A New Three Phase Seven Level Asymmetrical Inverter with Hybrid Carrier and Third Harmonic Reference

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ABSTRACT: *Carrier based techniques have been used widely for switching of multilevel inverters due to their simplicity, flexibility and reduced computational requirements compared to Space Vector Modulation (SVM). A novel carrier based Pulse Width Modulation (PWM) technique for three phase Asymmetrical Multi Level Inverter (AMLI) with Third Harmonic Injection (THI) reference is proposed in this paper. The technique is based on the combination of the Control Freedom Degrees (CFD). The combination of inverted sine carrier and triangular carrier is used as hybrid carrier in order to produce pulses for the power switches used in the proposed seven level three phase cascaded inverter. This paper investigates the potentials of hybrid carrier based cascaded multilevel inverter in the development of medium power AC power supplies with specific emphasis on Power Conditioning Systems (PCS) for alternate sources of energy. The performance of chosen inverter is evaluated based on MATLAB/ SIMULINK simulation. The performance indices used are Total Harmonic Distortion (THD), RMS value of output voltage and DC bus utilization. It is observed that Carrir over lapping PWM provides better DC bus utilization and Phase opposition Disposition (POD) technique creates less distortion for* m_a*=0.7-1*

Keywords: *APOD, COPWM, PD, POD, ISPWM*

I. INTRODUCTION

In recent years, multi-level Voltage Source Inverters (VSIs) are widely used as static power converter for high-power applications. MLIs can operate at both fundamental switching frequency and high switching frequency PWM. The topologies of MLIs are classified into three types: the flying capacitor inverter, the diode clamped inverter and the modular H-bridge inverter. Seyezhai and Mathur [1] have described a technique that combines the advantage of inverted rectified sine wave and variable frequency carriers for a seven level inverter for balancing the switch utilization and have also stated that the switching losses for the chosen modulation scheme is very less. Chandra and Kumar in [2] presented an automatic switching pattern generation for multilevel cascaded H-Bridge inverters with equal DC voltage sources based on the Space Vector Pulse Width Modulation (SVPWM) technique. Seyezhai and Mathur [3,4] have done a comparative evaluation between hybrid modulation strategy and the conventional Phase Disposition (PD) PWM method in terms of output voltage quality, power circuitry complexity, Distortion Factor (DF) and THD. Jeevananthan et al [5] have proposed an Inverted Sine Carrier PWM (ISCPWM) method which used the conventional sinusoidal reference signal and an inverted sine carrier to produce better spectral quality and a higher fundamental component compared to the conventional Sinusoidal PWM (SPWM) without any pulse dropping. A survey of topologies, controls and applications of MLIs has been carried out by Rodriguez et al [6]. The common topology is the cascaded inverter shown in Fig.1 for three phase structure. The three multilevel modulation methods most discussed in the literature include multilevel carrier-based PWM, multilevel space-vector PWM and selective harmonic elimination [6]. Analysis of multicarrier PWM methods for a single phase five level inverter was proposed by Calais Borle and Agelidis [7]. A novel clew for the research on carrier based PWM methods for multilevel inverters is proposed by Wu et al [8] based on the concept of combination of the Control Freedom Degrees (CFD). Sun [9] have presented a new asymmetrical multilevel inverter topology. The new topology can improve the number of output voltage levels greatly using a bidirectional auxiliary switch. Further they have proposed multicarrier PWM method for the asymmetrical inverter [9]. Taleb et al [10] have proposed a neural implementation of a Harmonic Elimination Strategy (HES) to control a Uniform Step Asymmetrical Multilevel Inverter (USAMI). Mihalache [11] has proposed an asymmetrical PWM modulation technique which is known to offer lower harmonic content as compared to the symmetrical modulation. Nami et al [12] have optimized asymmetrical arrangement compared with a conventional four level inverter and found that it exhibits lesser switching losses and lesser harmonics. In some application with different DC input sources such as electric vehicles, a modular H-bridge asymmetrical inverter can be used to drive a traction motor from a set of solar cells or fuel cells. A seven level output voltage is achieved with two bridges in asymmetrical inverter whereas only five level output voltage will be achieved with three bridges in case of conventional cascaded MLI. In AMLI with lesser number switches more voltage levels can be achieved. Fig.1. shows the chosen asymmetrical three phase inverter. Each cell has two pairs of complementory switches S1 and S3 and S2 and S4. There are six cells used in the three phase inverter each leg containing two cells each. Since the carrier based method have good CFD, this paper focusses on the hybrid carrier arrangement using triangular carrier in the positive side and inverted sine carrier waveform in the negative side with Phase Disposition (PD), Phase Opposition Disposition (POD), Alternate Phase Opposition Disposition (APOD), Carrier Overlapping (CO) and Inverted Sine (IS) strategies. Fig.2. shows a sample SIMULINK model developed for PWM strategy of a three phase inverter.

