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Decoupled Inverter Fed - Open end Winding Induction Motor Drive for Three Level Voltage SPWM Strategy

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***Abstract**: An open-end winding induction motor, fed by two 2-level inverters connected at either end produces space vector locations, identical to those of a conventional 3-level inverter. In this paper, two switching algorithms are proposed to implement space vector PWM for the dual inverter scheme. The proposed algorithms do not employ any look-up tables. The time consuming task of sector identification is altogether avoided in both these algorithms. The proposed algorithms employ only the instantaneous reference phase voltages for the implementation of the space vector PWM. An equal switching duty for both the inverters is also ensured with one of the proposed PWM strategies. Also, it is observed that the speed torque and voltages in motor phases is significantly reduced with the proposed PWM strategies.*

I. Introduction

Three-level inversion has been extensively researched in the past and several circuit topologies were suggested. Of these topologies, the neutral point clamped topology [1], the flying capacitor topology [2] and the H-bridge topology [3] have become popular. Recently, a circuit configuration to obtain three-level inversion by cascading two 2-level inverters has also been suggested [7]. Stemmler's pioneering work has shown that three-level inversion can be achieved by the open-end winding connection of an induction motor with two two-level inverters feeding the motor from either end [4]. In this work [4], sine-triangular modulation technique is employed for the control of inverters. Various derivatives of this power circuit and/or the associated PWM schemes are also reported in the recent past [6]-[14]. The inverters may be controlled with space vector modulation technique as it improves the DC-bus utilization compared to the sine-triangle modulation technique. A space vector modulation technique for the open-end winding topology has been suggested in [6]. In this work [6], the implementation of space vector modulation requires sector identification, which is a time consuming task. Further, this switching scheme employs lookup tables, enhancing the memory requirement with a typical Digital implementation.

In this paper, two space vector modulation techniques are suggested, which obviate the need for the sector identification. Also these PWM schemes do not employ any look-up table, thus reducing the memory requirement.

This section gives a general background and review of the paper or work done by other engineers in the field. It should be well supported by citations. Moreover, the citations are served as a guide for those who want to learn more about the field.

Fig.1 shows the basic open-end winding induction motor drive operated with a single power supply. The symbols $v_{BO,}$ $v_{AO,}$ and v_{CO} denote the pole voltages of the inverter-1. Similarly, the symbols $v_{A'O}$ and $v_{B'O}$ 'denote the pole voltages of inverter-2. The space vector locations from individual inverters are shown in Fig.2. The numbers 1 to 8 denote the states assumed by inverter-1 and the numbers 1' through 8' denote the states assumed by inverter-2 (Fig.2).

Table-1 summarizes the switching state of the switching devices for both the inverters in all the states. In Table-1, a '+' indicates that the top switch in a leg of a given inverter is turned on and a '-' indicates that the bottom switch in a leg of a given inverter is turned on.

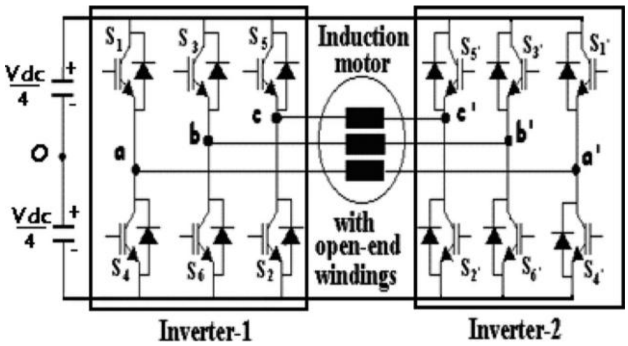


Fig1: The primitive open end winding induction motor drive

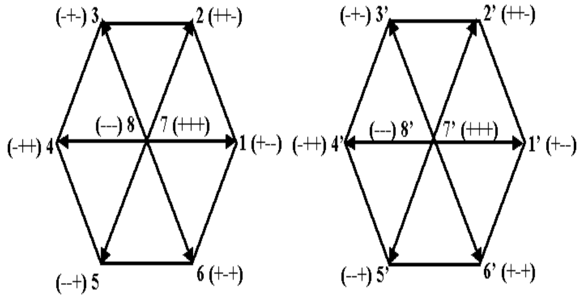


Fig 2: Space vector locations of inverter-1 (Left) and inverter-2 (Right)

As each inverter is capable of assuming 8 states independently of the other, a total of 64 space vector combinations are possible with this circuit configuration. The space vector locations for all space vector combinations of the two inverters are shown in Fig.3. In Fig.3, |OA| represents the DC-link voltage of individual inverters, and is equal to Vdc/ 2 while |OG| represents the DC-link voltage of an equivalent single inverter drive, and is equal to V dc

Fig.1 shows the basic open-end winding induction motor drive. It cannot be operated with a single power supply, due to the presence of zero-sequence voltages (common-mode voltages) [5], [6]. Consequently, a high zero-sequence current would flow through the motor phase windings, which is deleterious to the switching devices and the motor itself. To suppress the zero-sequence components in the motor phases, each inverter is operated with an isolated dc- power supply as shown in Fig.4. From the Fig.4, when isolated DC power supplies are used for individual inverters, the zero-sequence current cannot flow as it is denied a path. Consequently, the zero-sequence voltage appears across the points 'O' and 'O''. The zero-sequence voltage resulting from each of the 64 space vector combinations is reproduced in from [6] to facilitate an easy reference.

