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DEVELOPMENT OF MULTI CARRIER PWM TECHNIQUE FOR FIVE LEVEL VOLTAGE SOURCE INVERTER

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ABSTRACT Multilevel converters have received increased interest recently as a result of their ability to generate high quality output waveforms with a low switching frequency. This makes them very attractive for high-power applications. A cascaded H-bridge converter (CHB) is a multilevel topology which is formed from the series connection of H-bridge cells. In this paper, the different multi-carrier PWM techniques are investigated and several interesting characteristics of them are revealed. A newmethod of multi-carrier PWM strategies is also proposed and compared with different conventional multi-carrier PWM techniques. Reduction of total harmonics distortion (THD) and improvement of the harmonic spectrum of inverter output voltage are some advantages of the proposed control method. The simulation results based on the MATLAB/SIMULINK software are presented to validate the capabilities of the proposed modulation method.

Key words: Multilevel inverter; multi-carrier PWM techniques; phase disposition PWM; phase opposition disposition PWM; alternate phase opposition disposition PWM.

I. INTRODUCTION

Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power inverter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel inverter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources suchas photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel inverter system for a high power application[1].A multilevel converter is a power electronic system that synthesizes a desired output voltage from several levels of dc voltages as inputs. Compared with the traditional two-levelvoltage converter, the primary advantage of multilevel converters is their smaller output voltage step, which results in high power quality, lower harmonic components, better electromagnetic compatibility, and lower switching losses [2].The first topology introduced was the series H-bridge design [3], but several configurations have been obtained for this topology as well [4-5]. Since this topology consist of series power conversion cells, the voltage and power level may be easily scaled. An apparent disadvantage of this topology is the large number of isolated voltages required to supply each cell. The H-bridge topology was followed by the diode-clamped converter which utilized a bank of seriescapacitors [6]. Another fundamental multilevel topology, the flying capacitor, involves series connection of capacitor clamped switching cells [7]. This topology has several unique and attractive features when compared to the diode-clamped inverter. One feature is that added clamping diodes are not needed. Furthermore, the flying capacitor inverter has switching redundancy within the phase which can be used to balance the flying capacitors so that only one dc source isneeded [2]. Different modulation strategies have been used in multilevel power conversion applications within the technical literature. They can generally be classified into three categories: fundamental frequency switching, space vector PWM (SVPWM) and multi-carrier PWM techniques. This paper focused on the multi-carrier PWM technique which has been extended using multiple references. Multi-carrier PWM techniques can be categorized into three groups: phase disposition PWM (PD-PWM), phase opposition disposition PWM (POD-PWM) and alternate phase opposition disposition PWM (APOD-PWM) techniques. In these modulation strategies, the reference waveform is sampled through a number of carrier waveforms displayed by contiguous of the reference waveform amplitude [8-11].The different multi-carrier PWM modulation strategies for multilevel inverters will be reviewed in this paper. This paper is organized into the following way: first, the different multicarrier PWM methodsaredescribedandseveral interesting characteristics of them are revealed. After this, a new method of multi-carrier PWM technique is proposed. The proposed method is compared with different conventional multi-carrier PWM techniques basedonsimulationresultsusing MATLAB/SIMULINKsoftware.

II. CONVENTIONALCARRIER-BASED PWM METHODS

Multicarrier PWM techniques entail the natural samplingof a single modulating or reference waveform typically being sinusoidal, through several carrier signals typically being triangular waveforms [9].In order to describe the different multi-carrier PWMmethods the following definitions should be considered:

- The frequency modulation index is defined as mf = fc / fr, where fc is the frequency of carriersignals and fr is the frequency of the reference signal.
- The amplitude modulation index is defined as ma = Ar / Ac, where Ar is the amplitude ofreference signals and Ac is the peak to peak value of the carrier signal [8].

A. PD-PWM method

The PD-PWM method, as one of the carrier-based PWM methods, is based on a comparison of a sinusoidal reference waveform with vertically shifted carrier **waveforms. The PDPWM method uses N −1** carrier signals to generate the N - level at output voltage. The carrier signals have the same amplitude and the same frequency and are in phase. The sinusoidal reference wave has a frequency fr and an amplitude Ar. At each instant, the result of the comparison is decoded in order to generate the correct switching function corresponding to a given output voltage level. In PD-PWMmethod, with even and odd mf, the significant harmonic energy is concentrated on the carrier frequency. For instance,with mf = 39 , the significant harmonic energy is in 39th harmonic. The PD-PWM method yields only odd harmonics for odd mf and yields odd and even harmonics for even mf .Also, this method yields quarter wave symmetry only for odd mf [8-11].