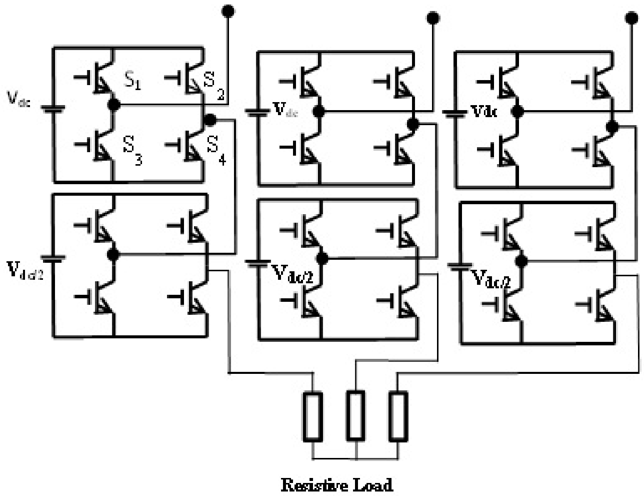

Fig.1. A three phase asymmetrical cascaded seven level inverter

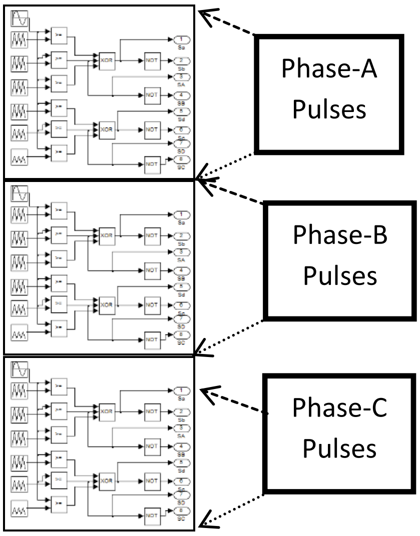

Fig.2.A sample SIMULINK model developed for PWM strategy of a three phase inverter

II. HYBRID CARRIER BASED BIPOLAR MODULATION SCHEMES WITH THI REFERENCE

The maximum modulation index of a three phase inverter can be increased by including a common mode third harmonic term into the target reference waveform of each phase leg. In this method, the modulation index m_a can be increased beyond m_a=1.0 without moving into over modulation.

II (a) PDPWM hybrid carrier strategy

This technique employs (m-l) carriers which are all in phase for a m level inverter. In seven level converter all the six carrier waves are in phase with each other across all the bands as described in Fig.3 for a phase leg of a seven level cascaded structure with m_a = 0.8.

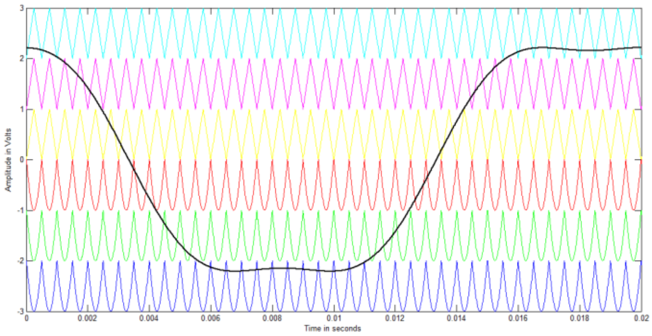

Fig.3.Carrier arrangements for PDPWM hybrid carrier strategy

II (b) PODPWM hybrid carrier

This technique employs (m-1) carriers which are all in phase above and below the zero reference. In seven level converters all the six carrier waves above zero reference are phase shifted by 180 degrees with the ones below zero reference. The PODPWM is explained in the Fig.4 in which all the carriers above the zero reference are in phase and carriers below the zero reference are also in phase but are phase shifted by 180 degree with respect to that above zero reference. Fig.4 illustrates the POD PWM hybrid carrier and THI reference arrangements for a phase leg of a three phase seven level cascaded structure with m_a = 0.8.

