Indian Journal of Science and Technology, *Vol 10(30), DOI: 10.17485/ijst/2017/v10i30/115525, August 2017*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Harmonic Reduction in Single Phase AC-AC Converter

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Abstract

Objective: To design the trapezoidal pulse width modulation (TPWM) technique in order to reduce the total harmonic distortions at the output of the converter particularly the AC-AC frequency converter. **Methods/Analysis:** The proposed scheme of modulation technique is used as a modification as compared to that of an unmodulated converter. Two different parameters, namely frequency of the output from the converter and the frequency of the carrier wave, were varied to obtain the harmonic profile of the output voltage of the converter. Results were verified using MATLAB/SIMULINK software environment. **Findings:** The generalized 1 ϕ AC-AC frequency converter discussed, can be operated both as cyclo-converter (step down) and cyclo-inverter (step up). The output from these converters contain high THD values at the output. The techniques of filtering cannot be used due to numerous reasons. So the TPWM technique is implemented on the frequency converters. The least THD obtain was 0.983 % at 250 Hz for a step up configuration and THD was about 0.8019 % at 25 Hz in case of a step down converter. In addition to varying the output frequency, carrier frequency, f_c, of the carrier wave was also varied to check the THD response of the converter and it was least at 1 kHz of about 0.9316 %. In all case, magnitude of output voltage was on higher side of fundamental frequency component. **Novelty/Improvement:** Simulation results shows that the THD values have been reduced with the application of modulation techniques as compared to that of the output from an unmodulated converter which can help in various application requiring AC-AC converters.

Keywords: Cyclo-Converter, Cyclo-Inverter, Matrix Converter, Total harmonic distortion (THD), Trapezoidal Pulse Width Modulation Technique (TPWM)

1. Introduction

Power electronics is strongly related to power engineer and also to electronics engineer. Power engineer basically deals with generation, transmission, distribution and utilization of electric energy at high efficiency and convert electrical energy from one form into the next in an efficient, clean, compact and robust mode for convenient utilization. Electronics engineering, on the other hand, is concerned with reception of data and signals of very low power level, of the order of couple of watts or mill watts, without much consideration to the efficiency. The increasing need for power in every sector, calls into the use of power electronics. Power electronics here implies the use of high frequency converters whose output are rich in harmonics resulting in deficiency in efficiency[1]. The orthodox system of filtering that is generally used cannot be used as there will be problems of designing and implementation. Along with this, the usage of tuned filters also not possible as it is impractical to remove each harmonics component due to varying nature of the converter output. The only solution to this is the use of different modulation techniques. Several modulation techniques are proposed in the literature to reduce the harmonic in the converter circuit are sinusoidal pulse modulation technique[2], delta modulation[3-8], space vector modulation[9-10]

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and staircase modulation[11-12]. Trapezoidal modulation has been discussed and compared[13-15]. Different process in implementation of AC-AC converters are also available in literatures[16-19].

2. Principle of Operation

Figure 1 displays the power supply circuit of the proposed frequencies converters using 8 IGBT switches separated into two group, first being the Positive Converter (PC) and second being Negative Converter (NC), coupled in anti-parallel. IGBT switches are utilized because of its very high switching abilities and very high current carrying abilities necessary for extremely high power applications. Thus the desired output can be obtained by proper toggling of the IGBT switches ensuring the switches do not short-circuit the voltages source and do not open-circuit the current source. There is a firing sequence for a known value of N_r, to create the high or low frequency output, f_0. The output frequency of the cyclo-inverter (step up operation) is $f_0 = f_i \times N_r$ and on other hand output frequency for cyclo-converter (step down operation) is, $f_0 = f_i / N_r$, where f_i is the input / source frequency and N_r is a number that describes the amount of times the output frequency is more value or less value than input frequency. The same leg switches should not be triggered at same instant else they will sort circuit the voltage source.