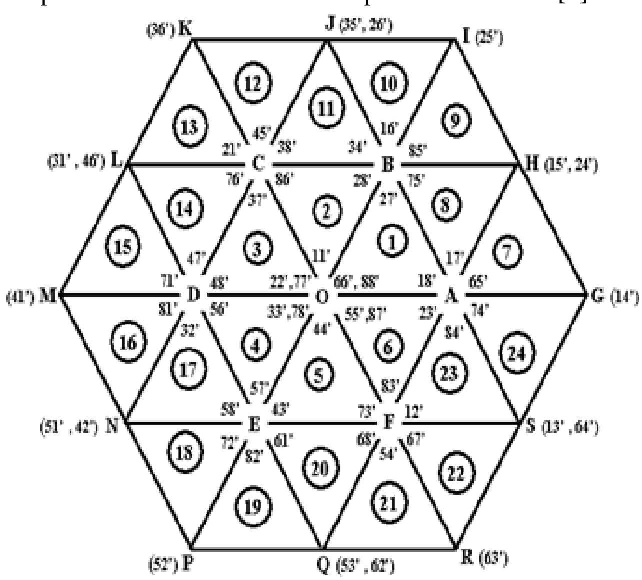


Fig 3: Resultant space vector combinations in the dual-inverter scheme

In Fig.5, the vector OT represents the reference vector (also called the reference sample), with its tip situated in sector-7 (Fig.3). This vector is to be synthesized in the average sense by switching the space vector combinations situated in the closest proximity (the combinations situated at the vertices A, G and H in the present case) using the space vector modulation technique. In the work reported in reference [7], the reference vector OT is transformed to OT' in the core hexagon ABCDEF by using an appropriate coordinate transformation, which shifts the point A to point O. In the core hexagon, the switching timings of the active vectors OA, OB and the switching time of the null vector situated at O to synthesize the transformed reference vector OT' are evaluated. The switching algorithm described in reference [5] is employed to evaluate these timings. These timings are then employed to produce the actual reference vector OT situated in sector-7 by switching amongst the switching.

Table – 1: Switching states of the individual inverters

State of Inverter-1	Switches turned on	State of Inverter-2	Switches turned on
1 (+ - -)	S_6, S_1, S_2	1' (+ - -)	$S_{6'}$, $S_{1'}$, $S_{2'}$
2 (+ + -)	S_1, S_2, S_3	2' (+ + -)	$S_{1'}$, $S_{2'}$, $S_{3'}$
3 (- + -)	S_2, S_3, S_4	3' (- + -)	$S_{2'}$, $S_{3'}$, $S_{4'}$
4 (- + +)	S_3, S_4, S_5	4' (- + +)	$S_{3'}$, $S_{4'}$, $S_{5'}$
5 (- - +)	S_4, S_5, S_6	5' (- - +)	$S_{4'}$, $S_{5'}$, $S_{6'}$
6 (+ - +)	S_5, S_6, S_1	6' (+ - +)	$S_{5'}$, $S_{6'}$, $S_{1'}$
7 (+ + +)	S_1, S_3, S_5	7' (+ + +)	$S_{1'}$, $S_{3'}$, $S_{5'}$
8 (- - -)	S_2, S_4, S_6	8' (- - -)	$S_{2'}$, $S_{4'}$, $S_{6'}$

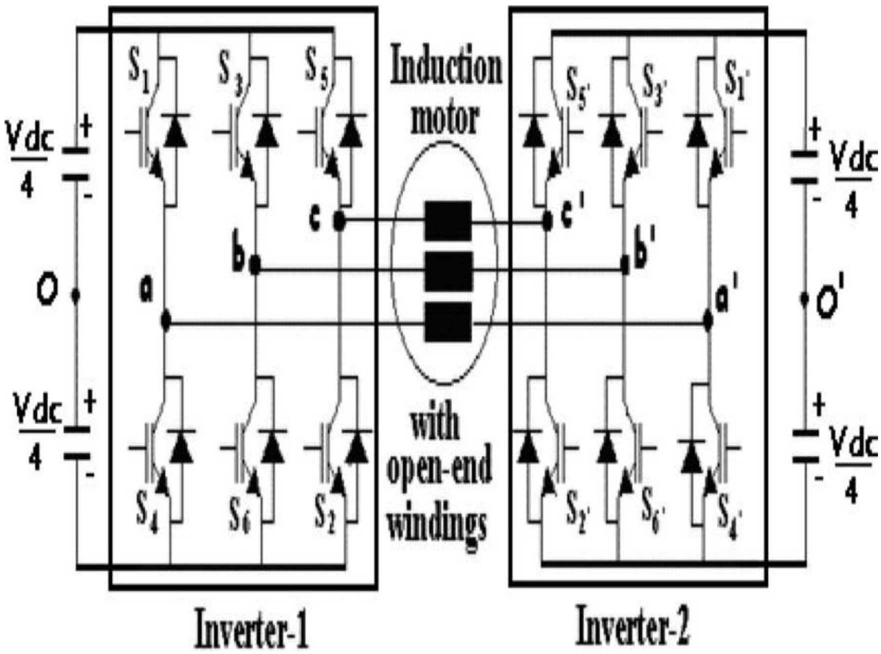


Fig 4: A dual-inverter fed open-end winding induction motor drive with isolated power supplies

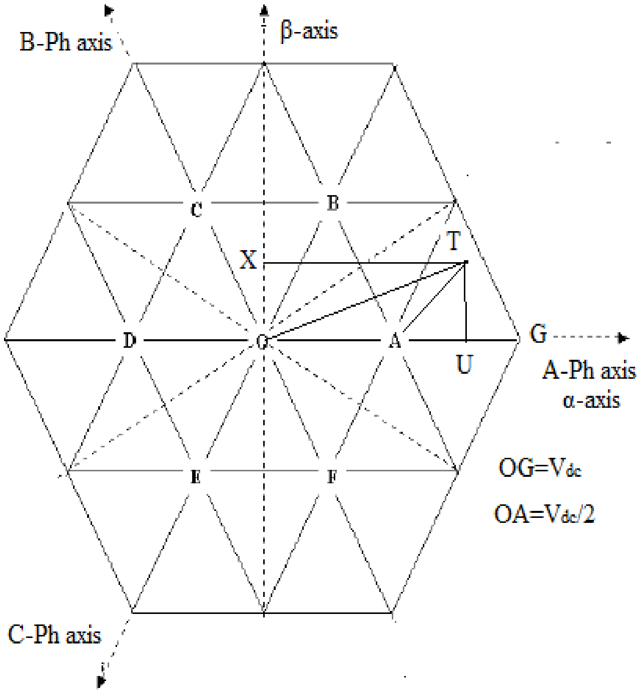


Fig 5: Principle of biasing inverter PWM strategy

II. Simulation Of The Proposed Scheme

The Simulation is carried out using MATLAB and the results are verified by implementing the decoupled scheme through dual two level inverters on a 1kW Open end winding Induction motor drive.