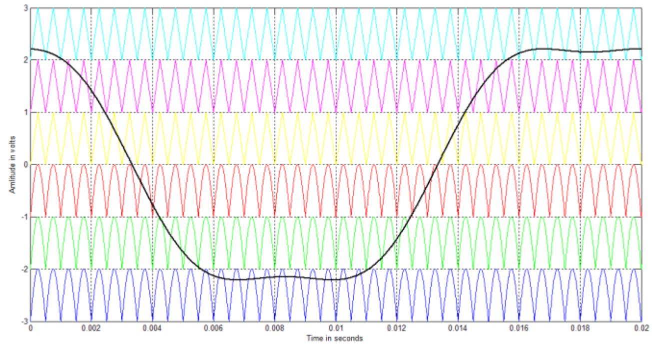

Fig.4. Carrier arrangements for PODPWM hybrid carrier strategy

II (c) APODPWM hybrid carrier strategy

This technique requires each of the m-l carrier waveforms for an m-level phase waveform to be phase displaced from each other by 180 degrees alternatively. In The APOD hybrid carrier and THI reference arrangements for a phase leg of a three phase seven level cascaded structure with m_a=0.8 are illustrated in Fig.5.

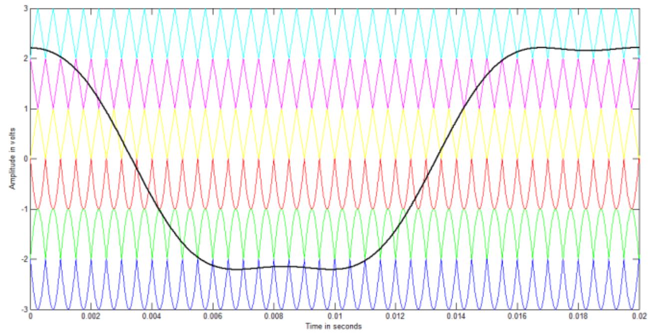

Fig.5. Carrier arrangements for APODPWM hybrid carrier strategy

II (d) COPWM hybrid carrier

For an m-level inverter using carrier overlapping technique, (m-1) carriers with the same frequency (f_c) and same peak-to-peak amplitude (A_c) are disposed such that the bands they occupy overlap each other; the overlapping vertical distance between each carrier is $0.5A_c$. The reference waveform has amplitude of A_m and frequency of f_m and it is centered in the middle of the carrier signals.

Fig.6 shows the COPWM hybrid carrier and THI reference arrangements for a phase leg of a three phase seven level cascaded structure with m_a =0.8.

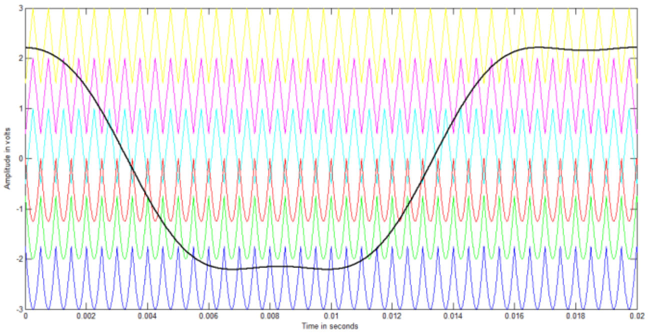

Fig.6. Carrier arrangements for COPWM hybrid carrier strategy

II (e) VFPWM hybrid carrier strategy

Fig.7 illustrates the VFPWM hybrid carrier and THI reference arrangements for a phase leg of a seven level three phase cascaded structure with m_a = 0.8.

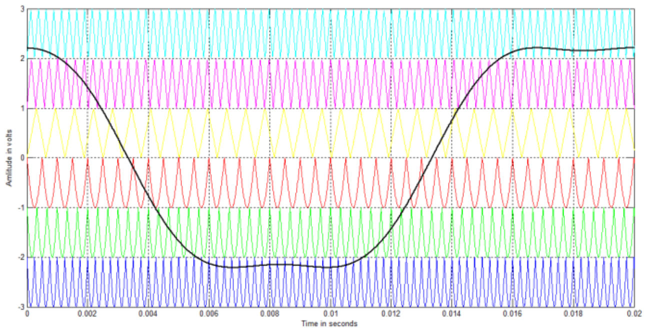

Fig.7. Carrier arrangements for VFPWM hybrid carrier strategy

The frequency modulation index

$$m_f = f_c/f_m$$

The amplitude modulation index

$$m_a = 2A_m/\,(m\text{-}1)\;A_c$$

where

f_c – Frequency of the carrier signal
f_m – Frequency of the reference signal
A_m –Amplitude of the reference signal
A_c – Amplitude of the carrier signal