B. POD-PWM method

In the POD-PWM method the carrier signals above the zero axis are in phase. The carrier signals below zero axis are also in phase but 180 degrees phase shifted. For even and odd values of frequency modulation index, the significant harmonics are located in two sidebands around the carrierfrequency. There is no harmonics at fc. For instance, with mf =39 the significant harmonics are 28th and 40thharmonics For odd mf, the POD-PWM waveform has odd symmetry resulting in only even harmonics. For even mf, the waveforms have quarter wave symmetry resulting in onlyodd harmonics [8-11].

C. APOD-PWM method

This technique requires each of the N −1 carrier waveforms for an N -level phase waveform, to be phase displaced from each other by 180 degrees alternately. For even and odd mf, the most significant harmonics are sidebands of the carrier frequency. But there is no harmonics fc. For odd mf, the APOD-PWM waveform has odd symmetry resulting in only even harmonics. For even mf, the waveforms have quarter wave symmetry resulting in only odd harmonics [8-11].

III. PROPOSED MODULATION METHOD

For reducing the number of carrier signals and alsoimprovement of the THD and harmonic spectrum of inverteroutput voltage, a new modulation strategy is proposed in thispaper. The proposed multi-carrier PWM method uses (N -1) / 2 carrier signals to generate the N -level at outputvoltage. The carrier signals have the same amplitude, Ac andthe same frequency, fc, and are in phase. The sinusoidalreference wave has a frequency frand an amplitude Ar. Inthe proposed method, the sinusoidal reference and its inverseare used for generating the required gate signals. Thefrequency of the output voltage is determined by thefrequency of the sinusoidal reference waveform. Theamplitude of the fundamental component of the outputvoltage is determined by the amplitude modulation index,ma .Fig. 1 shows the proposed multi-carrier PWM method for a single-phase 5-level inverter. As this figure shows, the proposed method uses two reference signals and two carrier signals. This method is based on a comparison of the sinusoidal reference waveforms with carrier waveforms. For even and odd values of frequency modulation index, mf, the significant harmonics are located in two sidebands around the frequency, 2 fc. As a result, the frequency spectrum of theoutput voltage is improved. So, the size of the required filter will be small. It is important to note that the design of filter is not the objective of this work. Reduction of the THD of the output voltage is other important advantage of the proposed method. It is noticeable that the conventional modulationmethods generate the significant harmonics in two sidebands around the carrier frequency, fc.

