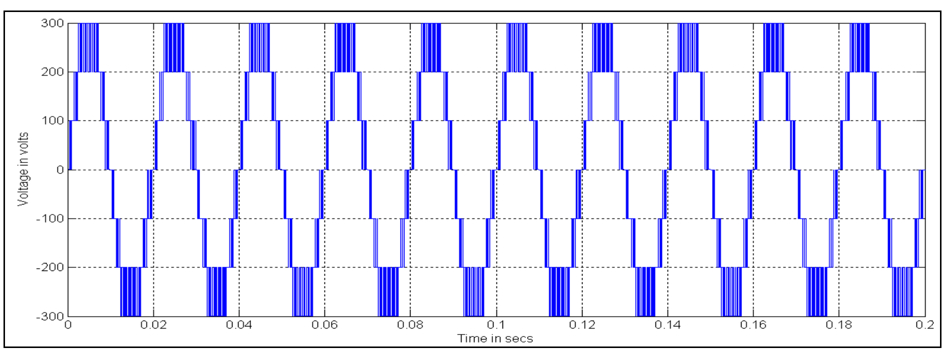

Figure 11 (a): Output Voltage generated by UMCPDPWM method with trapezoidal reference

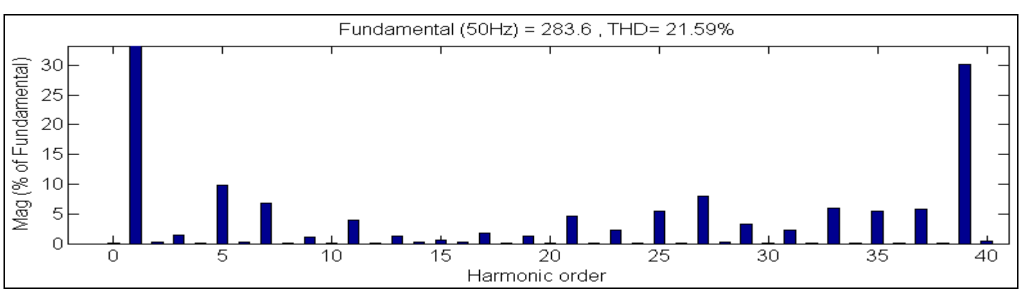

Figure 11 (b): FFT Plot for output voltage of UMCPDPWM method with trapezoidal reference