The proposed Scheme involves two, two level Inverters which are collectively feeding the open ended winding of the induction motor by proportionately dividing the reference voltage among themselves. Here lies an important difference between the proposed method and the one used in the conventional SVPWM scheme.

In the present case the pole voltages are separately consumed from each inverter which is enabled to realize half of the reference voltage and then difference among of both these pole voltages is captured which serves as a phase component and is thus fed to the induction motor phases. Where as in the equivalent conventional scheme (i.e. a scheme in which a single two level inverter feeds a motor), the pole voltages of the inverter are initially converted into phase voltages and then these are fed to the three phases of the induction motor.

The block representation of the proposed scheme and that of a conventional SVPWM scheme is as shown in. The powerful block represented in both these schemes is used to carry out the FFT analysis.

When the induction motor is fed from the corresponding phase voltages then the output phase currents and the torque & speed parameters are separately consumed from which the current harmonics are analyzed with each other.

The d-q model of a three phase Induction motor in a stationary frame is represented as shown in the Fig (6) from which the proposed scheme is analyzed.

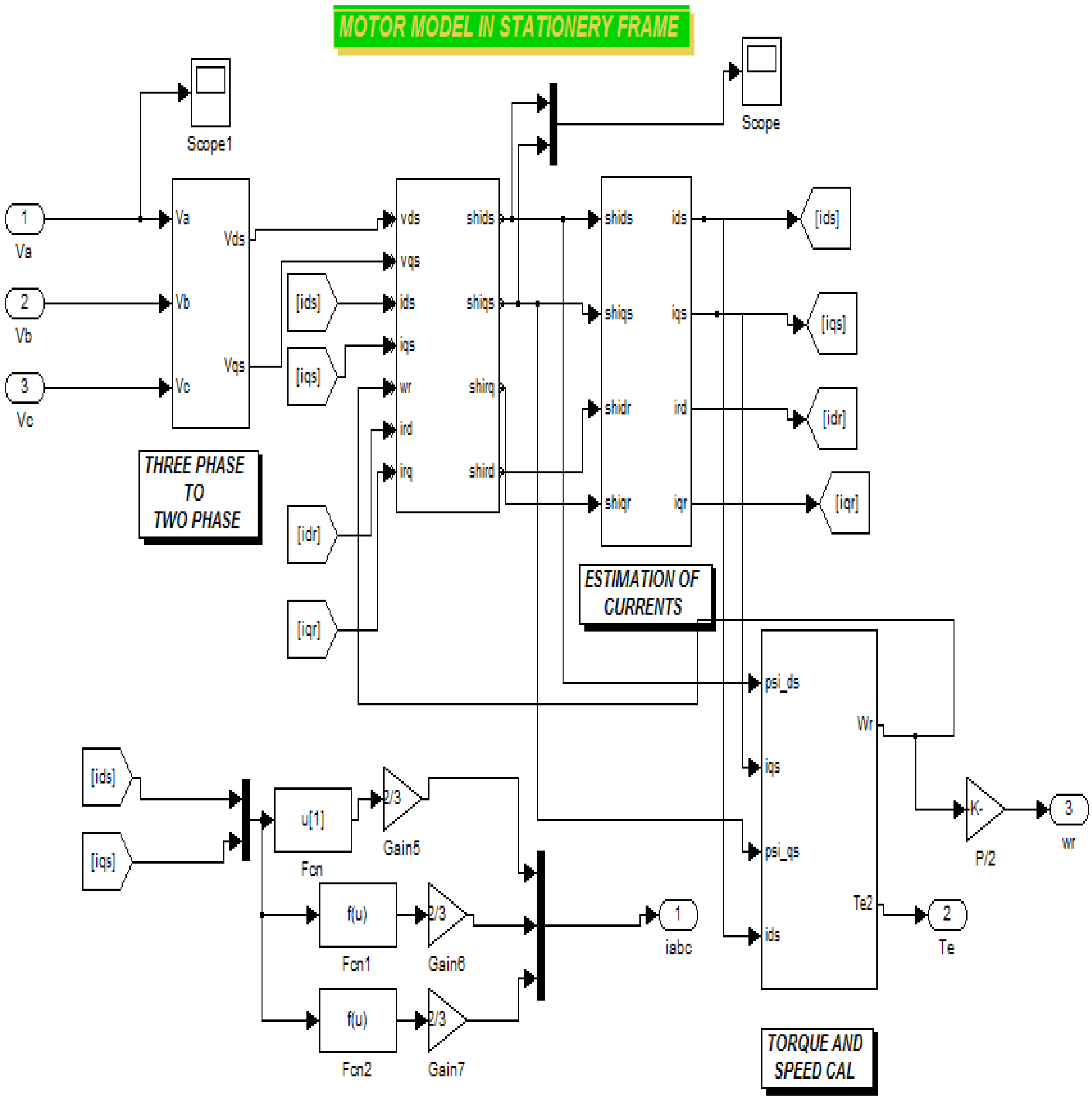


Fig 6 : Proposed model of the Induction motor

III. Generation Of Gating Pulses

The Gating pulses for both the inverters are generated by a m-file program separately and the corresponding pole voltages are obtained for the respective inverters and the difference in these pole voltages are fed to the three phases of a 1kW open end winding Induction Motor.

The input motor parameters are initialized accordingly and are provided to the motor before they are fed from the inverters.

The generation of gating pulses is accomplished by the proposed scheme whose diagrammatical representation is as shown in the figure (7), where three reference sinusoidal signals with a phase difference of 120^o are used which are instantly converted to two phases from three phase to two phase transformation or by using functional block (embedded with transformation commands within).