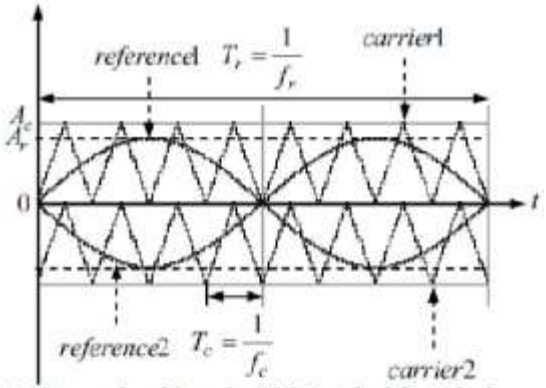


Fig. 1. Proposed multi-carrier PWM method for a single-phase 5-level inverter

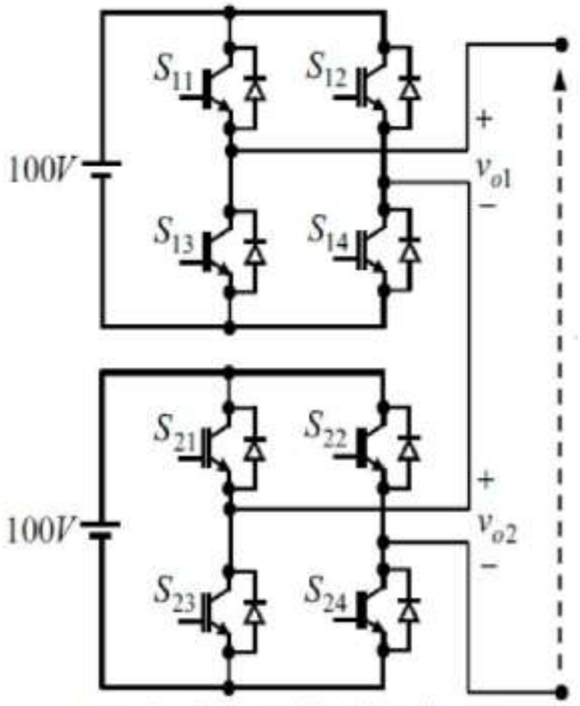


Fig. 2. Five-level cascaded multilevel inverter

IV. SIMULATION RESULTS

To examine the performance of the proposed control method, a single-phase 5-level cascaded inverter is simulated.The MATLAB software has been used for simulation. Fig. 2 shows the 5-level cascaded inverter topology. This inverter consists of two full-bridge converters. The amplitudes of dcvoltage sources are considered 100V. It is assumed that the inverter is adjusted to produce a 50Hz, 5-level staircase waveform. The amplitude of the fundamental component is considered 160V. Test has been made on R-L load (R=20ohms and L =55mH). Fig. 3 shows the control block diagram ofthe inverter based on the proposed control method. As shown in this figure, both switches on a leg cannot be on simultaneously, because a short circuit across dc voltage sources would be produced.Fig. 6 shows the references and carriers waveforms. As this figure shows, the amplitude and frequency of the reference waveform have been considered Ar=0.9pu and fr=50Hz, respectively. The frequency of the multi-carrier is assumed fc =1050Hz. Since the load of the inverter is almost a low pass filter (R-L), then the output current contain less high order harmonics than theoutput voltages. The frequency spectrum of the output voltage and current is shown in Figs. 7-8, respectively. The output voltage waveform of the inverter as shown in Fig. 6 is made up from a fundamental frequency sine wave and a few numbers of harmonics. Fig. 7 shows that the amplitude of the fundamental component is 182.2V that has good agreement with the forecasted amplitude of the output voltage. The frequency spectrum of the output voltage shows that the significant harmonics are located in two sidebands around the 20th harmonic. The THDs of the output voltage and currentbased on simulation are 32.99% and 15.66%, respectively. To generate a desired output voltage with best quality of the waveform, the frequency of the carrier signals should be increased.

