

HARMONIC ELIMINATION FOR SUPER – MULTIPLE OF SUPPLY FREQUENCY CONVERTER BASED ON DISCRETE AMPLITUDE MODULATION BY USING DOUBLE SHIFT COMB FILTER TECHNIQUE

Ibraheem Mohammed Khaleel
Computer and Communications Engineering Dept.
AL- Rafidain University College, Baghdad, Iraq
Ibraheemmohammed1978@gmail.com

Abstract: One of most important challenge that face industrial electronics is to enhance the performance of converters used switching device. This paper gives a sufficient method to reduce total harmonic distortion for super- multiple of supply frequency based on converting (50) Hz to (400) Hz, this method depends upon comb filter technique, by shifting the main supply by suitable two angles phase shift (ϕ_1 and ϕ_2) using two phase shifting transformers and applying these sources to three converters to create three distorted (400) Hz waveforms each one have different displacement angle, three waveforms added to gather in order to create new 400Hz has low distorted waveform, applying this method will reduce the THD from 70% to 36 %.

Keywords: comb filter, frequency changers, PTSS, harmonic elimination.

1. INTRODUCTION

For AC to AC frequency multiplier based on amplitude modulation there is a big advantage over the other converters that is this converter doesn't need for DC link, but the output of this converter has a large amount of total harmonic distortion about 70% [1], so that to use this converter in industrial electronics we must reduce THD to acceptable value, in order to use the converter in high frequency applications such as airplane and aircraft power supplies which operates with THD about 20% [2] and induction heating supplies which operates with waveforms have THD about 30%[3] . One of important techniques used to reduce THD is

comb filter which is based on shifting the spectrum of distorted output waveform of converter by a suitable phase shift and add the shifted spectrum with original spectrum the resultant of this technique will be a frequency spectrum with low THD [4], as shown in Fig.1

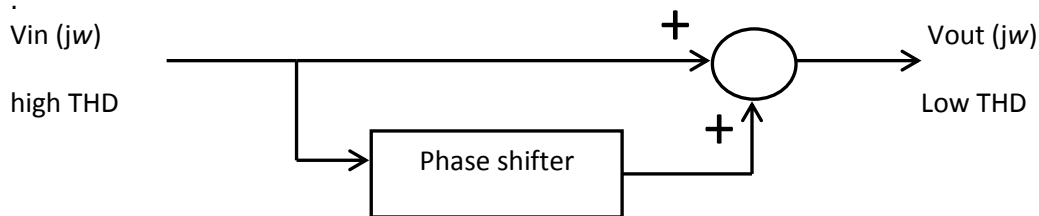


Fig.1: Ordinary comb filter

For 400 Hz converter (AC to AC frequency changer), the frequency spectrum of the converter shows large magnitudes for 300 Hz sub harmonic and 500 Hz harmonic, these most predominant frequencies with respect to magnitude of fundamental caused increasing in amount of THD as shown in Fig.2.

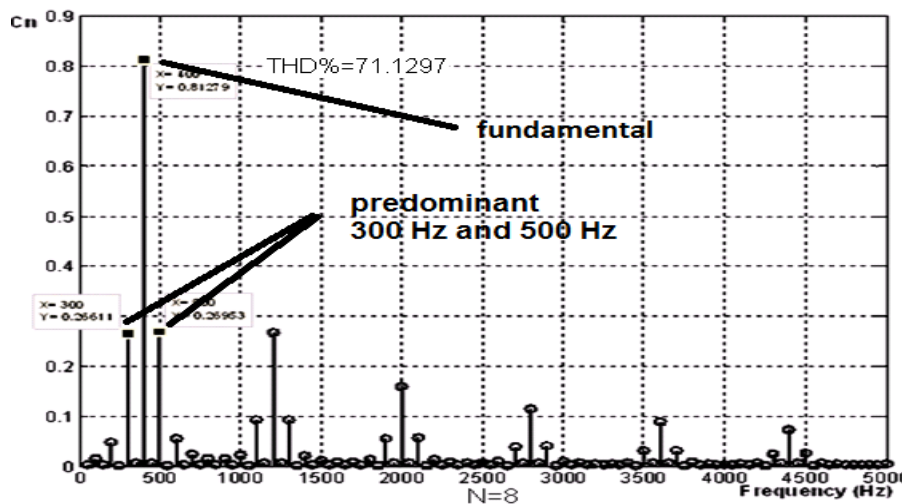


Fig.2: Spectrum of AC to AC frequency changer operates at 400 HZ

According to this fact and since that the THD completely depends upon the magnitude of the harmonics and sub harmonics appears in the frequency spectrum of distorted waveform and the magnitude of fundamental frequency as shown in equation (1).

$$THD = \frac{1}{A_1} \sqrt{\sum_{n=0}^k A_n^2} \quad \text{where } k \neq 1 \quad (1)$$

Where A_n represent the magnitude of harmonics and sub harmonics and A_1 represent the magnitude of fundamental frequency. The comb filter must be designed to eliminate or reduce these tedious frequencies, unfortunately the comb filter technique established by shifting the distorted output of the converter by a suitable angle, the suggested phase shift depends upon the desired frequency that is wants to eliminate or reduced as shown in equation (2)[4].

$$\phi = \frac{180}{0.02fd} \quad \text{fd is the frequency must be eliminated} \quad (2)$$

The ordinary comb filter operates with phase shift 120° which can be investigated by using the balanced three phase outputs of the converter, this phase shift cannot applied for AC to AC frequency multiplier operates with $N=8$ to generate 400 Hz important frequency in industrial electronics, because this filter with phase shift of 120° cannot eliminate or reduce 300Hz and 500 Hz harmful frequencies without effect the magnitude of the 400Hz fundamental frequency as shown Fig.3.