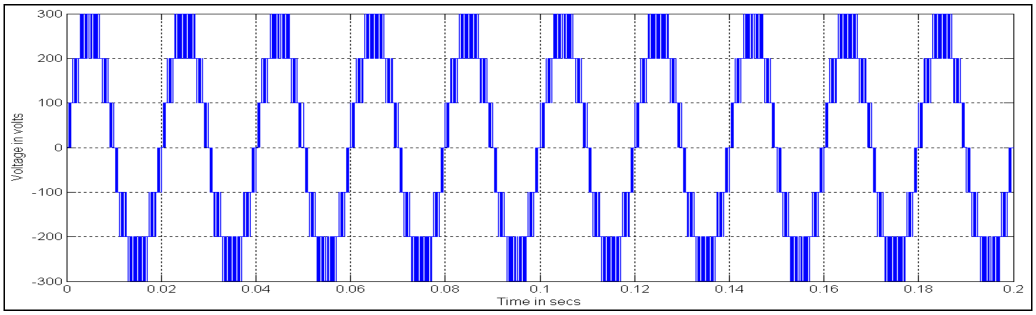

Figure 12 (a): Output Voltage generated by UMCAPODPWM method with sine reference

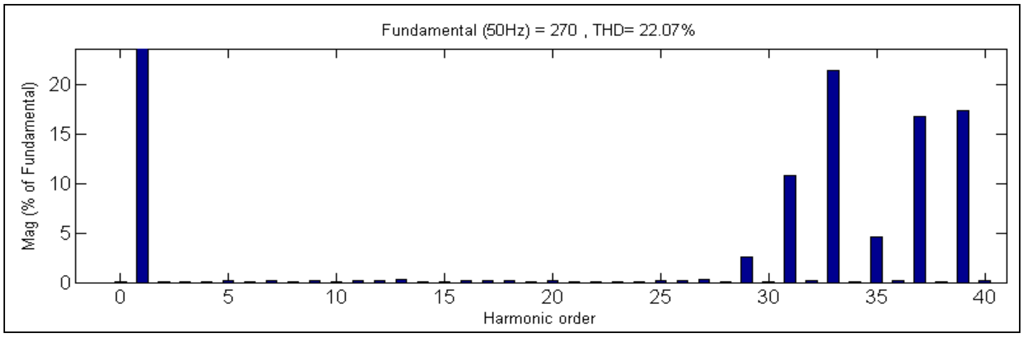

Figure 12 (b): FFT Plot for output voltage of UMCAPODPWM method with sine reference

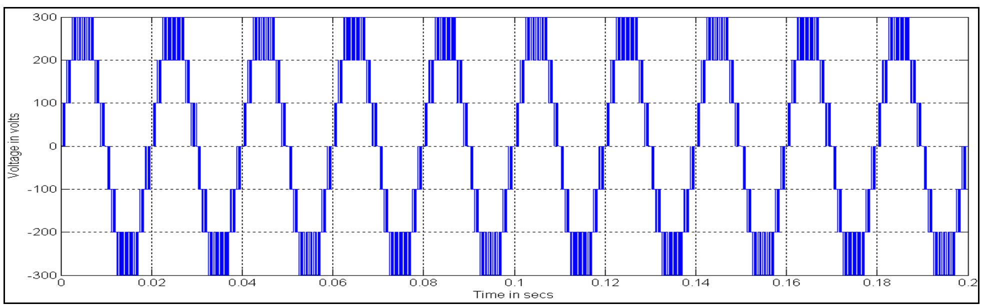

Figure 13 (a): Output Voltage generated by UMCAPODPWM method with trapezoidal reference

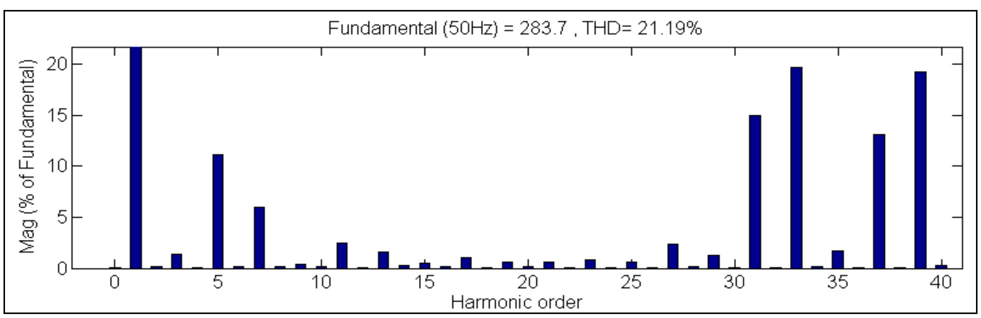

Figure 13 (b): FFT Plot for output voltage of UMCAPODPWM method with trapezoidal reference

