

Zero Current Switched Cyclo-Inverter

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Abstract— This paper proposes a new zero current switched, IGBT based cyclo-Inverter, capable of converting power at the main frequency to a higher frequency. An auxiliary switch along with an inductor is used to commutate the IGBT at zero current in order to decrease total internal losses and total harmonic distortion factor in the converter. The proposed converter is compared with the conventional cyclo-inverter and it has been demonstrated that the losses has been reduced approximately 50% by this new switching technique. A prototype of the converter is developed in the lab for verification of the results.

Keywords— Cyclo-Inverter, IGBT, Triggering Pulses, Zero Crossing Detector (ZCD).

I. Introduction

Cyclo-inverter is ideal for high frequency generation without any intermediate DC link. It finds its application in induction heating, fluorescent lighting, ballast, high frequency power supplies and so many other applications where high frequency reduces the size of equipment. A wide variety of cyclo-converter circuits are possible depending upon the output frequency and voltage [1-4]. Simplest is the single phase centre-tapped transformer configuration cyclo-inverter [5]. The output voltage of a hard switched cyclo-inverter is fairly rich in harmonics [6] and the switching losses are also high which do not only adversely affect the inverter efficiency but the additional heat sinking need increases its size and weight [7]. This can be improved by using resonant cyclo-inverter where the switches can be configured to operate at either zero current or zero voltage points in the waveform, and thus greatly reducing their stress levels [8].

In this paper a zero voltage switched cyclo-inverter has been proposed where zero voltage switching is achieved by addition of a resonant inductor along with an auxiliary power semiconductor switch that decreases total internal losses as well as total harmonic distortion factor in order to increase its efficiency. Trigger requirements are obtained for single-phase centre tapped transformer configuration. Results are presented for R-L load where resonant inductance is used as a part of load.

II. Proposed ZCS Cyclo-Inverter

Figure 1 shows the detailed circuit of the proposed ZVS cyclo-inverter. It consists of two converters a positive converter PC and a negative converter NC connected in anti parallel. Two types of switches have been used: the Main switches (i.e. T1M, T2M, T3M, and T4M) and Auxiliary (Energy transfer) switches (i.e. T1A, T2A, T3A, and T4A). Main switches take energy from source and supply to the load while Auxiliary switches are used to transfer the potential energy to the load that is stored in the inductor. Output is obtained through proper conduction of IGBTs in the two input cycles. For example, to generate an output frequency double to the input frequency a firing sequence of 14, 23, 14, ..., and so on, is adopted whereas for an output frequency of three time that of input frequency, this firing sequence becomes 141, 323, 141, ..., and so on. Thus, the output of converter will have a frequency, $f_o = f_i \times N_r$ where N_r is an integer and f_i is the source frequency.

When the main switch T_{1M} turns ON during the period T_{ON} , current flowing through the source is responsible for charging of inductor. The voltage across the inductor is in the form of magnetic field.

$$V_L = V_{ac}(1 - e^{-Rt/L}) \quad (1)$$

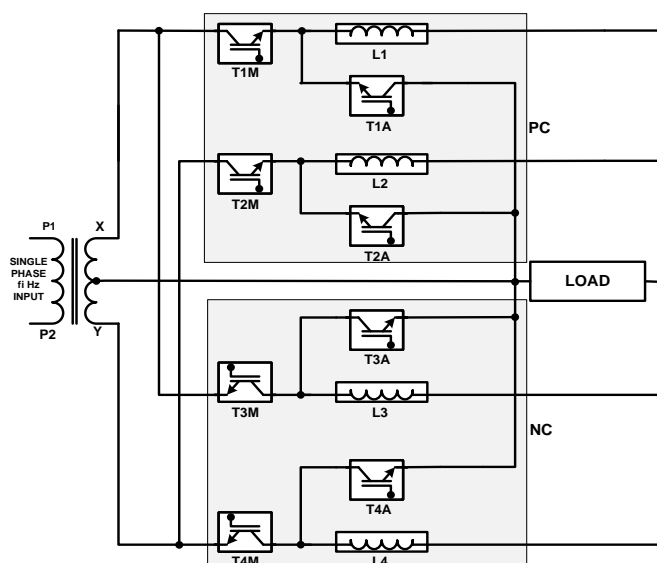


Fig. 1. IGBT Based ZCS Cyclo-inverter

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Figure 2 shows the idealized waveform with a firing sequence of 14, 23, 14, ..., for an output frequency double to the input frequency for a purely resistive load.