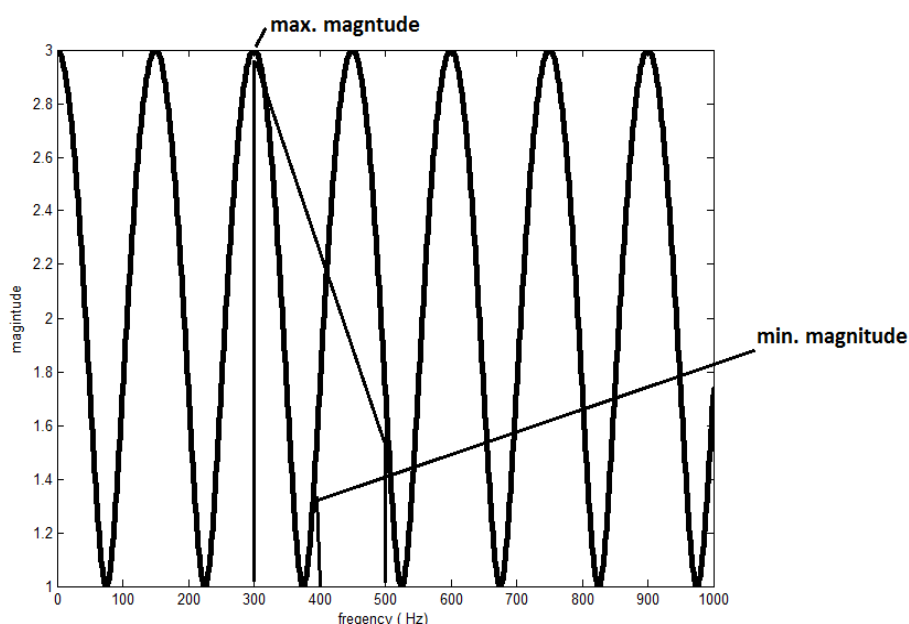


Fig.3: Frequency response of ordinary comb filter

A new approach suggested in order to enhanced the performance of comb filter by inserting another phase shifter and makes the comb filter operates with two phase shifters at two different angles, in this paper a new approach will be discussed, proved, and applied for (AC to AC) frequency multiplier operates with $N=8$ in order to eliminate or reduce most effective harmful harmonics (300Hz and 500Hz) by changing the positions of (zeros against frequency) that appears in the transfer function of the comb filter.

2. PROPOSED COMB FILTER

The suggested enhanced comb filter system depends upon adding two phase shifters with two different angles (ϕ_1 and ϕ_2) that is means (shifting the output of AC to AC frequency multiplier) to generate an important 400 Hz source, as shown in Fig.4 these shifting angles will be change the position of magnitude for transfer function at a certain frequency. However the transfer function of proposed new approach comb filter derived to be depends upon the value of applied angles of phase shifters that subjected to eliminate or reduce the magnitude of desired harmful frequencies.

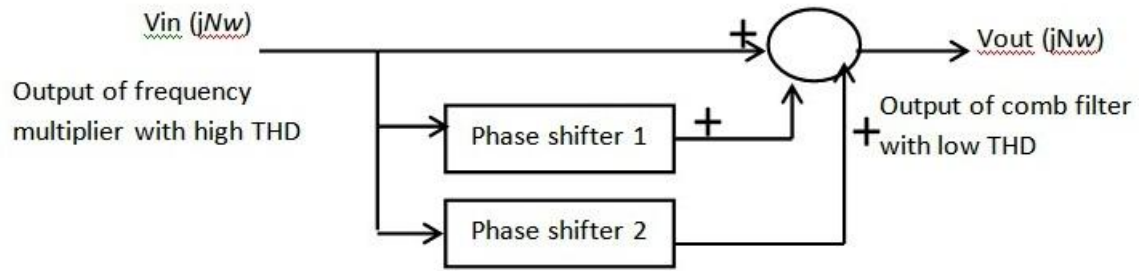


Fig.4: Proposed double shift comb filter

2.1 Mathematical model

Suppose that the comb filter capable to shift distorted output of frequency multiplier with two angles (θ_1 and θ_2) so that the output of enhanced comb filter can be determine in frequency domain as shown in equation (3):

$$V_{out}(jNw) = V_{in}(jNw) + V_{in}(jNw)e^{-j\theta_1} + V_{in}(jNw)e^{-j\theta_2} \quad (3)$$

$$V_{out}(jNw) = V_{in}(jNw)[1 + e^{-j\omega T_1} + e^{-j\omega T_2}] \quad (4)$$