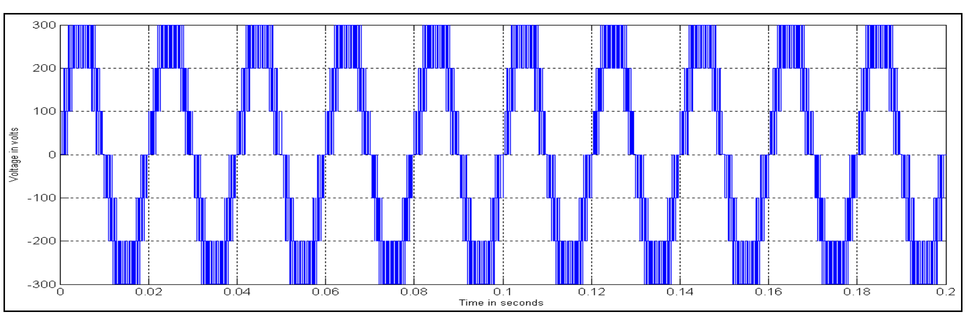

Figure 14 (a): Output Voltage generated by UMCCOPWM method with sine reference

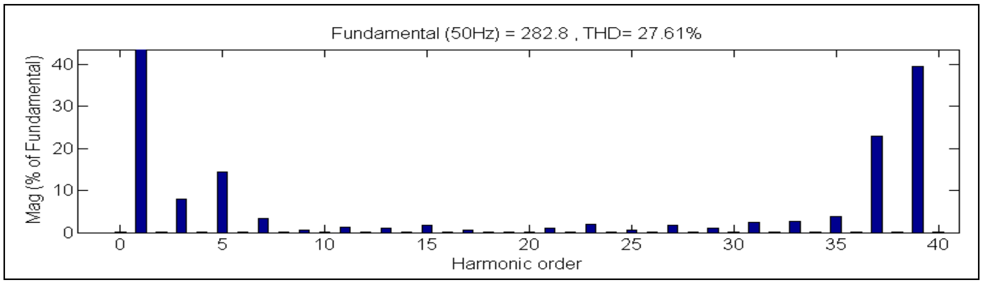

Figure 14 (b): FFT Plot for output voltage of UMCCOPWM method with sine reference

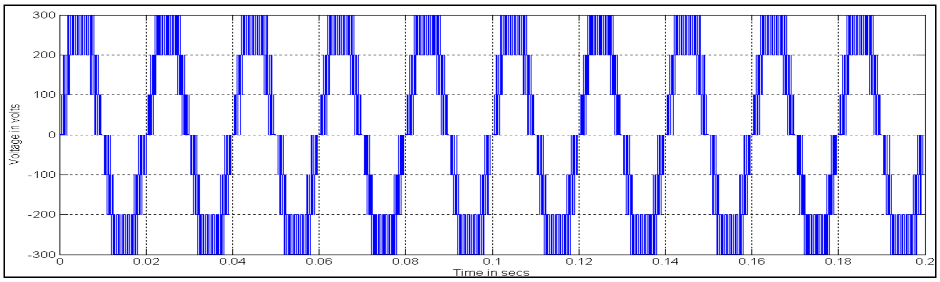

Figure 15 (a): Output Voltage generated by UMCCOPWM method with trapezoidal reference

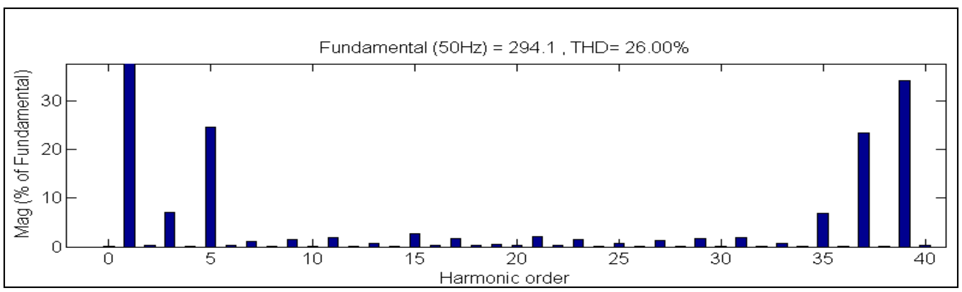

Figure 15 (b): FFT Plot for output voltage of UMCCOPWM method with trapezoidal reference