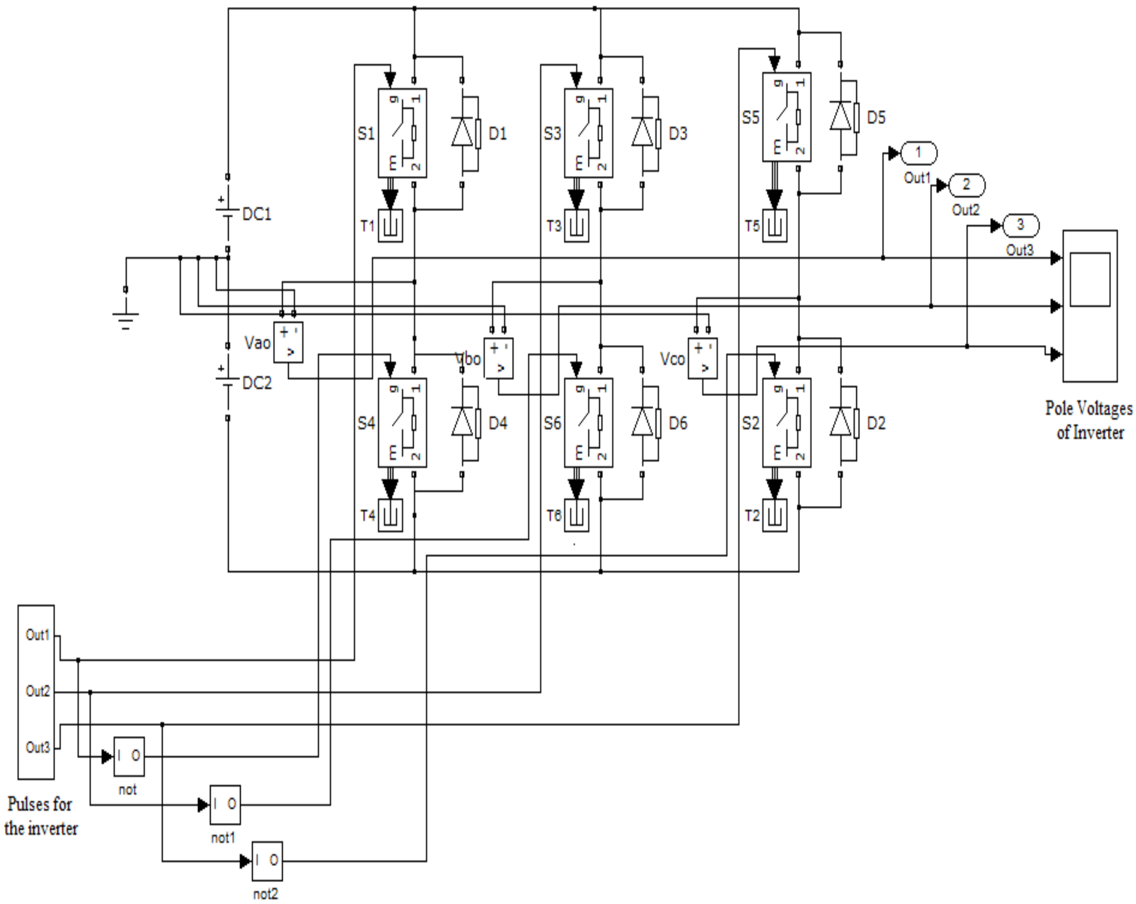


Fig 7: Generated gating signals fed to the inverter.

Then with the use of "Cartesian to polar" block the magnitude and the phase parameters are separated and are fed to "MATLAB fcn" block along with the timing factor. This block is the one where an "M-file program" is embedded for the generation of gating pulses which takes into account the magnitude, angle of the reference vector and its time.

Thus the three gating signals are generated from a M-file program and these are meant to be fed to the top switches of each of the inverter's leg and the bottom switches are fed with the gating signals which are negotiated (reversed) from the former, which accompanies a fact that either one of the switch (top/bottom) is turned-on in one instant. Hence with this method all the six gating signals are generated and fed to the appropriate switches of the inverter as shown in figure (7).

IV. Simulation Results

The gating pulses are thus generated by the use of a m-file program separately for both the inverters and from the present scheme of generation it is designed ought to get the gating pulses along with the sector number for the prescribed inverter. So a diagrammatical representation of these pulses and their respective sector number is as shown in the figure (8)

These Gating pulses generated by use of the program stands to be common for both the cases i.e. for a dual two level inverter scheme and for a conventional single inverter scheme.

In the Dual inverter scheme the m-file program for the other inverter will be designed in such a way that the other inverter realizes the other half reference vector whose phase will be shifted 180^o from the original reference vector (as discussed in chapter 3).The gating pulses generated from the proposed scheme will be negotiated and all these six pulses will be provided for the switches of Inverter as shown in Fig (9)

These gating pulses from the propose generating schemes are fed to inverter-1 and inverter- 2 and their corresponding pole voltages are as shown in fig (10) respectively.

The difference in these pole voltages is obtained and the resultant is given to the three phase of open end winding induction motor. The voltage difference thus captured is shown in figure (11).

A similar procedure is followed in the case of a conventional Single inverter scheme for the generation of gating pulses. Thus the so obtained pole voltages from the single two level inverter are converted to phase voltages and are then fed to the Induction motor. The simulated pole voltages and the converted neutralized phase voltages are shown in the Fig's (12) and (13) respectively.