So that the transfer function of double shift transfer function is

$$\frac{V_{out}(jNw)}{V_{in}(jNw)} = 1 + e^{-j\omega T_1} + e^{-j\omega T_2} \quad (5)$$

$$e^{-j\omega T_1} = \cos\omega T_1 - j\sin\omega T_1 \text{ and } e^{-j\omega T_2} = \cos\omega T_2 - j\sin\omega T_2 \quad (6)$$

according that

$$\frac{V_{out}(jNw)}{V_{in}(jNw)} = 1 + \cos\omega T_1 - j\sin\omega T_1 + \cos\omega T_2 - j\sin\omega T_2 \quad (7)$$

Where T_1 and T_2 are corresponding times that represent the phase shifts (θ_1 and θ_2), this can be illustrated as shown in equation (8):

$$T_1 = \frac{0.01 \cdot \theta_1}{180} \quad \text{and} \quad T_2 = \frac{0.01 \cdot \theta_2}{180} \quad (8)$$

Finally we can estimate the magnitude of transfer function as function of θ_1 and θ_2 as shown in equation (9)

$$\left| \frac{V_{out}(jNw)}{V_{in}(jNw)} \right| = \sqrt{\left(1 + \cos\omega \frac{0.01 \cdot \theta_1}{180} + \cos\omega \frac{0.01 \cdot \theta_2}{180}\right)^2 + \left(-\sin\omega \frac{0.01 \cdot \theta_1}{180} - \sin\omega \frac{0.01 \cdot \theta_2}{180}\right)^2} \quad (9)$$

As shown in equation (9) the magnitude of transfer function for enhanced double shift comb filter is completely depends upon value of angles (θ_1 and θ_2), so that we need to estimate the vales of θ_1 and θ_2 at which harmful harmonics for(AC to AC frequency multiplier operates with $N=8$) (300Hz and 500 Hz) will eliminate or reduce and doesn't effected on the fundamental frequency (400 Hz).illustrating the transfer function of enhanced comb filter as function of θ_1 and θ_2 to find optimum phase shift angles that eliminate 300Hz and 500Hz as shown in Fig.5.

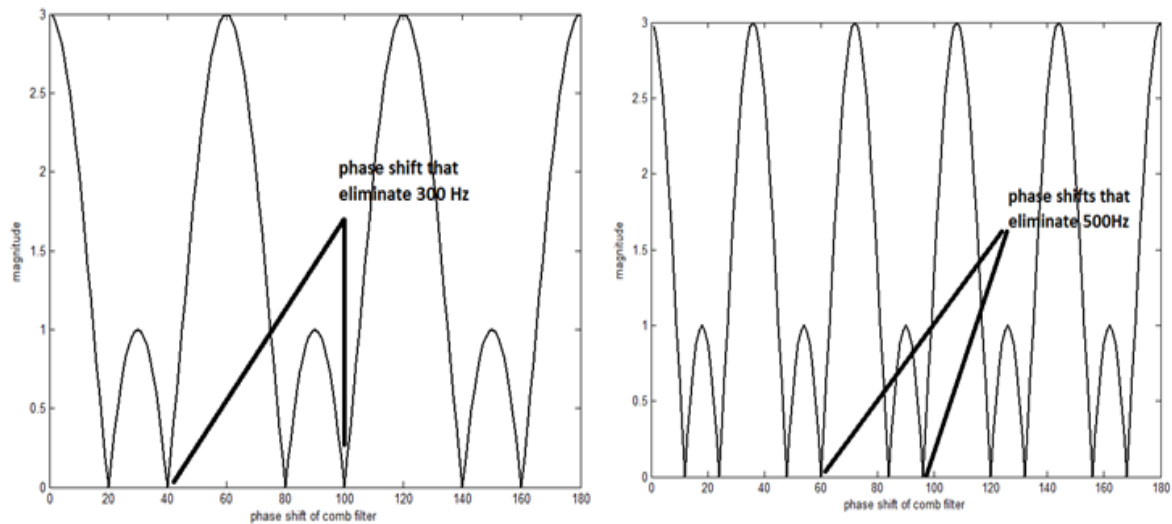


Fig.5: Magnitude of transfer function against phase shift variation at certain frequency

As shown in Fig.5 after illustrating equation (9) at $f=300\text{Hz}$ and $f=500\text{Hz}$ there were many zeros in the variation of the magnitude of transfer function against the variation of angles of phase shifters at these desired frequencies, and the phase angles which eliminate both 300Hz and 500Hz lie between $(95^\circ \text{ and } 100^\circ)$, and to estimate the angles of the shifters for double comb filter the magnitude of transfer function was estimated in the suggested range of angles to get optimum values of angles needed to eliminate tedious frequencies as shown in table.1.

θ_1	θ_2	Normalized magnitude of 400Hz	Normalized magnitude of 300Hz	Normalized magnitude of 500Hz
95	-95	2	0.015	0.005
96	-96	2.2	0.01	0
97	-97	2.2	0.005	0.005
98	-98	1.2	0.005	0.005
99	-99	1.2	0.005	0.01
100	-100	1.5	0	0.015

Table 1: Phase shift variation against magnitude of fundamental and predominate harmonics

From table.1 the optimum angles phase shifting that eliminate 300 Hz and 500 Hz for double shift comb filter estimated to be $(\theta_1=97^\circ \text{ and } \theta_2= -97^\circ)$, because at these angles the normalized magnitude of transfer function for double comb filter gives maximum amplitude for fundamental frequency, while for harmful desired frequencies the magnitude of transfer function is minimum.