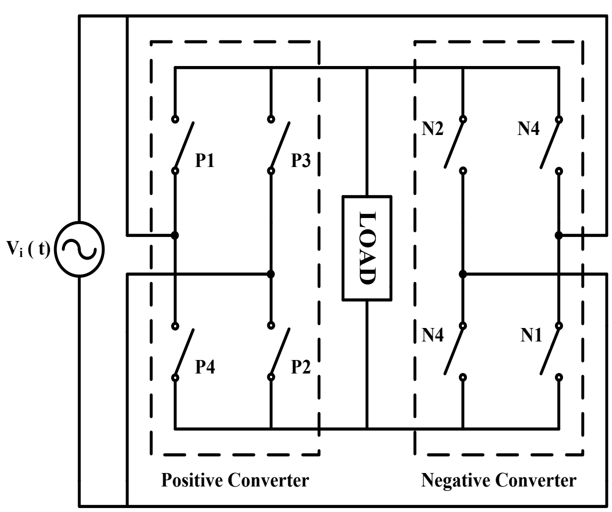

Figure 1. Power circuit of frequency converter.

Frequency converter can be utilized both as a step up converter and step down converter. In order to obtain a positive output from the converter with input also being positive, the switch pairs P1 and P2 operates. Input being positive indicates that the positive half cycle of the AC waveform is being considered. Now taking input as positive if the required output from the converter is negative then switch pairs N1 and N2 starts their operation. The same can also be extended for the negative half cycle of the AC input wave, i.e. for the an output positive requirement, switches P3 and P4 toggle together and for a negative output requirement switch pairs N3 and N4 will complete the circuit.

In order to generate trigger pulses for the suggested frequencies converters, eight primary signals are necessary which will serve as the signals for the IGBT switch pairs. These signals for cyclo-inverter and cyclo-converter are shown in Figure 2 and Figure 3 respectively. Trigger signals are generated from two signals namely X1 and X2 which are of 50 Hz and 150 Hz in case of cyclo-inverter. The signals X1' and X2' are the negation, NOT gate, of the signals X1 and X2. Now with these four signals rest signals are obtained just by using an AND gate. The signal X1X2 is obtained by simply passing X1 and X2 signals through an AND gate. These signals are applied to switches P1 and P2. Similarly signals X1X2', X1'X2 and X1'X2' are generated through simple mechanism are given as triggering signals to the switch pairs N1N2, P3P4 and N3N4 respectively. The same mechanism can be extended for the cyclo-converter configuration with step down conversion.

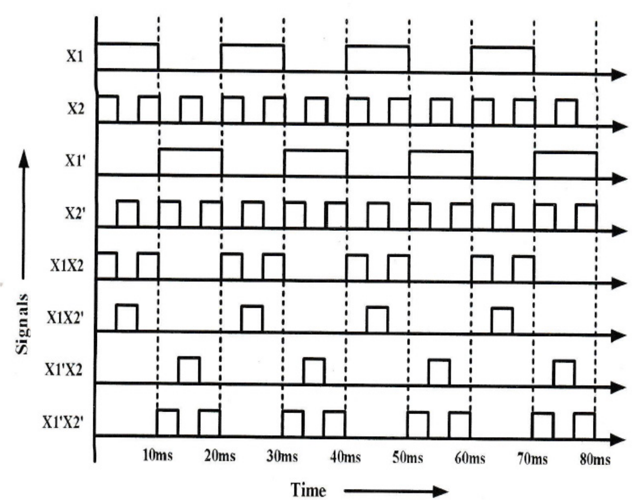

Figure 2. Basic trigger signals for cyclo-inverter (Nr =3).

2.1 Cyclo-Converter Operation

For a cyclo-converter or step down operation, to create an output frequency half the input frequency, a firing order that is assumed is P1P2, P3P4, N1N2, N3N4, and so on.

Output voltage wave can be seen from Figure 4 and Figure 5 as positive and negative output respectively. In addition to this, the firing sequence followed for output frequency one third the input frequency is P1P2, P3P4, P1P2, N3N4, N1N2, N3N4, and so on.