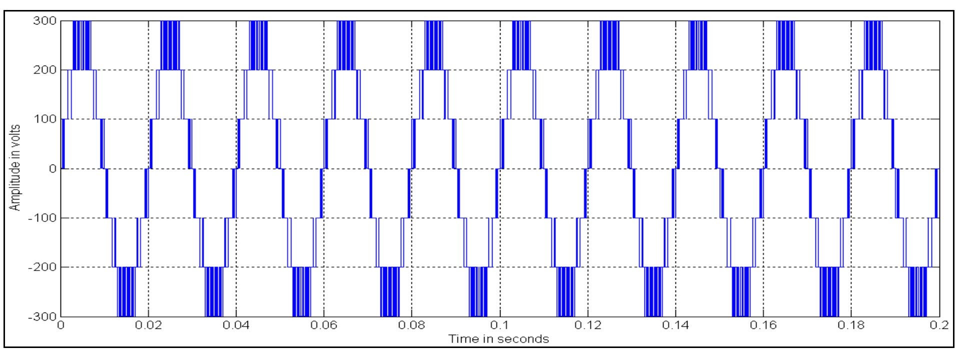

Figure 16 (a): Output Voltage generated by UMCVFPWM method with sine reference

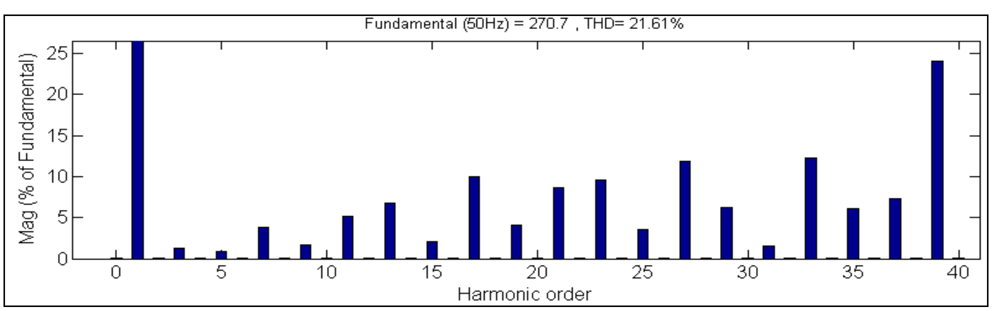

Figure 16 (b): FFT Plot for output voltage of UMCVFPWM method with sine reference

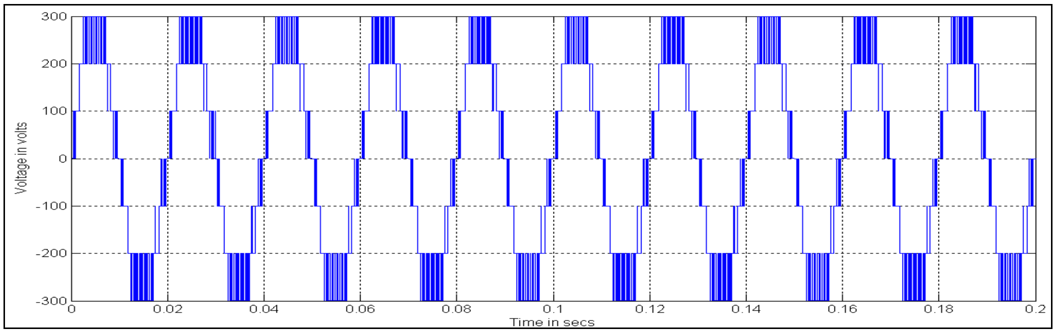

Figure 17 (a): Output Voltage generated by UMCVFPWM method with trapezoidal reference

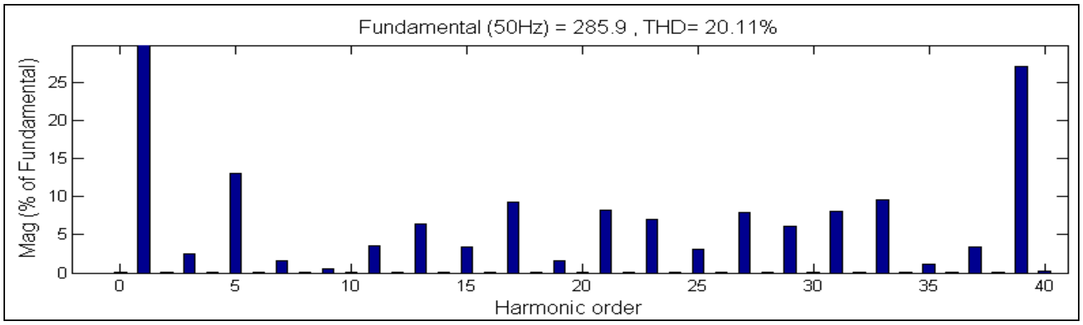

Figure 17 (b): FFT Plot for output voltage of UMCVFPWM method with trapezoidal reference

m_a	UMCPDPWM		UMCAPODPWM		UMCCOPWM		UMCVFPWM	
	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.
1	17.95	15.33	18.28	15.78	22.90	21.11	16.81	14.51
0.95	20.40	19.13	20.23	19.09	25.24	23.56	18.84	17.96
0.9	22.14	21.58	22.08	21.17	27.61	26.02	21.62	20.16
0.85	23.44	23.53	23.21	23.44	29.82	28.33	23.53	23.18
0.8	24.20	24.70	24.19	24.84	32.37	30.46	24.51	25.26