Unfortunately it is difficult to create a phase shifter for non-sinusoidal waveforms because "phase measurement systems that use phase-shifting techniques, phase errors that occur to non-sinusoidal waveforms can be minimized by applying synchronous phase-

shifting methods, however, when the phase-shift calibration is inaccurate, these methods cannot eliminate the effects of non-sinusoidal characteristics" [5].

According to this serious problem, the phase shifters location must be change in order to shift sinusoidal waveform, the phase shifters inserted to displace the main supply with suitable angles, the improved model with new position of phase shifters as shown in Fig.6.

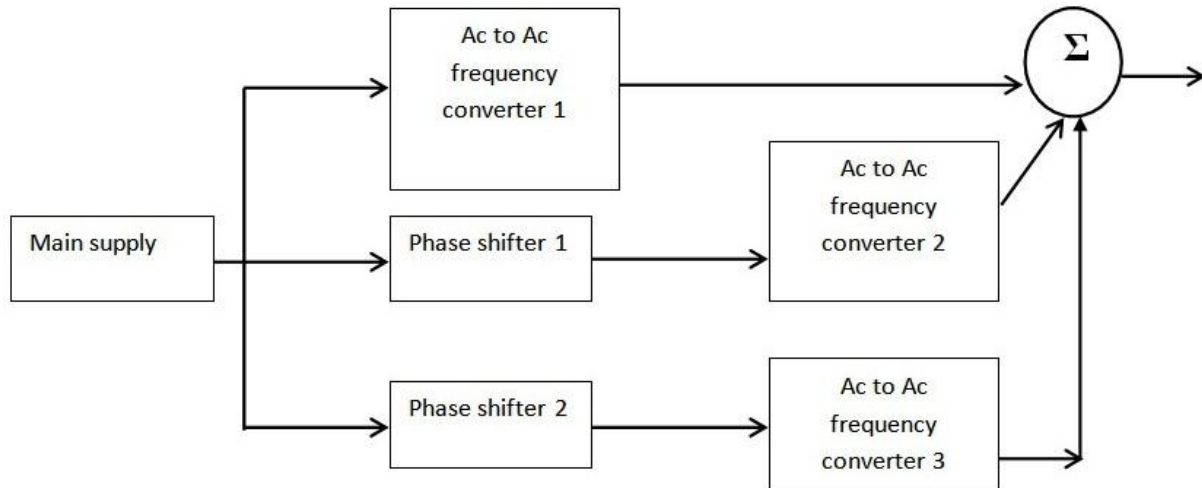


Fig.6: Improve double shifting comb filter

the improvement of double comb filter harmonic reduction technique depends upon time shifting theorem which is one of the properties of Fourier analysis which state that if **Fourier transform of $F\{f(t)\} = F(\omega)$ so that Fourier transform of $F\{f(t - t_0)\} = e^{-j\omega t_0} F(\omega)$** [6] where(t_0) corresponding time equivalent to phase shift, which can be established by $t_0 = \frac{\theta \cdot 0.02}{260}$ for ($f=50\text{Hz}$ supply frequency) so that a new transfer function for system shown in Fig(6) must be determined.

Assuming the main supply with sinusoidal wave form has frequency spectrum of $Vin(j\omega)$ and the output of converter 1 in frequency domain define as $Vo1(jN\omega)$, and the frequency spectrum of the output of phase shifters (1 and 2) as $Vin(j\omega)e^{-j\theta1}$ and $Vin(j\omega)e^{-j\theta2}$ respectively, the output of converters (2 and 3) will be $Vo2(jN\omega)e^{-j\theta1}$ and $Vo3(jN\omega)e^{-j\theta2}$ depending upon the linearity property the output of overall system can be defined as:

$$Vo(jN\omega) = Vo1(jN\omega) + Vo2(jN\omega)e^{-j\theta1} + Vo3(jN\omega)e^{-j\theta2} \quad (10)$$

According time shifting theorem the output of all converters (1,2,4) have the same magnitude at each frequency appears in the frequency spectrum but the output of converters (1,2) shifted by ($\theta1$ and $\theta2$) respectively[7] according that $|Vo1(jN\omega)| = |Vo2(jN\omega)| = |Vo3(jN\omega)|$

$$Vo(jN\omega) = Vo1(jN\omega) + Vo1(jN\omega)e^{-j\theta1} + Vo1(jN\omega)e^{-j\theta2} \quad (11)$$