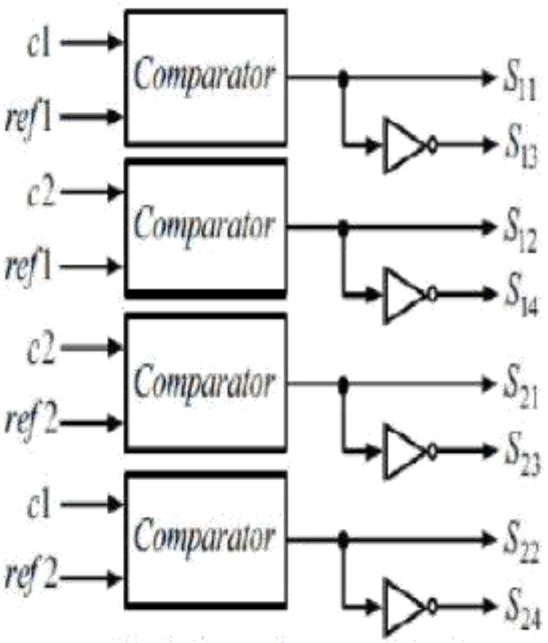


Fig.3. Control block diagram for proposed circuit

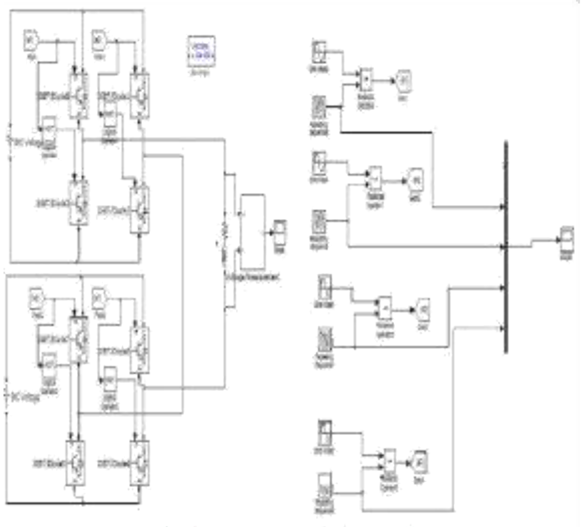
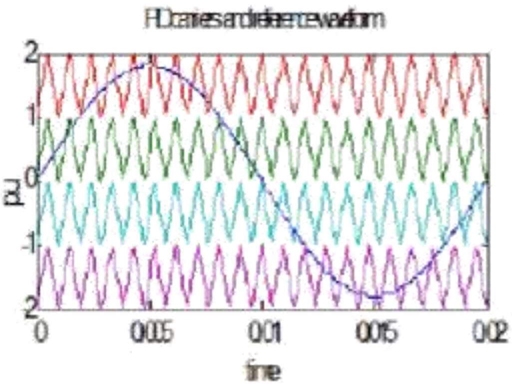
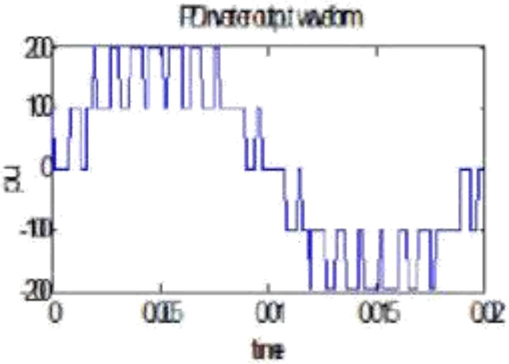
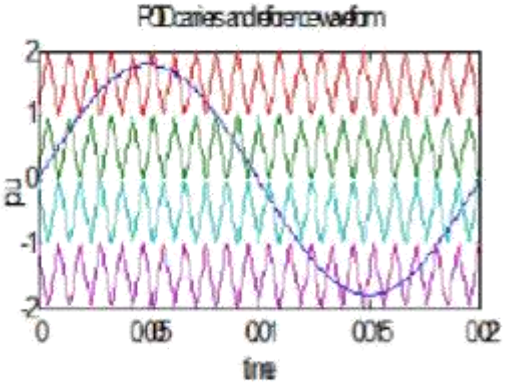
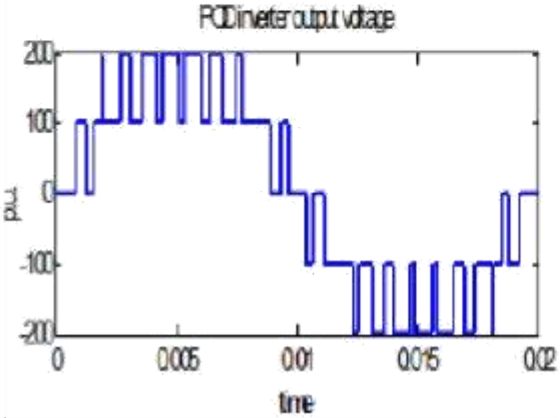


Fig.4. Simulink diagram of cascaded H-bridge five level inverter









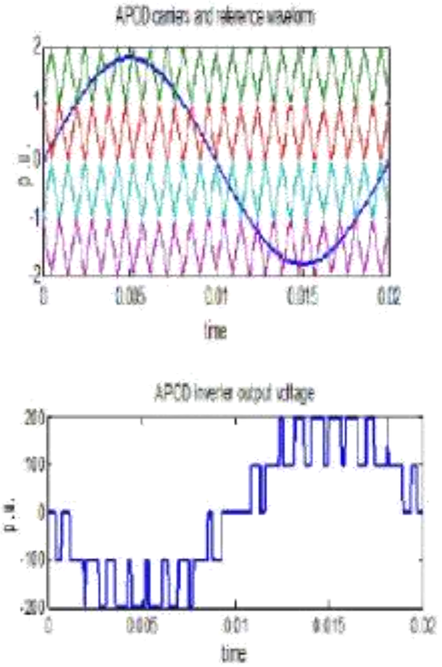
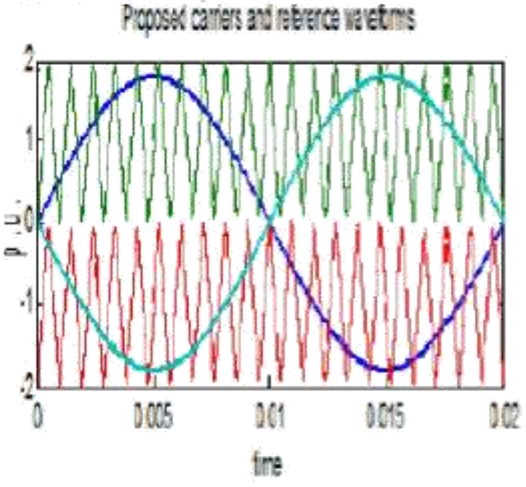
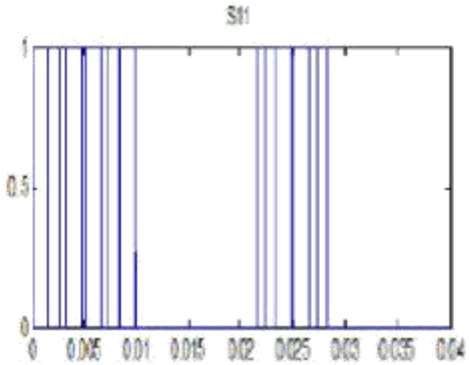
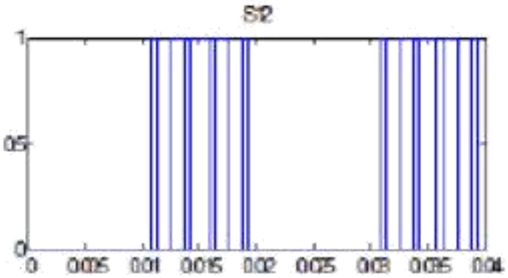
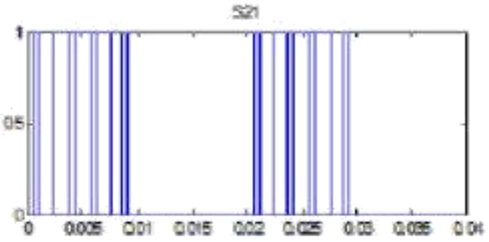