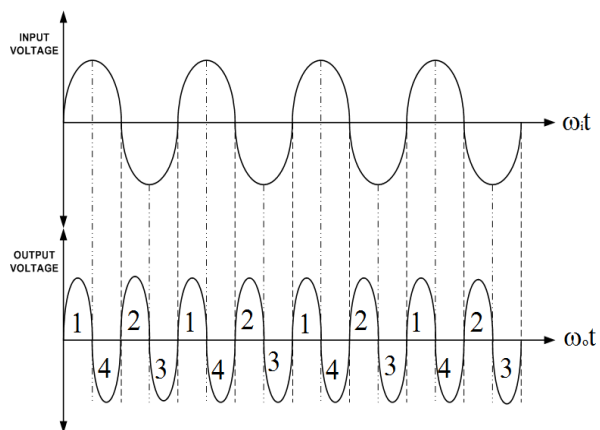


Fig. 2. Idealized Waveform of Frequency Multiplier for $f_{or} = f_i \times 2$

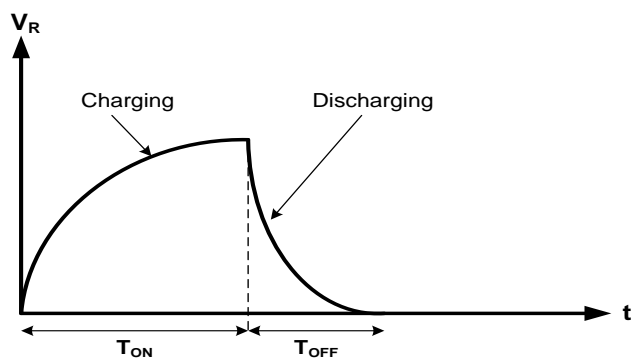


Fig. 3. Idealized Waveform for Charging and Discharging of inductor

At $t = T_o/4$, when main switch turns OFF, the auxiliary switch is turned ON, and stored energy in the inductor is dissipated across the load according to the equation given by (2).

$$V_R = i \times R \times e^{-Rt/L} \quad (2)$$

When all the stored energy is dissipated, the next main switch T2M is turned on at zero current. In this way each time the inductor connected in series with the switch will store the energy and then dissipate it to the load through corresponding auxiliary switch and thus attain zero current switching.

III. Principle Of Triggering Pulse Generation

Figure 4 shows the schematic details of the trigger scheme to generate the required high frequency output with zero current switching.. The input signal having frequency f_i , which has to be converted into high frequency signal, is stepped down from a step down transformer and converted into a square signal using Zero Crossing Detector (ZCD) in an input interfacing circuit. Two reference signals, having frequency f_o and $2f_o$ are derived directly from square wave generators. These three signals are synchronized in a synchronization circuit. The output of synchronizing circuit is fed to a pulse generator block which generates the required pulse for IGBT. The signal with frequency $2f_o$ with 70% duty ratio is used to transfer the energy from the inductor to the load when main switch is turned OFF. The output of pulse-wave generator is fed to the driver circuit which isolates and boosts the level of pulses. The isolated pulses thus obtained, drives the gate of individual IGBTs.

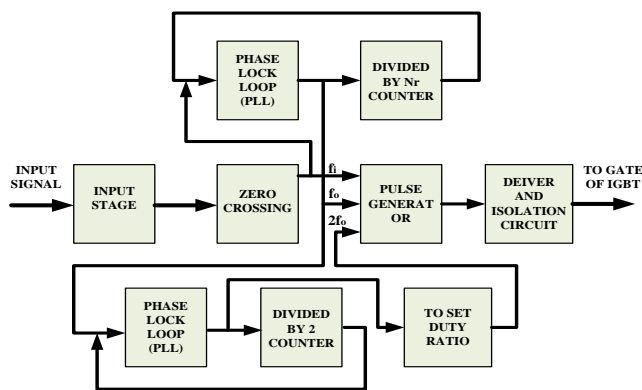


Fig. 4. Block Diagram for trigger pulse generation

The triggering pulses are different for the same IGBT for different values of N_r . For example for $N_r = 3$, the gating pulses are generated using three set of pulses having frequencies 50 Hz (input supply frequency), 150 Hz (N_r times the input supply frequency that is desired output frequency) and 300 Hz ($2 \times N_r$ times the input supply frequency that is desired output frequency) as shown in Figure 5.

Let X_1 represents the pulses at a frequency of 50 Hz, X_2 of 150 Hz and X_3 of 300 Hz. Then ANDing of X_1 , X_2 and X_3 will result the pulses required by the IGBT T1. Further if this X_2 is inverted by a NOT gate, then the ANDing of X_1 , $\overline{X_2}$ and X_3 will result the pulses required by the IGBT T4. Similarly, the pulses for other IGBTs are obtained as illustrated in Figure 6. The next section illustrates the MATLAB simulation of this technique.