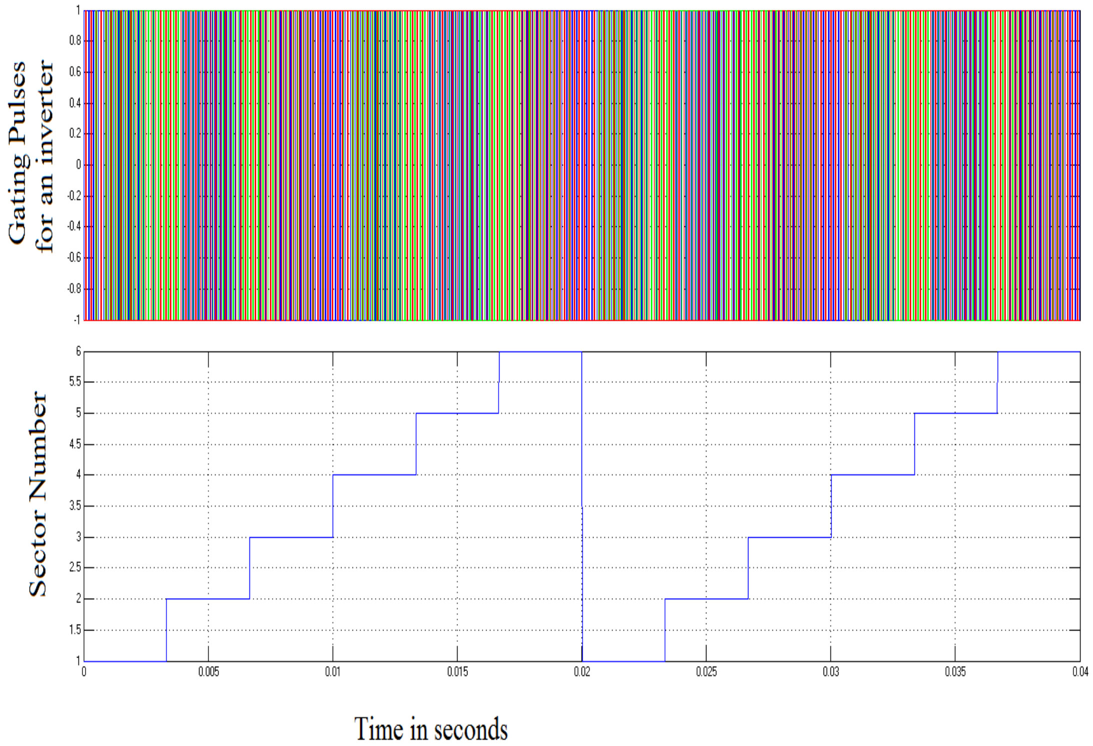


Fig 8: Combined Gating Pulses for all the sectors of an Inverter

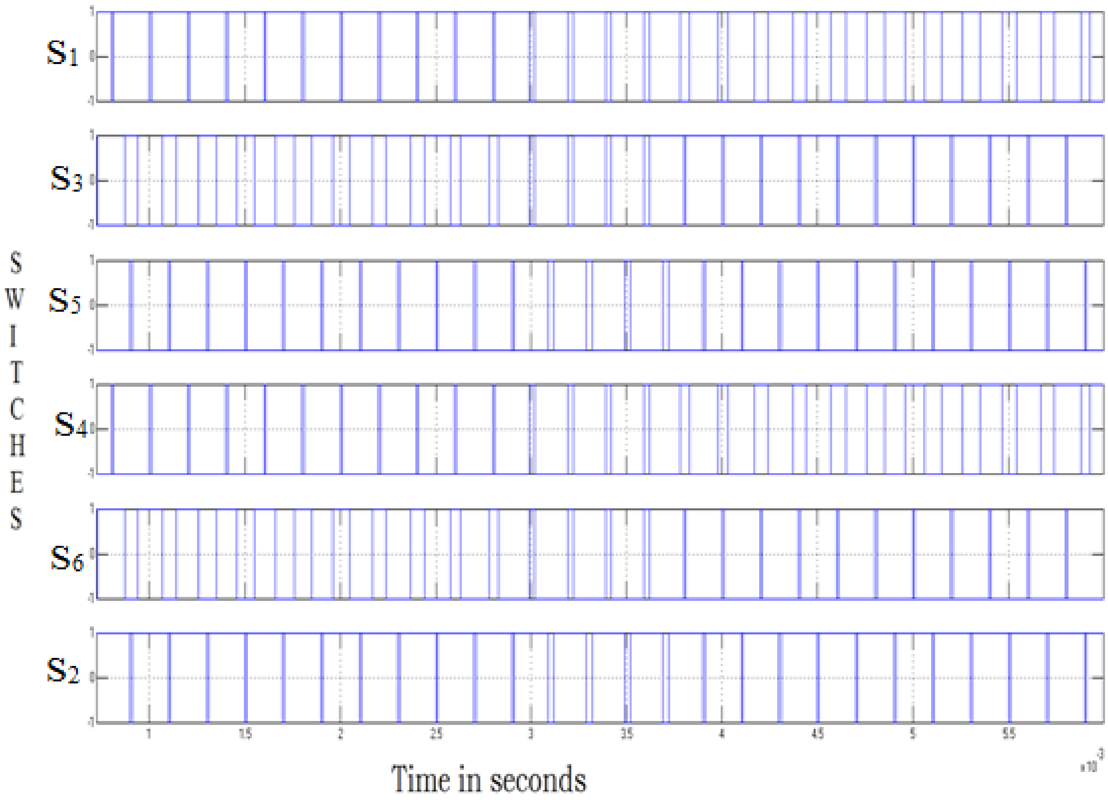


Fig 9: Gating Pulses For the Inverter

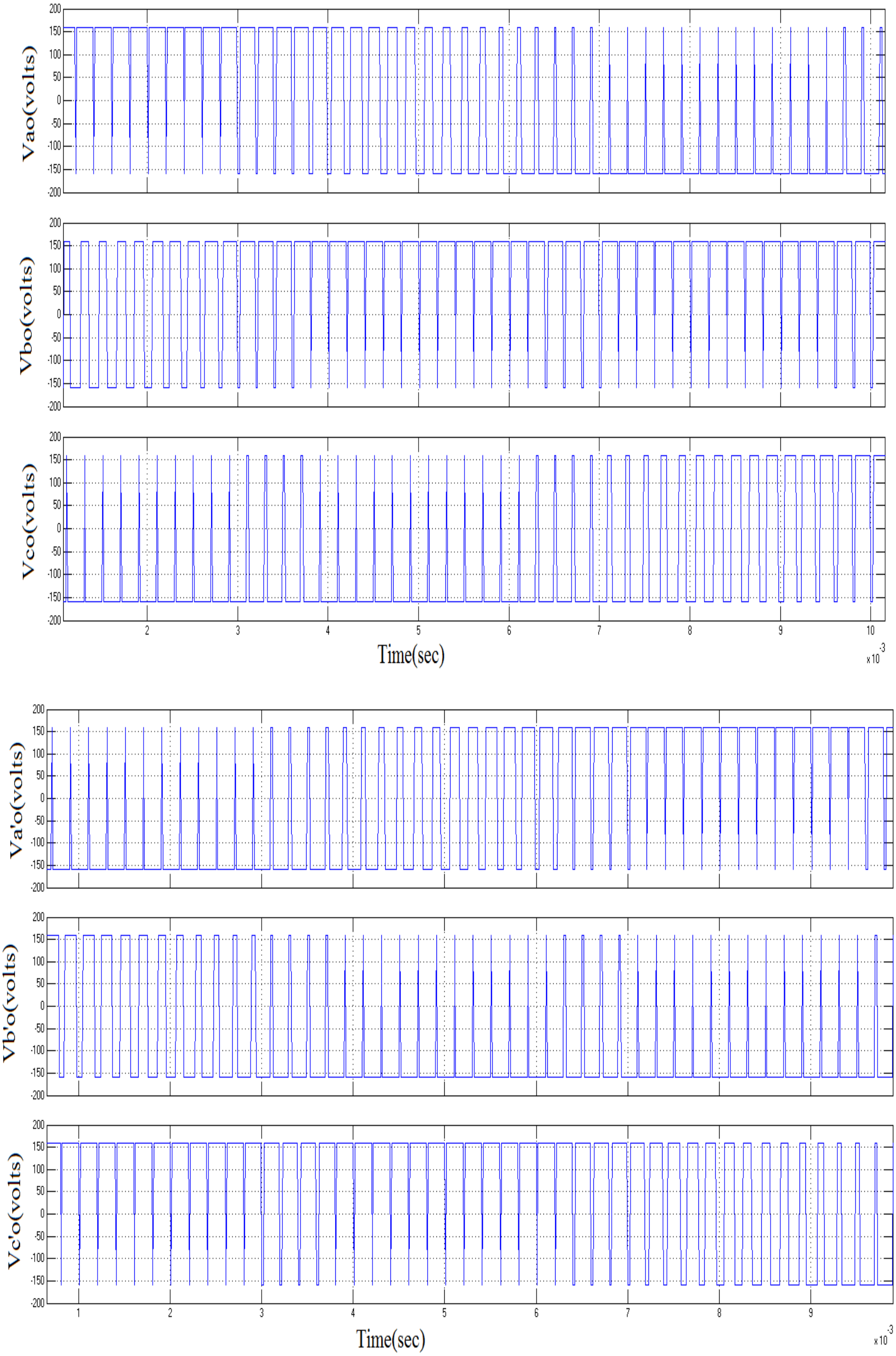


Fig 10: Pole Voltages for Inverter-1(top trace) and Inverter-2(bottom trace).