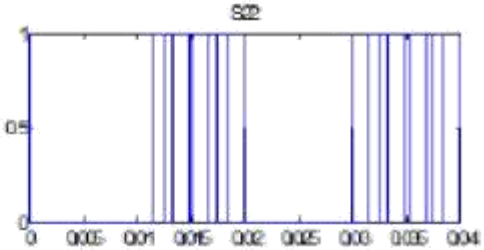
Fig. 5. Carrier, reference, and inverter output voltage waveforms for mf = 21, ma = 0.9

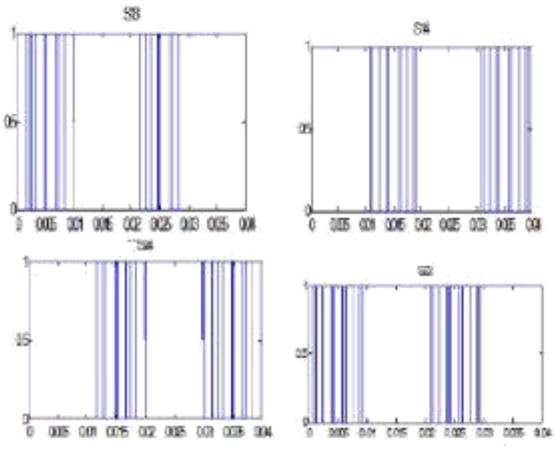


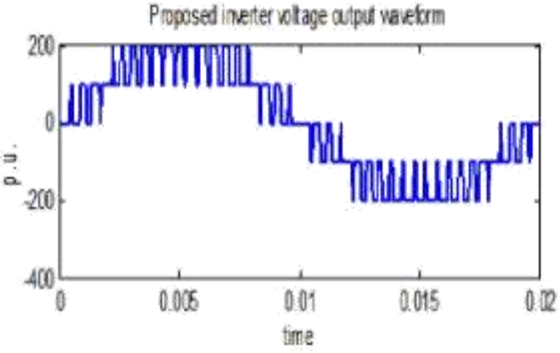












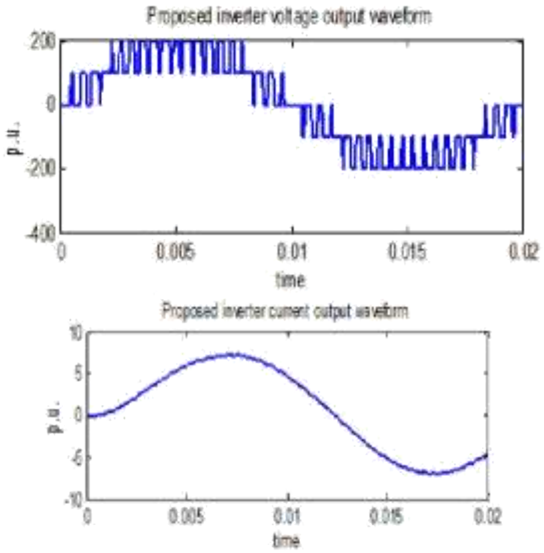


Fig.6. Carrier, reference, PWM pulses, current and inverter output voltage waveforms for mf = 21, ma =0.9