$$m_a = A_m\,/\,(m\,/\,4)^*\;A_c \quad \text{(COPWM)}$$

III. SIMULATION RESULTS

Simulation results have been obtained by using MATLAB/SIMULINK power system toolbox software. The input DC sources are asymmetrical i.e one of the cascaded bridge is fed with $V_{dc/2}$ and other by V_{dc}. Figs.8-12 illustrate the output voltages of three phase asymmetrical cascaded seven level multilevel inverter for m_a=0.8 only. The Root Mean Square (RMS) value, Total Harmonic Distortion (THD) and Form Factor (FF) of output voltage are evaluated with suitable formula and for various hybrid modulation schemes such as PD, POD, APOD, COPWM, VFPWM statergies for various m_a (0.7-1) as in Tables I-III. Fig.13-18 display the frequency spectra and %THD for chosen strategies. It is found that the DC bus utilisation of the three phase seven level cascaded multilevel inverter is much better in case of COPWM as in Table II. POD technique is formed to create less distortion. It is seen that 3^{rd},37^{th}, 39^{th} harmonics are dominant in PD and POD PWM where as 3^{rd},27^{th},31^{st},33^{rd},35^{th},37^{th},39^{th} harmonics are dominant in APOD PWM. VFPWM creates only 3^{rd},harmonic dominant energy where as in COPWM 3^{rd},35^{th},37^{th},39^{th} harmonics are dominant.The following parameter values are used simulation: V_{dc1} =100V, V_{dc2} =50V A_c=1, m_f=40 and R(load) = 100 ohms for each phase.