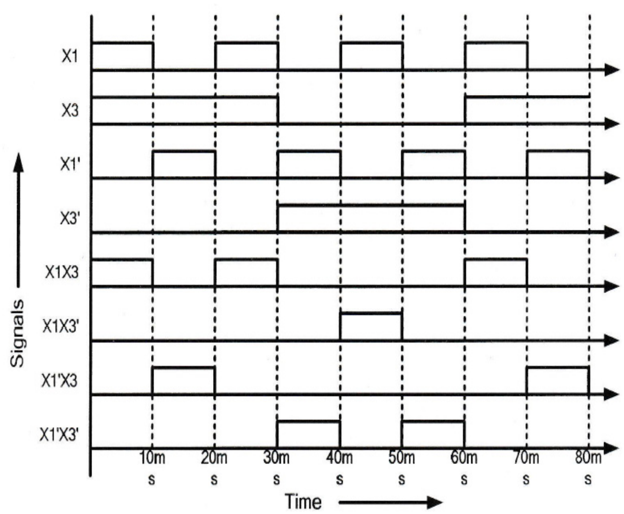

Figure 3. Basic trigger signals for cyclo-converter (Nr = 1/3).

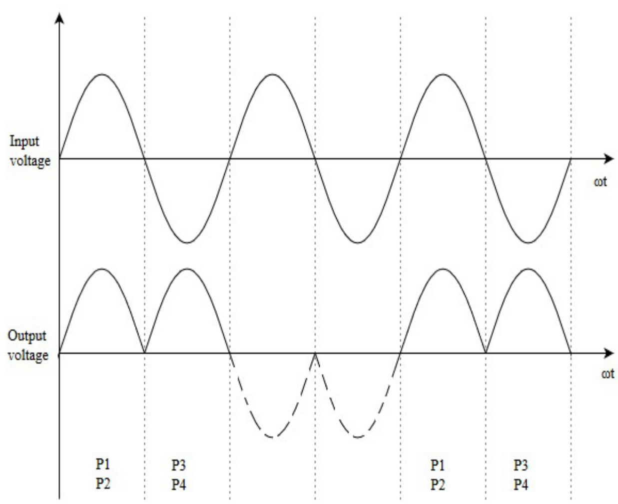

Figure 4. Positive output of cyclo-converter operation.

2.2 Cyclo-Inverter Operation

For the cyclo-inverter operation, otherwise step up method, to create an output frequency twice the input frequencies a firing order that follows is P1P2, N1N2, P3P4, N3N4, and so on. Output voltage wave can be seen from Figure 6 and Figure 7 representing positive and negative output for the cyclo-inverter respectively. Moreover the firing sequence followed for output frequency thrice the input frequency is P1P2, N1N2, P1P2, N3N4, P3P4, N3N4, and so on.

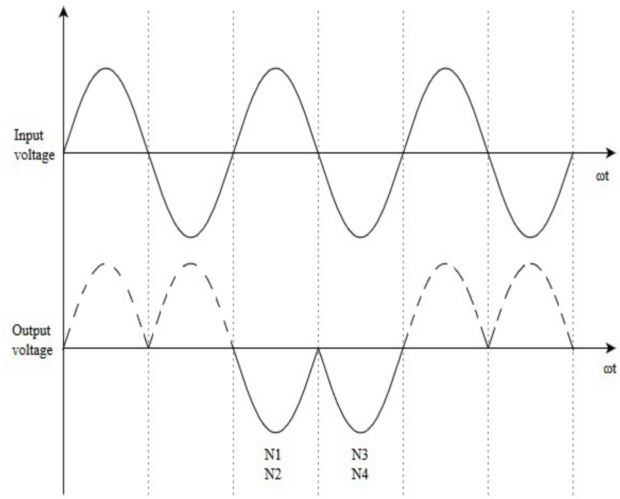

Figure 5. Negative output of cyclo-converter operation.

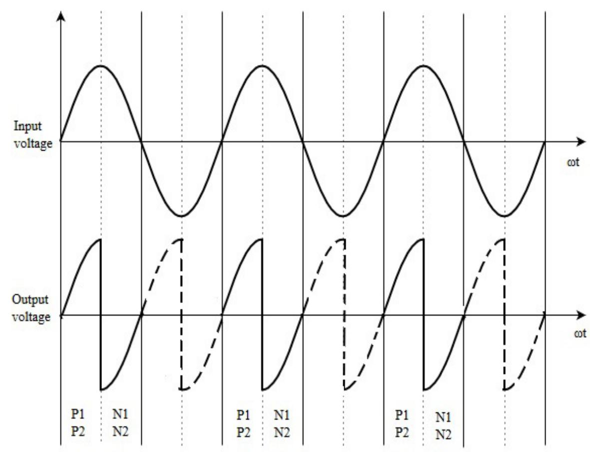

Figure 6. Positive output of Cyclo-inverter operation.