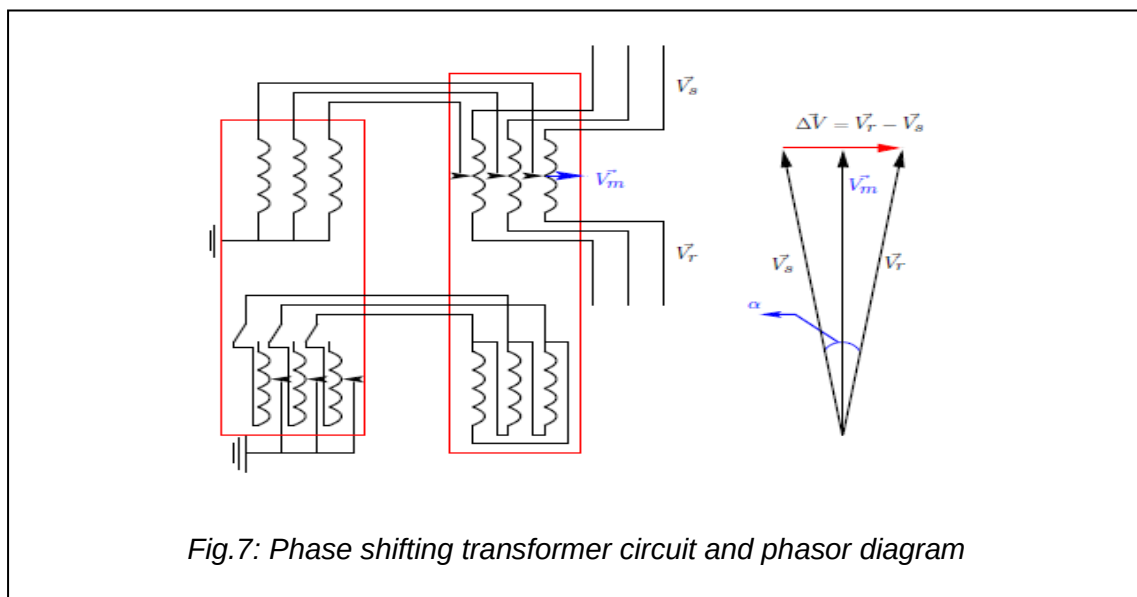
$$Vo(jN\omega) = Vo1(jN\omega)[1 + e^{-j\theta1} + e^{-j\theta2}] \quad (12)$$

$$\frac{Vo(jN\omega)}{Vo1(jN\omega)} = [1 + e^{-j\theta1} + e^{-j\theta2}] \quad (13)$$

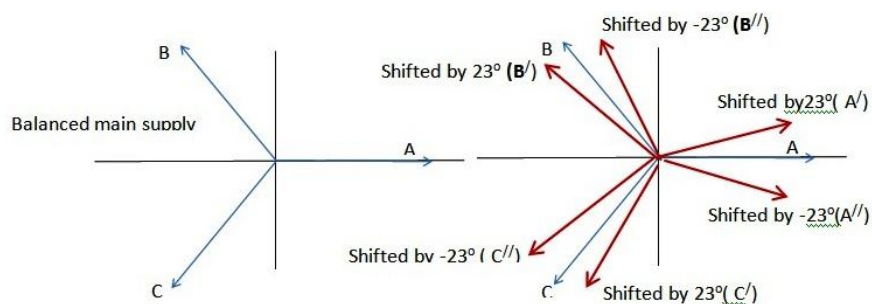
The transfer function for overall system shown in equation (13) is symmetrical to a transfer function of proposed comb filter in equation (5) which is completely depends upon (θ_1 and θ_2) so that a suitable phase shifter want to be established which is capable to shift the main supply with (97°) and (-97°) in order to eliminate tedious frequencies that makes the THD very high.

3. PHASE SHIFTER DESIGN USING PHASE SHIFTING TRANSFORMER

Phase shifting transformers are special forms of transformers able to control active power by regulating the voltage phase angle difference between two nodes of the power system [8]. Symmetric PSTs are which they have constant or nearly constant input and output voltages across the phase shift range (the input and output voltage vectors would describe circular arcs through the phase shifting range) [9]. This is achieved by adding a symmetrical PSTs voltage to the input and output phase angle, as shown in Fig.7



However the balanced main supply cannot shifted with (97° and -97°), since the phase shift transformer gives (30° and -30° in linear region of shifting) [9], the main supply must be shifted in previous range which is not comparable with is estimated to eliminate not useful frequencies, so that two shifting transformers used to shift the balanced three phase sources each one by (23° and -23°) to get three main sources described as (A, A', A'', B, B', B'', C, C', C'') which subjected to three (AC to AC frequency multiplier), the resultant phasor diagram can be describe as shown in Fig.8.



The resultant phases that produced by the two phase shifting transformers are almost balanced, and the phase angles of each phase shown in table.2.

Main supply	Applying 23° phase shifter	Applying - 23° phase shifter
Phase (A)	$A' = 23^\circ$ considered phase B shifted by -97°	$A'' = -23^\circ$ considered phase C shifted by 97°
Phase (B)	$B' = 153^\circ$ considered phase C shifted by -97°	$B'' = 97^\circ$ considered phase A shifted by 97°
Phase (C)	$C' = -97^\circ$ considered phase A shifted by -97°	$C'' = -143^\circ$ considered phase B shifted by -97°

Table2: Shifting sequences and new resultant phases

From table (2), phases B'' and C' considered to be phase **A** shifted by $(97^\circ$ and $-97^\circ)$ respectively, phases A' and C'' considered to be phase **B** shifted by $(97^\circ$ and $-97^\circ)$, and phases A'' and B' considered to be phase **C** shifted by $(97^\circ$ and $-97^\circ)$, all of these phases are distorted waveform, but after applying summing of shifted phases with zero with original output of frequency changer the resultant waveform has low total harmonic distortion, according that the output of improved system for each phase can be established in equations(12, 13, 14).

$$A''' = A + C' + B'' \quad (12)$$

$$B''' = B + A' + C'' \quad (13)$$

$$C''' = C + A'' + B' \quad (14)$$

4. SIMULATION AND RESULT

The proposed enhanced comb filter shown in Fig(6) was simulated using MATLAB SIMULINK package as shown in Fig.9, the system established using three AC to AC frequency changers, the chargers (2) and (3) designed to work with suggested phase shifts of (23°) and (-23°) respectively these angles implemented using two shifting transformers in order to get new 400 Hz frequency phases (A' , A'' , B' , B'' , C' , C'') these resultant 6 phase must be almost balanced, converter (1) used to generate 400Hz from main balanced supply directly to generate phases (**A**, **B**, **C**) the summing procedure was implemented using three multiwinding transformers.