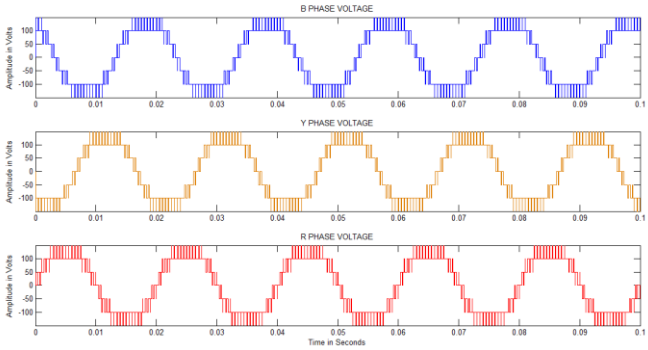

Fig.8.Output voltage of hybrid carrier THI-PDPWM strategy

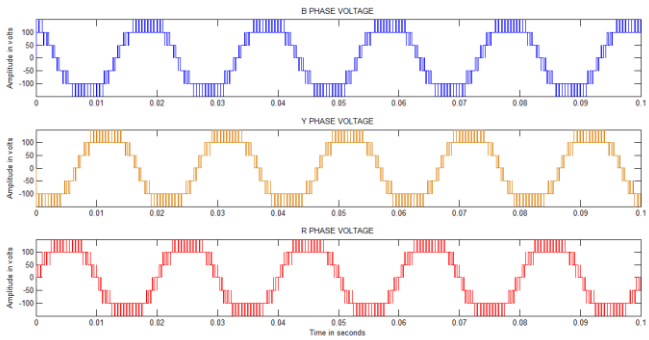

Fig.9.Output voltage of hybrid carrier THI-PODPWM strategy

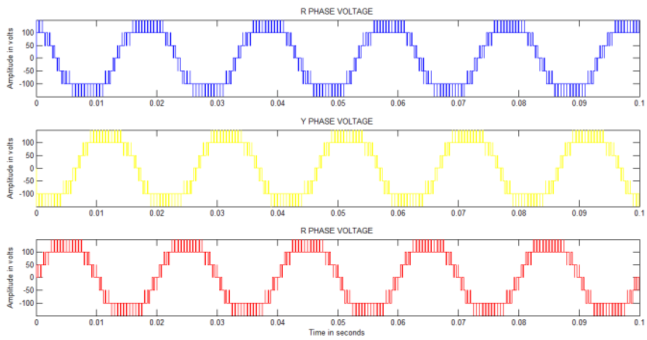

Fig.10.Output voltage of hybrid carrier THI-APODPWM strategy

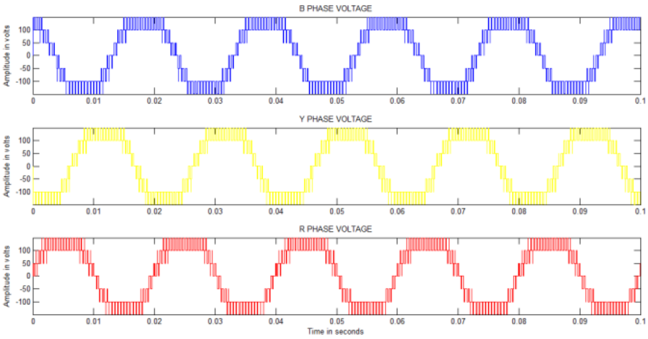

Fig.11.Output voltage of hybrid carrier THI-COPWM strategy

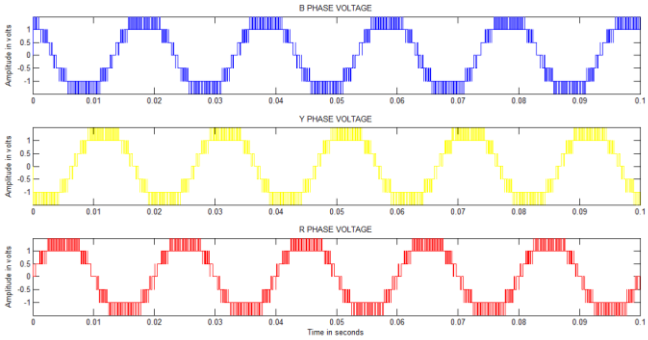

Fig.12.Output voltage of hybrid carrier THI-VFPWM strategy

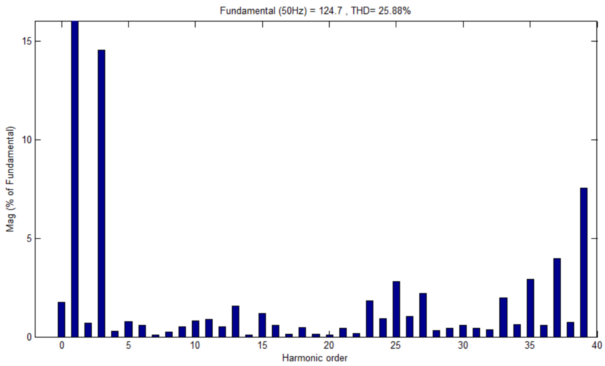

Fig.13. FFT spectrum for hybrid PDPWM strategy for m_a=0.8 m_f=40 with THI reference

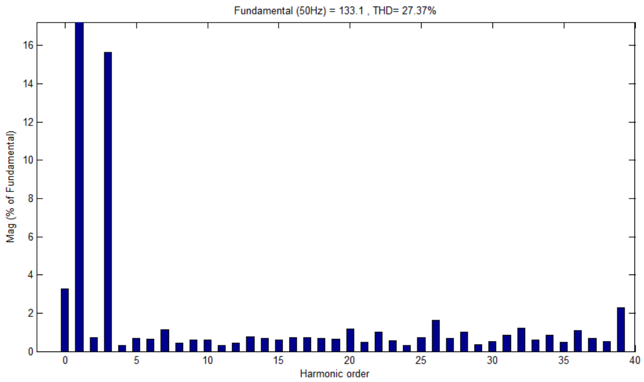

Fig.14. FFT spectrum for hybrid PODPWM strategy for m_a=0.8 and m_f=40 with THI reference

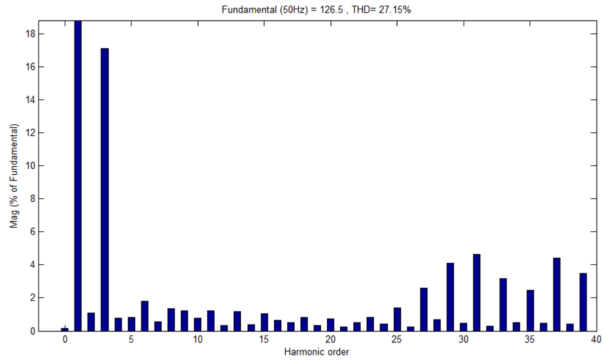

Fig.15. FFT spectrum for hybrid APODPWM strategy for m_a=0.8 and m_f=40 with THI reference