3. Trapezoidal Pulse Width Modulation Technique (TPWM)

In trapezoidal pulse width modulations technique, sinusoidal modulating signals of SPWM is swapped with a trapezoidal wave. This involves the comparison of this trapezoidal wave with a high frequency triangular signal. The points of intersection are taken into consideration. Pulses are generated whenever the magnitude of trapezoidal modulation signal is more than that of the magnitude of the triangular carrier signal. Figure 8 demonstrates the trapezoidal modulations technique to obtain the modulated pulses. These pulses obtained after comparison are then combined with the triggering pulses for all the IGBT switch pairs as explained in the above section, in order to make the switches operate as desired. Figure 9 shows the basic block diagram showing the process for generating the IGBT gate pulses.

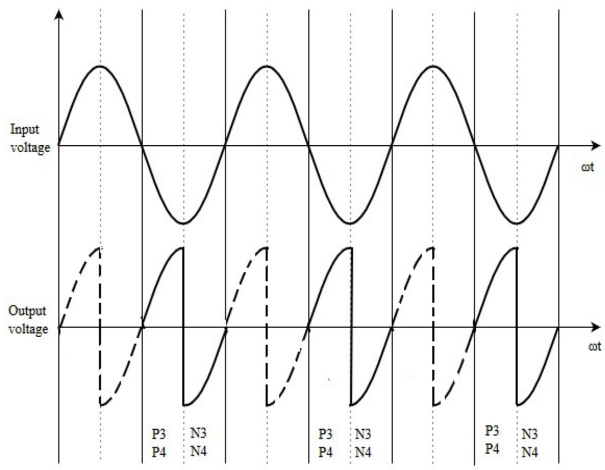

Figure 7. Negative output of cyclo-inverter operation.

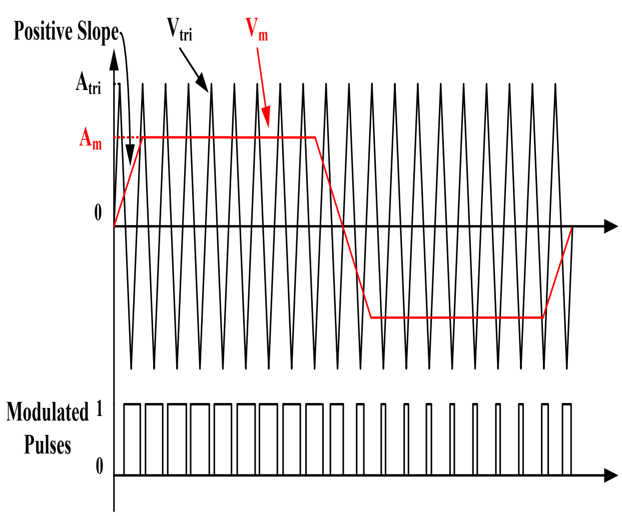

Figure 8. Modulated Pulses from TPWM Technique.

4. Simulation Results

The sole purpose of the research is to reduce the harmonic content at the output of the unmodulated converter. So it becomes utmost important for us to obtain and understand the performance of an unmodulated AC-AC converter where no modulation technique has been applied. Figure 10 demonstrates the output of the cyclo-inverter with its input supply frequency of 50 Hz and frequency at the output of the converter being 250 Hz. The %THD obtained in this case is around 32% which is very high as per the acceptable limits concerned with THD.

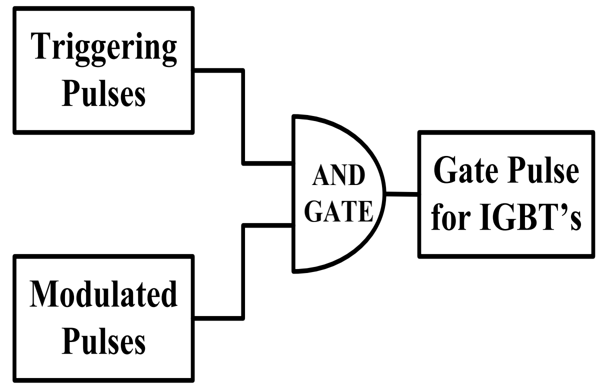

Figure 9. IGBT gate pulse generation.