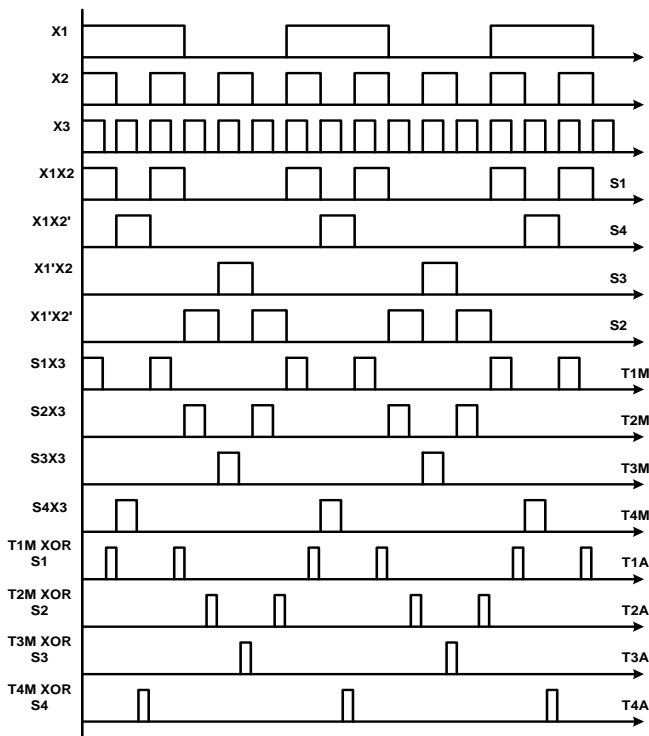


Fig. 5. Gate pulses for Different IGBTs

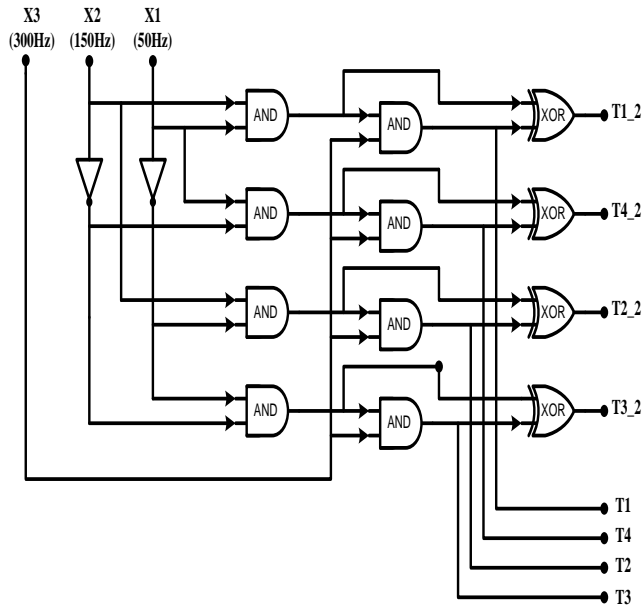
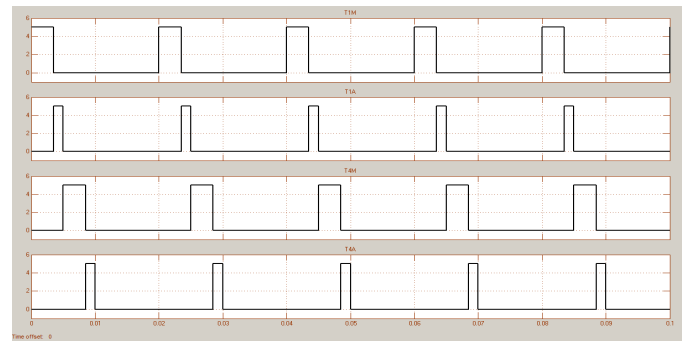