The outputs of each (AC to AC frequency multiplier) and its phase angles were described in Fig.10, the figure shows that the starting point of each phase differs from the other phases, that is mean the shifting angles between the resultant (9) waveforms are different.

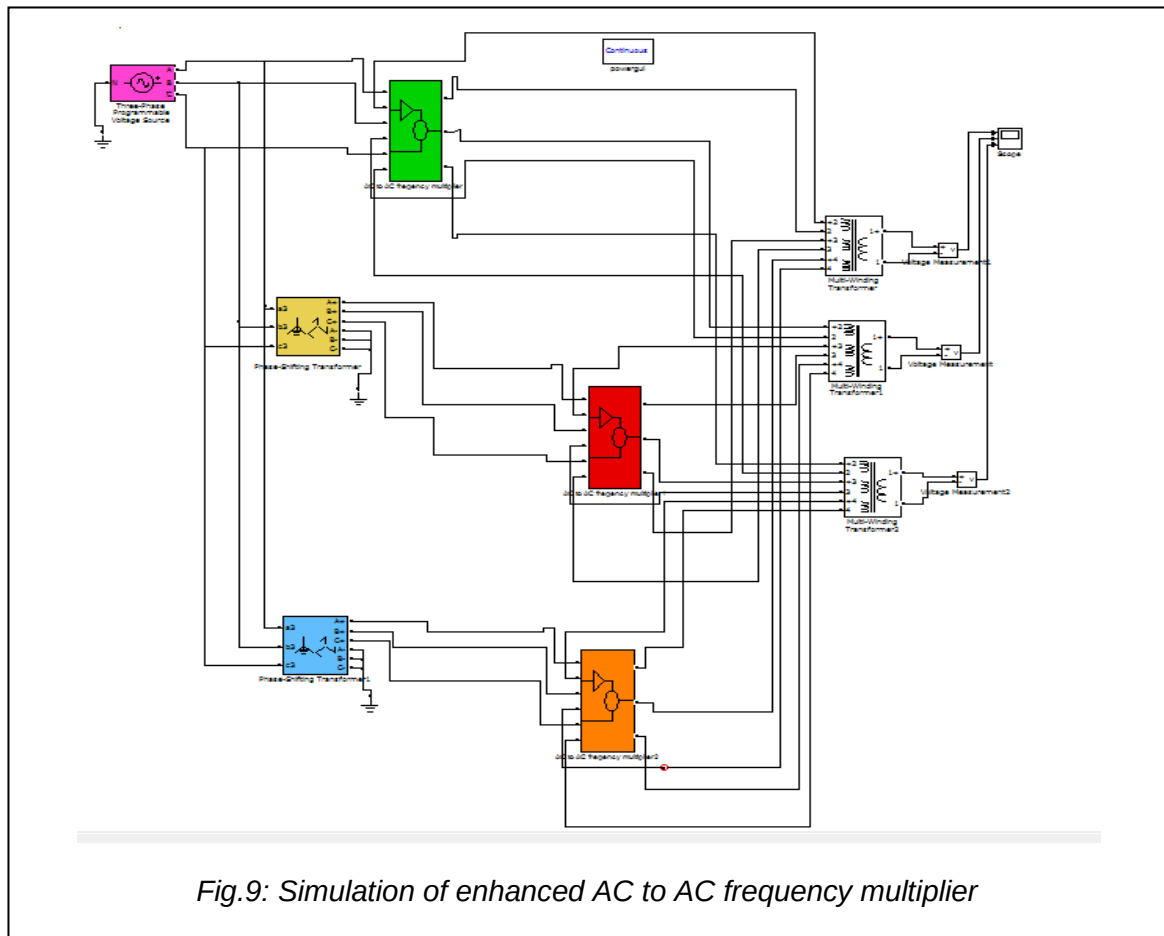
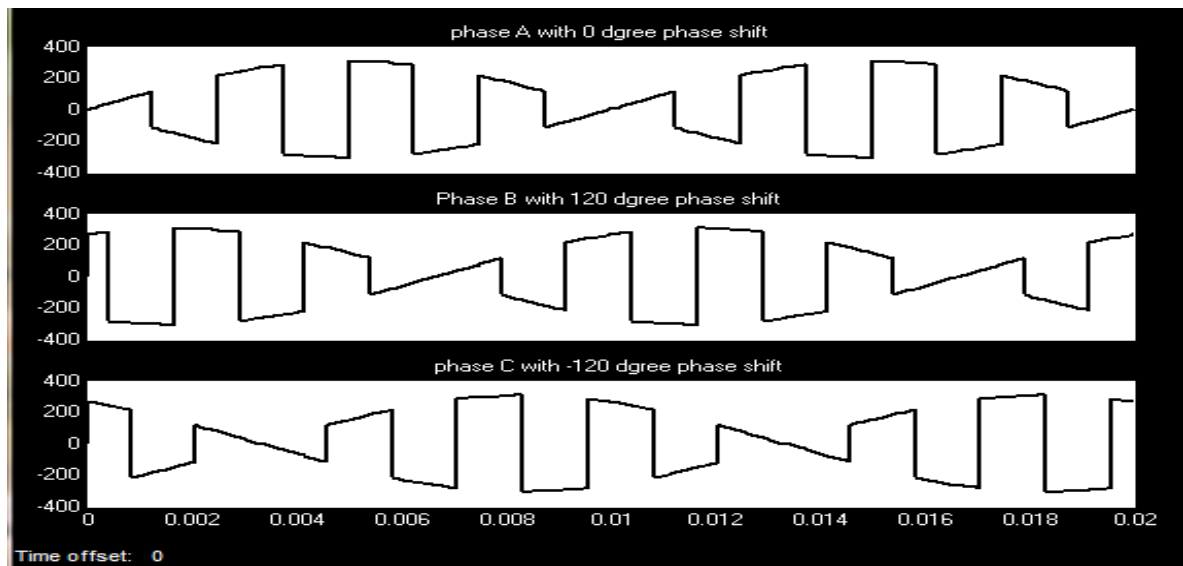