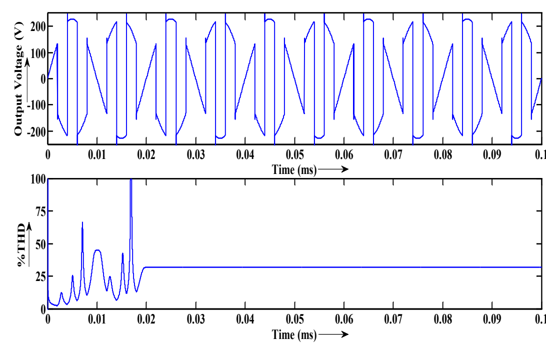

Figure 10. Output Voltage & %THD waveform for unmodulated cyclo-inverter (V_o = 250 Hz).

Trapezoidal Pulse Width Modulation (TPWM) technique is implemented on frequency converters to decrease the harmonics distortions in output. The converters are realized using MATLAB / SIMULINK software. A restive load of R = 10 Ω is taken and different parameters like output frequencies of the converters and carrier frequencies of carrier signals are varied and simulation results are obtained for each case. The output frequency of the frequency converter is varied and all the other parameters are kept constant.

4.1 Varying the Output Frequency, f_0

4.1.1 Cyclo-inverter Operation (Step Up)

Step Up operation or the cyclo-inverter operation of the AC-AC frequency converter is obtained from MATLAB environment. Figure 11 shows the output voltage and %THD for the variable output frequency of 250 Hz. The %THD obtained is 0.983 which is less than that of the unmodulated case. Figure 12 demonstrates the waveforms for an output frequency of 950 Hz. Similarly output of other frequencies can also be obtained as shown in Table 1.

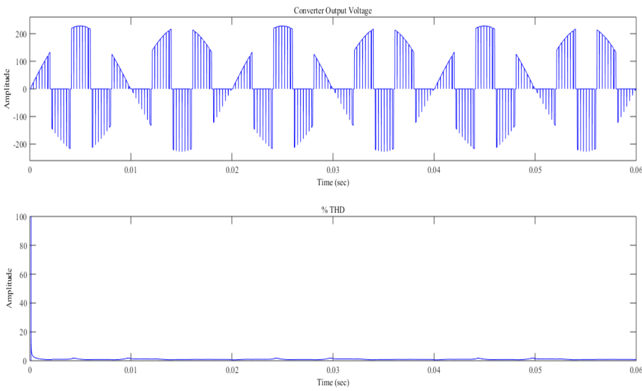

Figure 11. Output and % THD of cyclo-inverter with f_0 = 250 Hz.

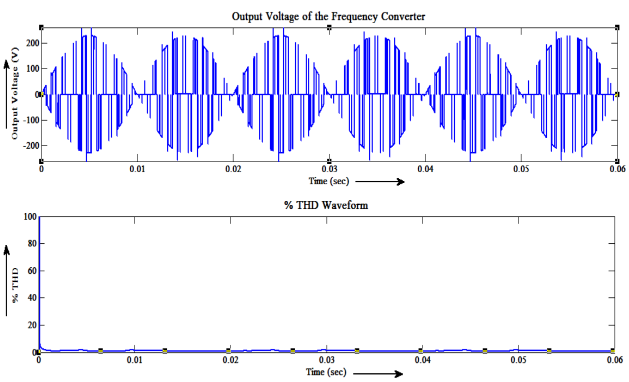

Figure 12. Output and % THD of cyclo-inverter with f_0 = 950 Hz.