Table 1: %THD for Different Modulation Indices

m_a	UMCPDPWM		UMCAPODPWM		UMCCOPWM		UMCVFPWM	
	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.
1	212.3	223.4	212.1	223	218.3	225.6	212.1	222.8
0.95	201.4	212	201.6	211.7	209.3	217	202.3	212.4
0.9	191.2	200.5	190.9	200.6	199.8	207.9	191.5	202
0.85	180.6	189.6	180.3	189.4	189.9	198.2	180.3	190.5
0.8	169.7	178.5	169.7	178.4	179.9	188.9	169.7	178.5

Table 2: V_{RMS} for Different Modulation Indices

m_a	UMCPDPWM		UMCAPODPWM		UMCCOPWM		UMCVFPWM	
	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.
1	1.414037	1.414056	1.413956	1.413901	1.414109	1.414007	1.413956	1.414273
0.95	1.414101	1.414151	1.414187	1.413793	1.414238	1.414286	1.414236	1.414313
0.9	1.414370	1.414464	1.413829	1.414257	1.413914	1.414622	1.414099	1.414356
0.85	1.414175	1.414557	1.414309	1.413939	1.414429	1.414228	1.414309	1.414173
0.8	1.41485	1.414885	1.41426	1.414238	1.414119	1.414505	1.41426	1.414566

Table 3: Crest Factor for Different Modulation Indices

m_a	UMCPDPWM		UMCAPODPWM		UMCCOPWM		UMCVFPWM	
	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.
1	1.364E+09	1.362E+09	1.364E+09	9.230E+03	1.387E+09	4.738E+03	1.368E+09	1.366E+09
0.95	1.366E+09	1.363E+09	1.367E+09	1.363E+09	5.734E+05	1.385E+09	1.37E+09	1.364E+09
0.9	1.363E+09	4.198E+03	1.373E+09	8.400E+03	1.387E+09	2.957E+03	1.357E+09	1.364E+09
0.85	1.357E+09	1.586E+03	1.367E+09	1.364E+09	1.392E+09	5.422E+05	1.365E+09	1.361E+09
0.8	1.366E+09	1.364E+09	1.367E+09	7.458E+03	1.41E+09	1.407E+09	1.365E+09	1.367E+09

Table 4: Form Factor for Different Modulation Indices

m_a	UMCPDPWM		UMCAPODPWM		UMCCOPWM		UMCVFPWM	
	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.	Sine Ref.	Trapezoidal Ref.
1	0.000290304	0.001798209	0.000206	0.001747	0.002015	0.003098	0.001021	0.002333
0.95	0.000164839	0.001719129	0.000113	0.001714	0.002501	0.003401	0.000691	0.002119
0.9	0.000383043	0.001564152	0.000135	0.001716	0.003916	0.004262	0.000648	0.002092
0.85	0.00034938	0.001612577	0.000157	0.001698	0.005525	0.005707	0.000686	0.001892
0.8	0.000217971	0.001783759	0.000264	0.001681	0.006987	0.007031	0.0006	0.001539

Table 5: Distortion Factor for Different Modulation Indices

5. Conclusion

In this paper, UMCPWM methods used for binary DC source seven level inverter have been presented. Binary DC source multilevel inverter gives higher output voltage with reduced number of switches and low harmonics. Performance factors like %THD, V_{RMS}, FF, CF and DF have been evaluated presented and analyzed. It is found that the UMCVFPWM method, trapezoidal reference with triangular carrier provides lower %THD. UMCCOPWM method, trapezoidal reference with triangular carrier is found to perform better since it provides relatively higher fundamental RMS output voltage. UMCAPODPWM method provides less DF with sine reference with triangular carrier.

6. References

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