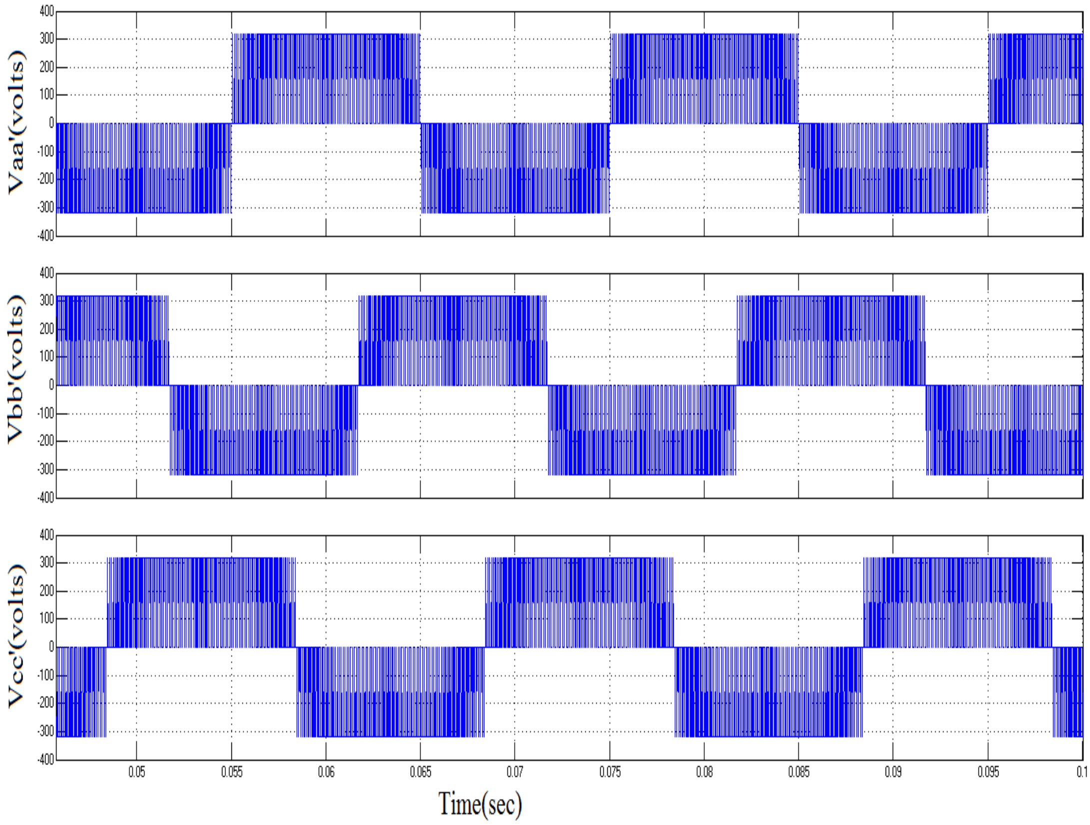


Fig 11: Difference in the pole voltages from both the inverters

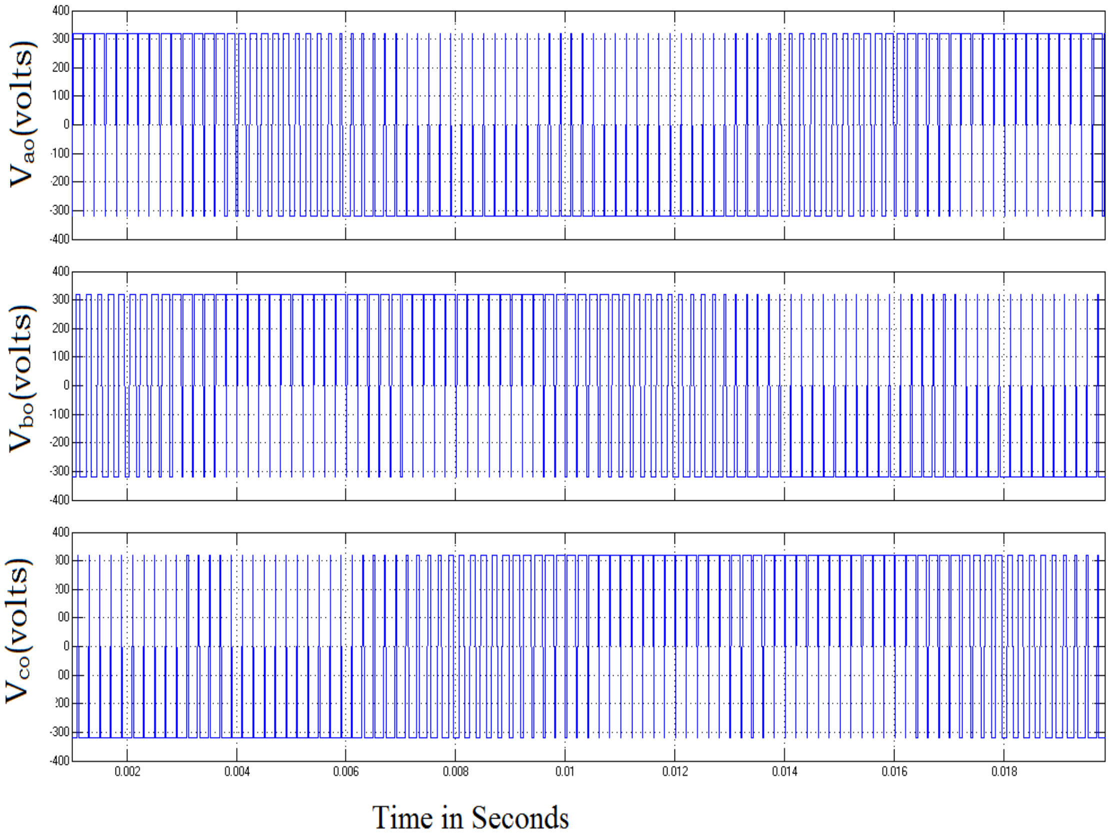