Table 1. % THD of cyclo-converter and cyclo-inverter at varying output frequency, f_0

OUTPUT FREQUENCY (Hz)	MEAN %THD	RMS %THD
5	0.8254	0.8911
10	0.8176	0.8765
12.5	0.8050	0.8665
25	0.8019	0.8562
50	0.8664	0.945
100	1.141	1.253
150	3.95	8.944
200	1.15	1.192
250	0.983	1.017
350	1.743	1.926
450	5.961	13.95
750	12.68	19.29
950	12.98	14.29

4.1.2 Cyclo-converter Operation (Step Down)

As in case of step up operation, the results for step down or cyclo-converter operation can also be obtained to check the % THD. Figure 13 and Figure 14 shows the waveform for an output frequency of 25 Hz and 5 Hz respectively.

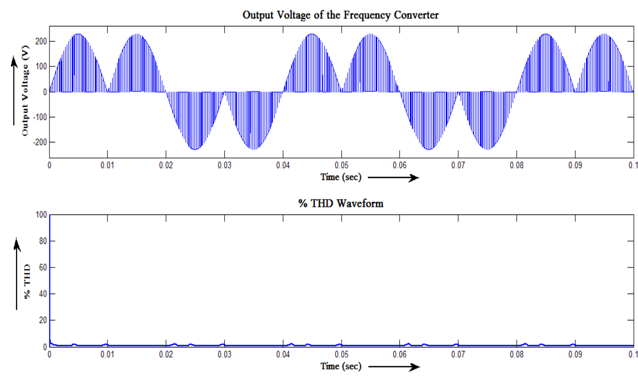

Figure 13. Output and %THD of Cyclo-converter (f_o = 25 Hz).

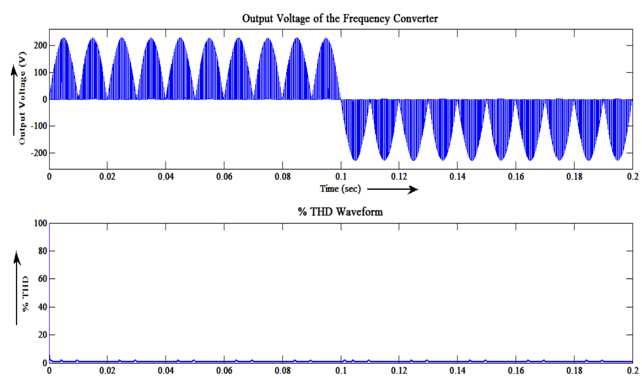

Figure 14. Output and %THD of Cyclo-converter (f_o = 5 Hz).

4.2 Varying the Carrier Frequency, f_c

Until now only output frequency f_0 was varied and the output waveforms along with the % THD was obtained. The second parameter that is the varied is the carrier frequency, *fc* of the high frequency triangular wave. Similar results can be obtained as in case of varying the output frequency. The carrier frequency was varied from 1 kHZ to 10 kHz and the %THD values are tabulated in Table 2 for the reference.

Table 2. % THD of cyclo-converter and cyclo-inverter at varying carrier frequency, f_c

CARRIER FREQUENCY (Hz)	MEAN %THD	RMS %THD
1000	0.9316	0.9767
1500	0.9372	0.9834
2000	0.9492	0.9906
2500	0.9843	1.02
3000	0.9796	1.014
3500	0.983	1.017
4000	0.9821	1.017
4500	0.9781	1.012
5000	0.9804	1.014
6000	0.9772	1.011
7000	0.9747	1.008
8000	0.9735	1.007
9000	0.9728	1.006
10000	0.972	1.005

5. Conclusion

Different modulation technique, namely, trapezoidal pulse width modulation arrangement has been applied to a generalized frequency converter for both cyclo-inverter (step up) operation and cyclo-converter (step down) operation to decrease the harmonic content in output, which is found in case of unmodulated output of the converter. The conventional filtering technique can't be utilized as it will have issue in both design and cost-effectiveness when it is applied to a variable frequency system. Also, due to changing frequency at the output of the converter, use of tuned filter for eliminating each harmonic component is not at all feasible. The solution for his is to utilize of modulation techniques. The modulation method is easy to simulate in MATLAB/SIMULINK. When the output frequency, f_o was varied, output of the converter contained harmonics of 0.983 % at 250 Hz for a step up connection while the harmonic content was about 0.8019 % at 25 Hz in case of a step down converter. In addition to varying the output frequency, carrier frequency, f_c, of the carrier wave was also varied to check the THD response of the converter and it was least at 1 kHz of about 0.9316 %.

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