Fig.9: Simulation of enhanced AC to AC frequency multiplier



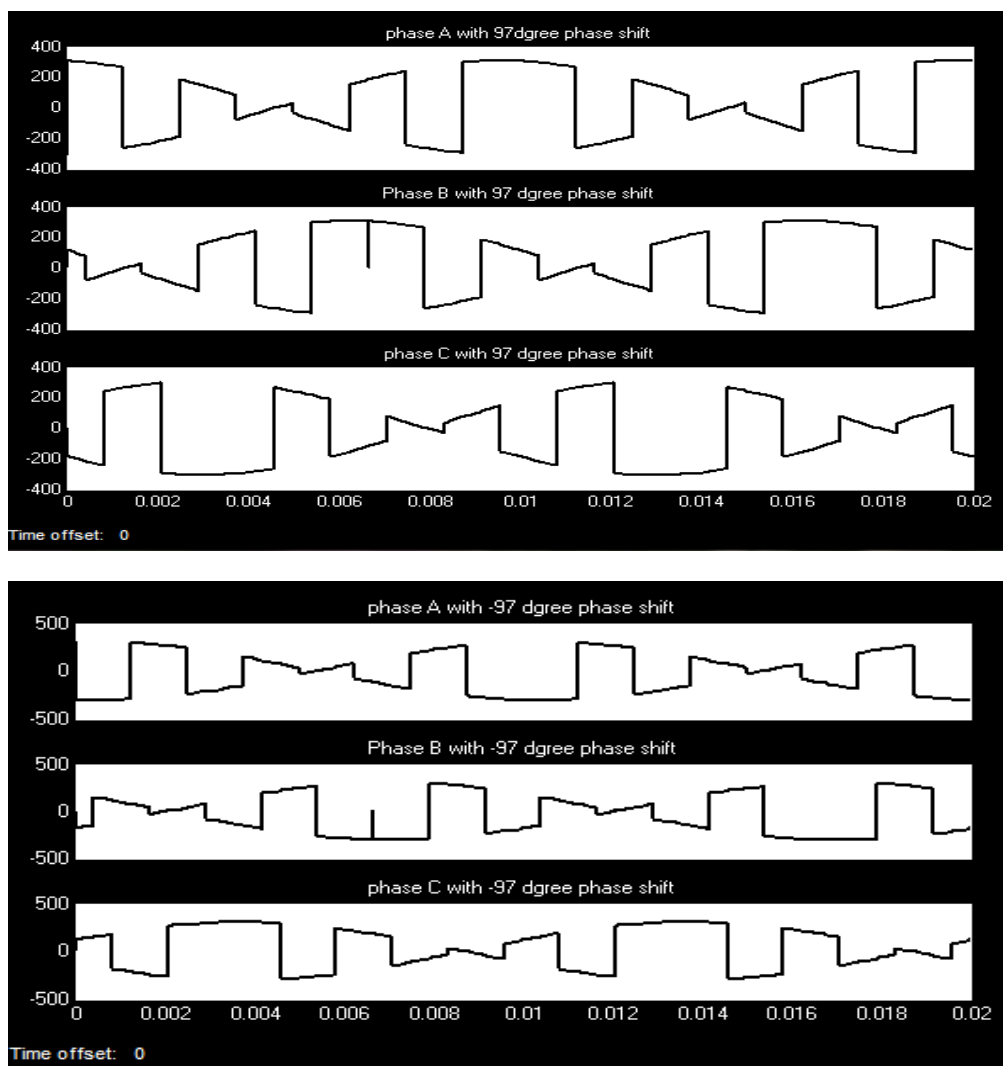


Fig.10: Outputs of AC to AC converters with phase angle of each phase

The overall output of the enhanced system after applying summing procedure using multiwinding transformers, the summing procedure according equations (12, 13, 14) result three phase low distorted waveforms as shown in Fig.11.