Fig 12: Pole Voltages of a conventional Single two level inverter

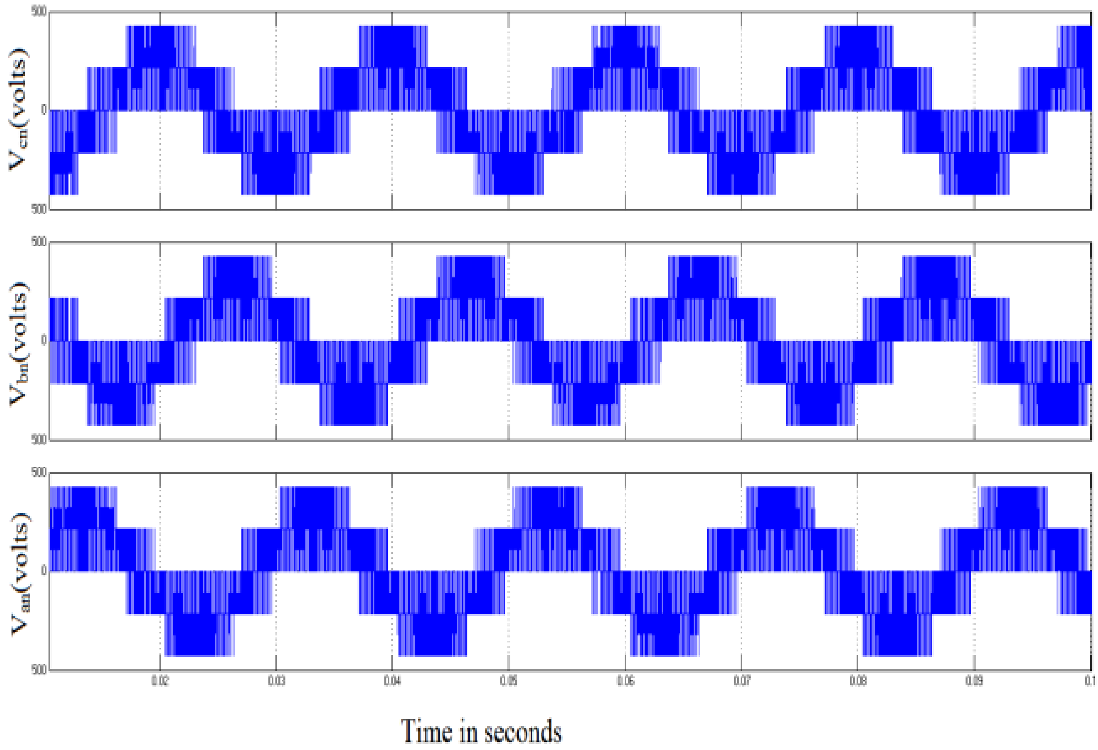
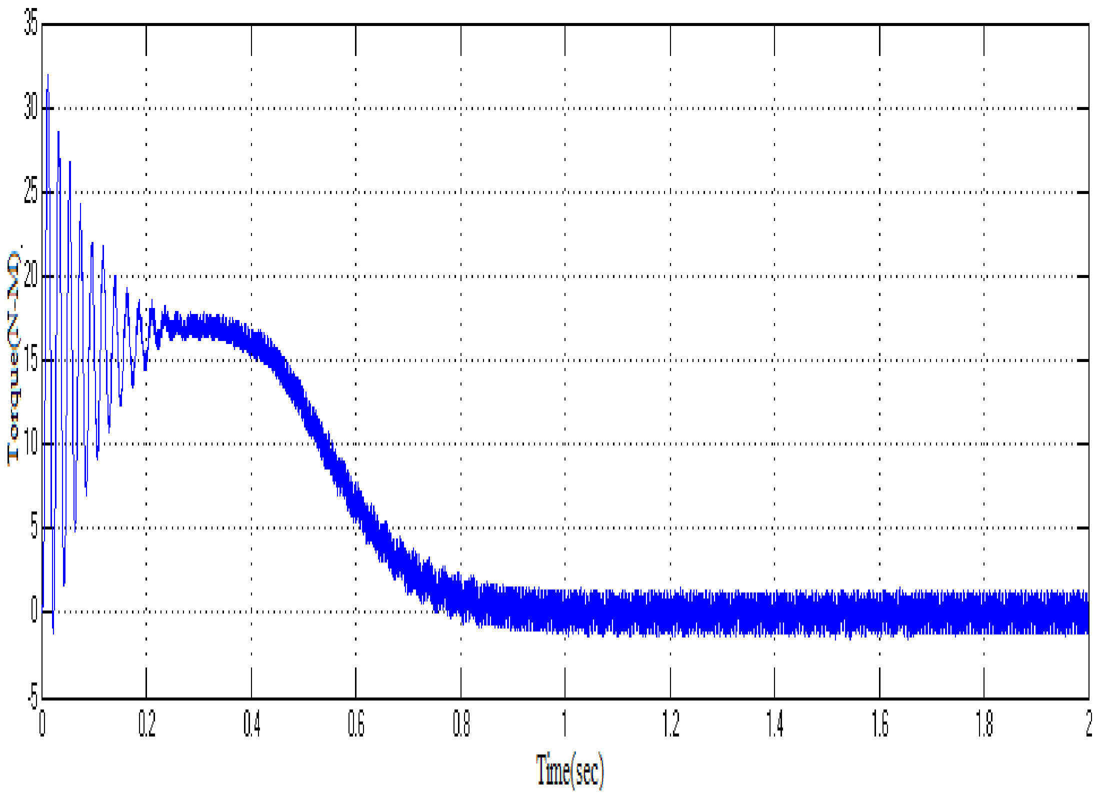