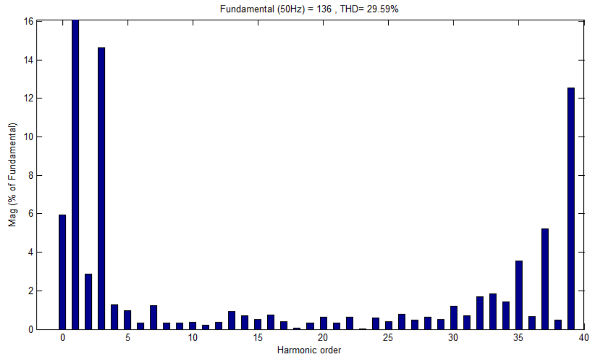

Fig.16. FFT spectrum for hybrid COPWM strategy for m_a=0.8 and m_f=40 with THI reference

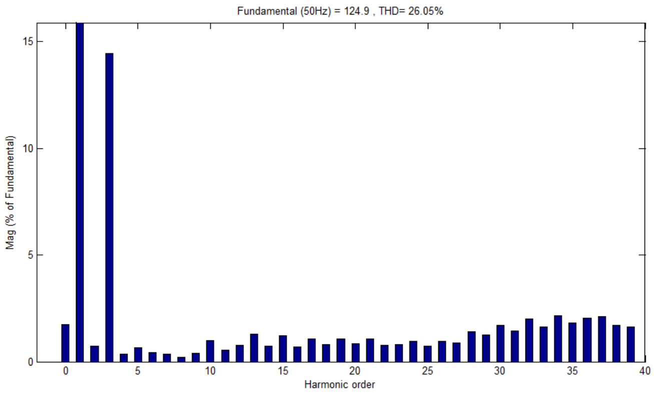

Fig.17. FFT spectrum for hybrid VFPWM strategy for m_a=0.8 m_f=40 with THI reference

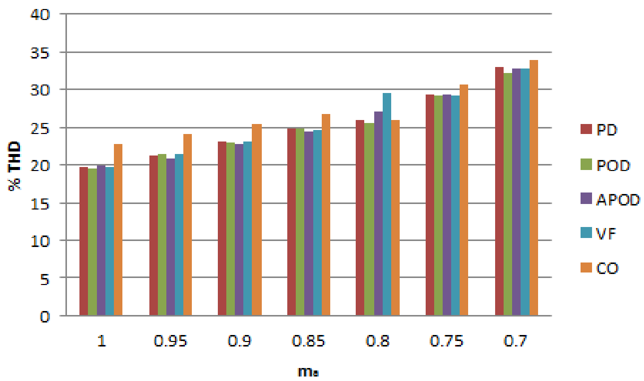

Fig.18.%THD Vs m_a for all strategies.

Table-I
%THD of output voltage of AMLI for various values of m_a

m_a	PD	POD	APOD	VF	CO
1	19.69	19.6	19.9	19.67	22.72
0.95	21.3	21.48	20.89	21.46	24.07
0.9	23.07	22.95	22.75	23.1	25.38
0.85	24.82	24.84	24.49	24.72	26.78
0.8	25.88	27.37	27.15	26.05	29.59
0.75	29.29	29.27	29.4	29.21	30.67
0.7	32.9	32.27	32.8	32.86	33.98

Table-II
RMS(Fundamental) value of output voltage of AMLI for different PWM strategies and various values of m_a

m_a	PD	POD	APOD	VF	CO
1	160.2	160.1	160.1	160	168.6
0.95	154	153.6	153.9	153.6	164
0.9	147.4	147.6	147.7	147.2	158.1
0.85	140.3	140.3	140.5	140.4	153.8
0.8	133.1	133.1	133	133	147.9
0.75	125.2	125.1	125.2	125.4	141.4
0.7	116.4	116	116.4	116.3	133.8

Table-III
FF of output voltage of AMLI for different PWM strategies and various values of m_a

m_a	PD	POD	APOD	VF	CO
1	432.97	1.6E+09	1.6E+09	2286	337.2
0.95	389.87	1.6E+09	1.6E+09	903.5	117.43
0.9	1179.2	1.6E+09	1.6E+09	320	2.08E+09
0.85	7936	1.6E+09	1.6E+09	322.8	2197.14
0.8	1064	1.6E+09	1.6E+09	682.1	870
0.75	1001.6	1.6E+09	1.6E+09	928.9	523.7
0.7	280.48	1.6E+09	1.6E+09	422.9	557.5

IV. Conclusion

A new hybrid modulation strategy is proposed for a three phase AMLI which achieves improvement in line to line voltage harmonics compared to the conventional modulation techniques. It is observed that COPWM provides better DC bus utilization and POD technique creates less distortion for m_a=0.7-1.

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