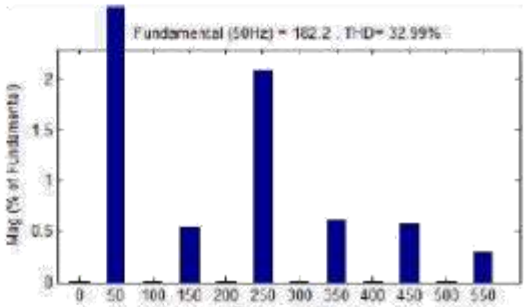


Fig.7. Frequency spectrum of the output voltage

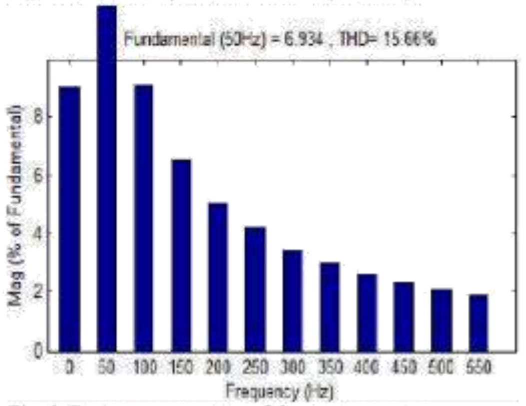


Fig. 8. Frequency spectrum of the output current

V.COMPARISON OF THE PROPOSED METHODWITHCONVENTIONAL CARRIER-BASED PWMMETHODS

For revealing the advantages of the proposed method in comparison with the conventional multi-carrier PWM methods, it is necessary to consider the frequency spectrums of the output voltages. Fig. 11 shows the THDs of different multi-carrier PWM methods versus mf for ma =0.9. Fig. 9 shows the THDs of different multi-carrier PWM methods versus ma for mf =21. As Figs. 9 and 10 show, fordifferent values of mf and ma, the THD of the proposed method is less than the conventional multi-carrier PWM methods.

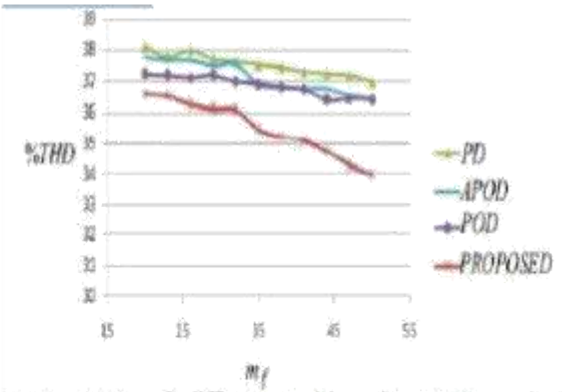


Fig.9. THDs of different multi-carrier PWM methods versus *mf forma* = 0.8

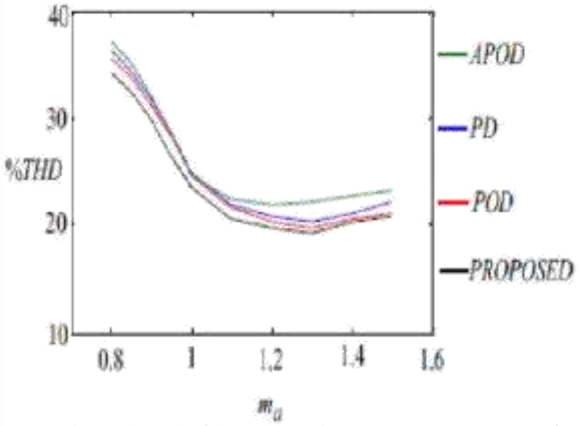


Fig. 10. THDs of different multi-carrier PWM methods versus *ma* for*mf* = 22

VI. CONCLUSION

In this paper, a new method of multi-carrier PWM method is proposed. The significant harmonics in conventional methods are located in two sidebands around mf and it's multiple. But in the proposed method, the significant harmonics are located in two sidebands around 2mf and it's multiple. As a result, the size of the required filter will be small. Reduction of the THD of the output voltage is other important advantage of the proposed method in comparison with other conventional multi-carrier PWM methods.

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