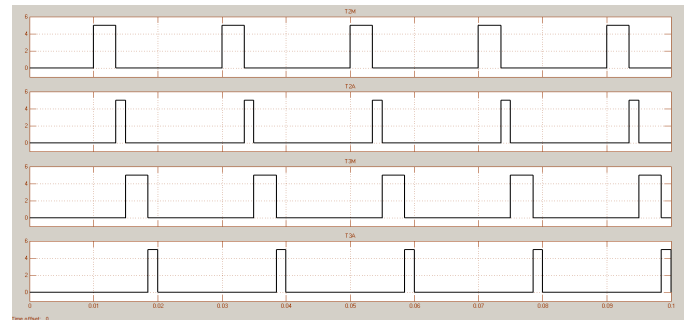
Fig. 6. The Circuit Diagram Generating the Gate pulses

iv. Simulation Results

MATLAB/Simulink has been used to design and test the circuit. Figure 7, shows the gate pulses generated to trigger the main IGBTs & auxiliary IGBTs. T1M to T4M are the trigger pulses for Main IGBTs while T1A to T4A are used to trigger Auxiliary IGBTs. Figure 7, shows the pulses for positive converter (PC) and negative converter (NC) respectively.



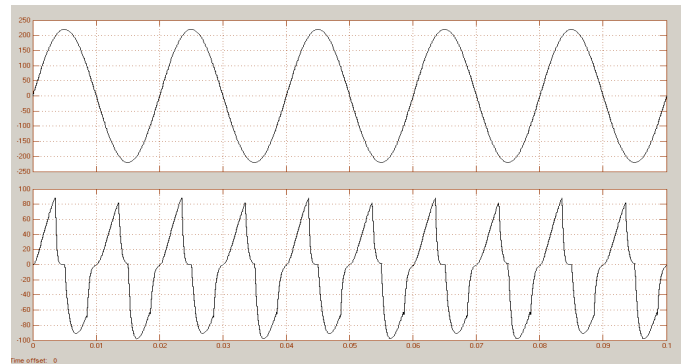
(a) Positive Converter (PC) pulses



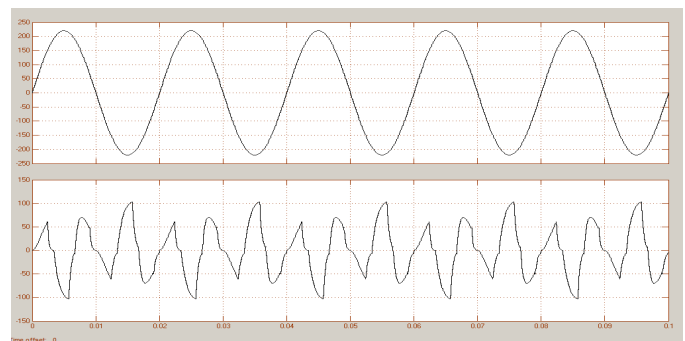
(b) Negative Converter (NC) pulses

Fig. 7. Gate pulses for IGBTs

Figure 8, illustrates the output of Cyclo-inverter for frequency $f_o = 100$ Hz, and $f_o = 150$ Hz. A comparative analysis with a Conventional Cyclo-inverter and Proposed Cyclo-inverter is given in Figure 9.