Fig 13 Converted pole to neutralize phase voltages from a Inverter



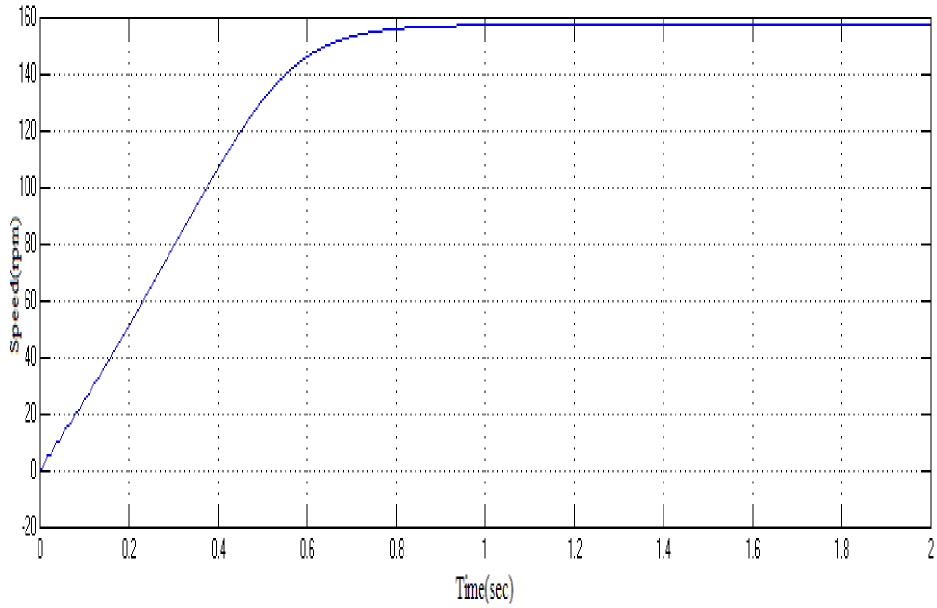


Fig 14: Torque and Speed of the induction motor for modulation index 0.75

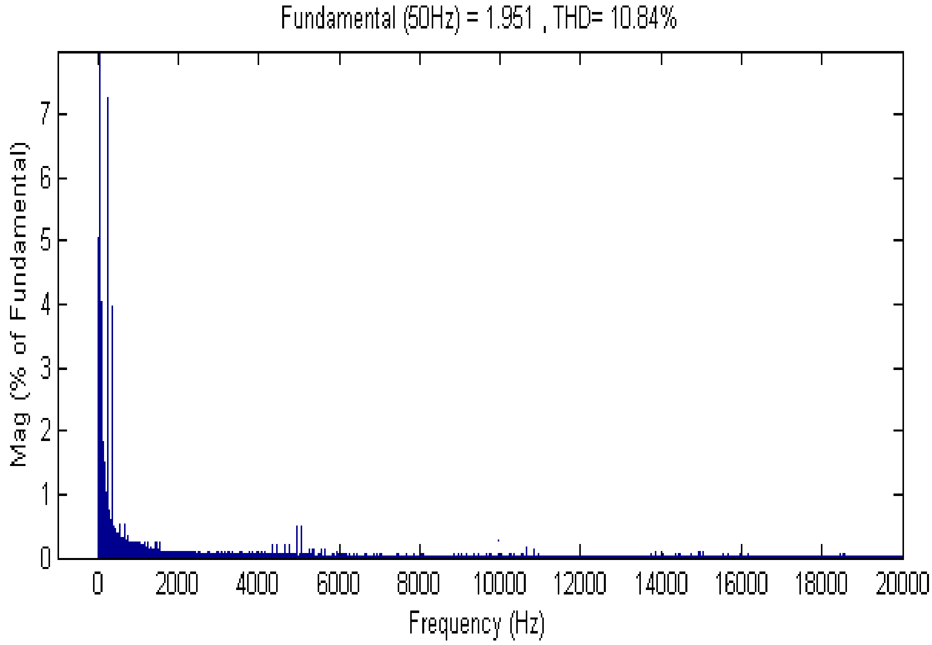


Fig 15: %THD of Induction motor drive for a modulation index of 0.75

S.No	Operating Frequency	Modulation Index	Biasing Inverter PWM Fed Induction Motor Drive Phase Current(I_a) % THD
1	50	0.1	13.25
2	50	0.21	13.01
3	50	0.45	12.17
4	50	0.75	9.84
5	50	0.85	8.28

V. Conclusion

In this project a dual two-level inverter capable of generating three level output voltage using the PWM switching scheme is simulated using MATLAB/SIMULANK With the biasing inverter PWM strategy the reference space vector is synthesized in the average sense by switching amongst the vector combinations available at the nearest three vertices. The time consuming process of sector identification and the Look-up tables are not needed with the proposed PWM strategy. The rms value of this harmonic content is decreasing with the increase in the modulation index of the dual-inverter feeding with the open-end winding induction motor. The higher modulation index range of 0.85 the harmonic content in the phase currents is low.

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