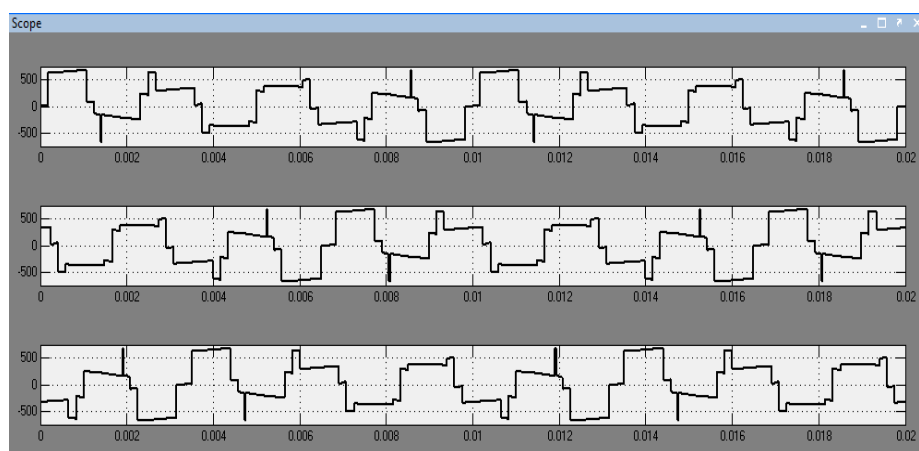


Fig.11: Output of overall enhanced system

As shown in Fig.11 the output is almost balance and showing an enhancement in performance with respect with the output of converter without applying enhanced double shifting comb filter, also after estimating harmonic analysis which result frequency spectrum illustrated using FFT analysis of MATLAB SIMULINK package shown in Fig.12.

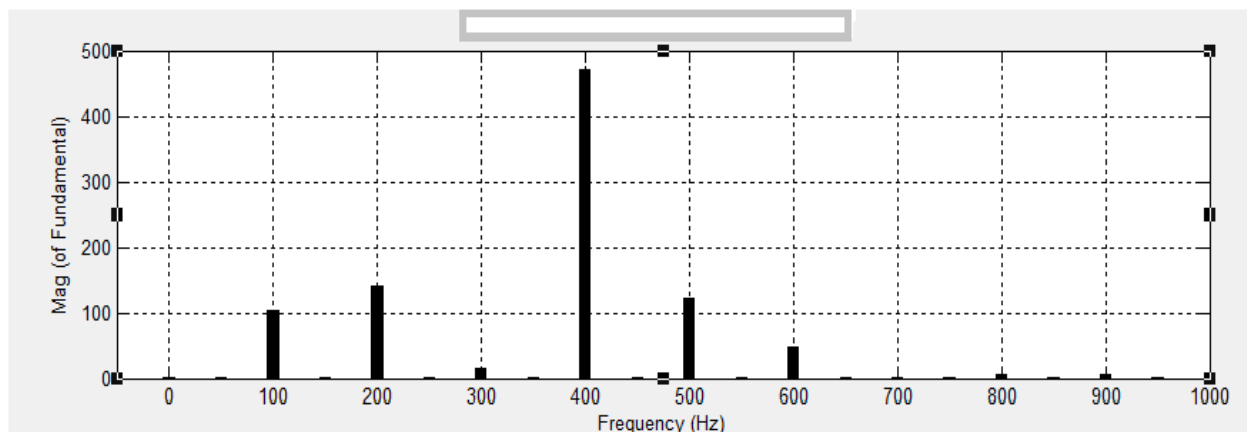


Fig.12: Frequency spectrum of enhanced AC to AC frequency multiplier

From Fig.12 we can notice that the predominates harmonics appears in original spectrum for (AC to AC frequency multiplier) that is makes the value of total harmonic distortion eliminated to minimum value, to estimate THD the distortion factor for each remaining harmonic can be determined as shown in table.4.

<i>Apparent frequency in the spectrum (Hz)</i>	<i>Distortions factor of each frequency %</i>	<i>Apparent frequency in the spectrum(Hz)</i>	<i>Distortions factor of each frequency %</i>
50	0	550	0
100	23.4	600	7
150	0	650	0
200	29.3	700	0
250	0	750	0
300	0	800	0
350	0	850	0
400	Fundamental	900	0
450	0	950	0

500	25	1000	0
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Table4: Distortion factor of apparent frequencies appears in the spectrum of AC to AC frequency multiplier

Finally after estimation of THD the value of this important value used to measure the performance of any converter used in industrial electronics, the use of enhanced comb filter technique makes THD reduced to 36% which is considered as good improvement in the performance since the THD of the converter before applying the new approach was 70%, however this improvement considered to be applicable in application of high frequency for power electronics.

5. CONCLUSION

Most important application in industrial electronic was changing of frequency of main supply by mean of switching devices, this application suffered from huge amount of total harmonic distortion, one of the techniques used to reduce THD is comb filter, this technique used with double angles of phase shifting (θ_1 and θ_2), the big problem suffered during this work is to shift non sinusoidal waveforms, the problem was overcome by shifting the source by a suitable angles that eliminate harmful frequencies in distorted output of the frequency changer, however the use of double shifting method which has been used in this paper makes good reduction in THD which decreased from **70% to 36%** which is considered to be an acceptable value with respect to previous methods which gives the same range of THD, however the disadvantage of proposed technique is the use of phase shifting transformers which have high cost to implement, so that as a future work we need to investigate a low cost phase shifter can be used to implement the proposed enhanced comb filter.

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