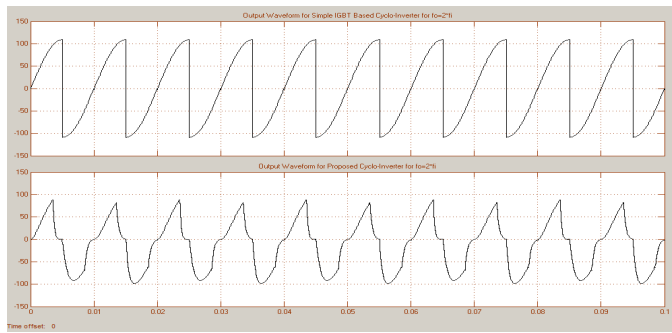


(a) $f_o = 100$ Hz

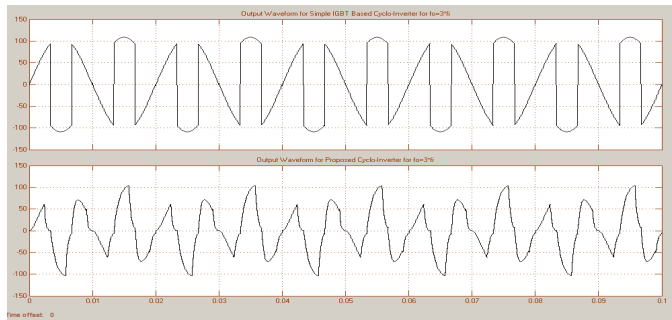


(c) $f_o = 150$ Hz

Fig. 8. Input - Output waveform

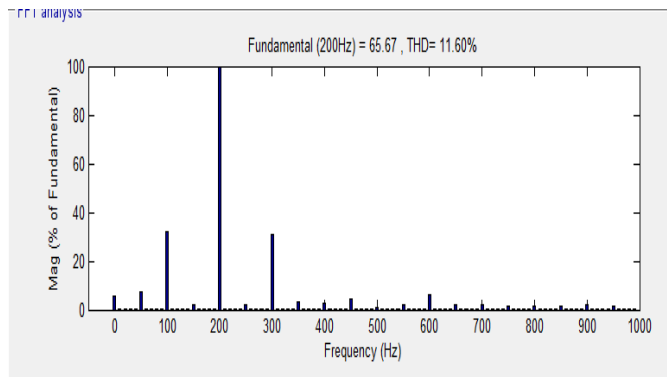


(a) $f_o = 100$ Hz

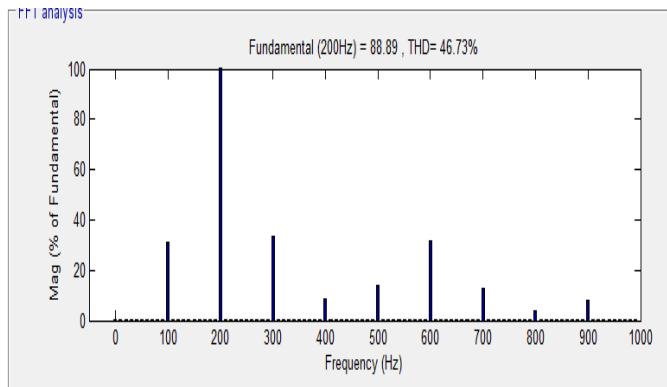


(b) $f_o = 150$ Hz

Fig. 9. Comparative Performance of Output Waveform



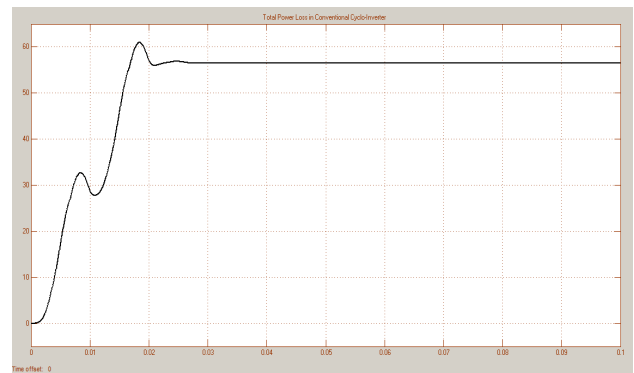
(a)



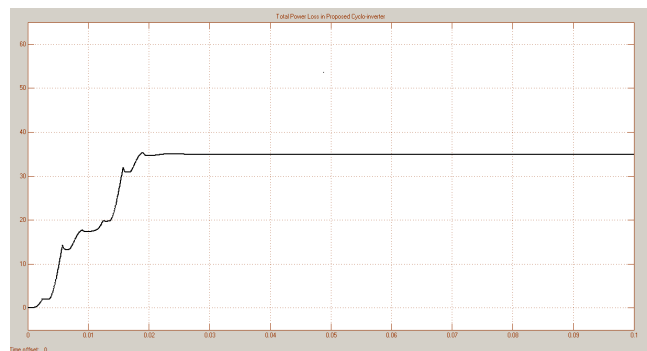
(b)

Fig. 10. Total Harmonic Distortion in (a) Proposed Cyclo-inverter (b) Conventional Cyclo-Inverter

Total Harmonic Distortion of proposed cyclo-inverter and conventional Cyclo-Inverter is illustrated in Figure 10. It can be observed from this figure that, though the side band harmonics are somewhat increased in the proposed converter but at the same time the third harmonic in the proposed converter has been reduced considerably as compared to conventional cyclo-inverter. Figure 11 depicts the total loss in the cyclo-inverter. It has been observed that the total loss calculated in the proposed cyclo-inverter has been reduced to half as compared to that of conventional cyclo-inverter. This increases the efficiency of cyclo-inverter. The converter is tested from 100 Hz to 10 KHz and the performance of cyclo-inverter has been found to be improved in each case.



(a)



(b)

Fig.11. Total Power Loss at $f_o = 3 \cdot f_i$ for (a) Conventional Cyclo-Inverter (b) Proposed Cyclo-inverter

v. Conclusion

A new zero voltage switched cyclo-inverter has been proposed which generates an output frequency that is high to the input frequency. A methodology is obtained for generating trigger signal such that each IGBT is turned OFF at zero voltage. This reduces the total power losses in the circuit and total Harmonic distortion also been reduced. The operation of proposed system has been found satisfactory.

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