SVPWM Based DTC of OEWIM Drive Fed With Four Level Inverter with Asymmetrical DC Link Voltages

G. Satheesh, T. Bramhananda Reddy, CH. Sai Babu

Abstract*—A new approach for a fixed switching frequency direct torque control (DTC) of an open end winding induction motor configuration using four level inverter is proposed. The four level SVPWM voltages are generated by using two conventional two level inverters which are fed with the unequal dc link voltages at a ratio of 2:1. A decoupled algorithm for the two inverters feeding the open end winding induction motor is proposed. However, the proposed DTC scheme does not require the sector information of the estimated fundamental stator voltage vector and its relative position with respect to the stator flux vector. With the proposed method simulation clearly demonstrate simple numerical calculations and results in a better dynamic manner.

***Index Terms*—Decoupled SVPWM Algorithm, Dual inverters, DTC, Four level SVPWM, Multi level Inverters, OEWIM, Unequal DC links, Zero sequence voltages.**

I. INTRODUCTION

Multi-Level inverter configurations are having many advantages compare to the conventional two level inverters configurations, and these are attracting many researchers nowadays but high power capability and multi level inverters controlling and flexibility in the controlling of the drive operation is not a classical one. A high power configuration for the induction motor drive is proposed in [3] and later researchers proposed more control configurations for the induction motor drives with flexibility and easy controlling methods. Generation of three level voltages using the two conventional two- level inverters for open end winding induction motor is proposed in [2]. After that many multi level configurations for open end winding induction motor with dual inverter fed operation are proposed in [4-6]. Two new approaches with decoupled strategy and NSHC strategies with the three level output is proposed in [9]. This configuration employed same amount of DC link voltage to feed the two conventional two-level inverters. Another new Space Vector Pulse Width Modulation (SVPWM) is presented in [6] feeding the two conventional two-level inverters with asymmetric DC link voltages. This method is the further extension to the work proposed in [9].

A numerous direct torque controlling techniques are presented for the induction motor drives and a new approach with SVPWM based multi-level inverter fed open end winding induction motor DTC control is presented in [13-15]. In [13] a decoupled strategy for the controlling of the open end winding induction motor is employed.

A new DTC approach for the open end winding induction motor fed with dual inverters with asymmetrical voltages is presented; the strategy specified in [7] employed for this approach. Transient and steady state and step change in load simulation results along with torque, speed current waveforms and also the voltage variations during the transient, step change steady state and speed reversal are discussed in this paper.

II. OPEN END WINDING INDUCTION MOTOR WITH FOUR LEVEL CONFIGURATION

Fig.1 shows the open-end winding induction motor drive; in which each inverter is operated with an isolated DC-power supply. If the DC-link voltages are equal, one results in three-level inversion [3, 10]. In this paper, the inverters are operated with unequal DC-link voltages. Inverter-1 is operated with a DC-link voltage of (2/3)*Vdc, while inverter-2 is operated with a DC-link voltage of (1/3)*Vdc. Thus, the sum of the two DC-link voltages is equal to Vdc, i.e. the DC-link voltage of a conventional two-level inverter drive.

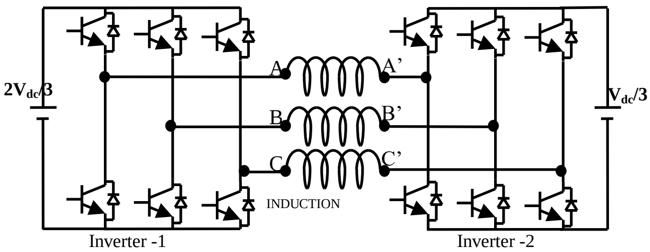

Fig.1: The four-level inverter drive with open-end winding topology.

The pole voltages of inverter-1 are represented by the symbols Vao, Vbo and Vco, while the symbols Va'o, Vb'o and Vc'o represent the pole voltages of inverter-2. Fig-2 shows the space vector locations from individual inverters. The numbers 1 to 8 refer to the states assumed by inverter-1. Similarly the numbers 1' to 8' indicate the states assumed by inverter-2 (Fig.2). Table-1 in [7] reviews the states offered by both of these inverters. The sum of the motor phase voltages Vaa', Vbb' and Vcc' do not add to zero, meaning that there exists a substantial Zero-sequence voltage. This zero sequence voltage would cause a strong zero sequence current,

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which is ruinous to the semi-conductor switching devices and the motor. But, here in this circuit configuration, a path is not provided to the zero sequence currents as each inverter is operated with an isolated power supply. Resulting, the zero-sequence voltage corresponding to the instantaneous values of the difference in pole voltages (Vaa', Vbb' and Vcc') and is removed across the neutral points O and O'. This zero-sequence voltage is given by:

$$V_{zs} = \frac{V_{aa'} + V_{bb'} + V_{cc'}}{3}$$

III. PROPOSED FOUR LEVEL DC-SVPWM ALGORITHM

The specified algorithm in [7] uses only the instantaneous reference voltages and is based on the concept of 'effective time'. The effective time is defined as the time "when the inverter supplies power to the motor in a given sampling time period and is denoted as T_{eff}. The sampling time period is denoted as T_s. The instantaneous phase reference voltages are obtained by projecting the tip of the reference vector Vsr on to the respective phase axes and multiplying the values of these projections with a factor of (2/3). The factor (2/3) arises because of the classical 'Two to Three phase' transformation. These instantaneous phase reference voltages are denoted as V_a*, V_b* and V_c*. The symbols Tga, Tgb and Tgc respectively denote the time duration for which a given motor phase is connected to the positive rail of the input DC power supply of the inverter in the given sampling time period Ts. The timings Tga, Tgb and Tgc are termed as the phase switching times.

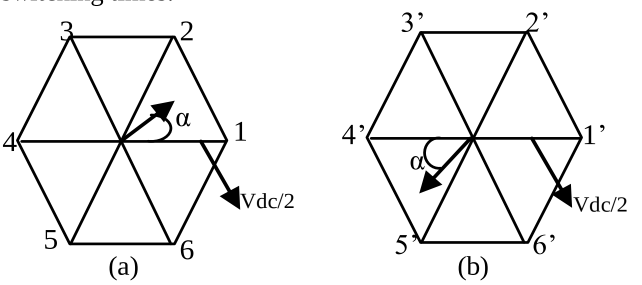

Fig.2: Voltage vectors for (a) inverter-1 and (b) inverter-2 for 3 level decoupled algorithm.

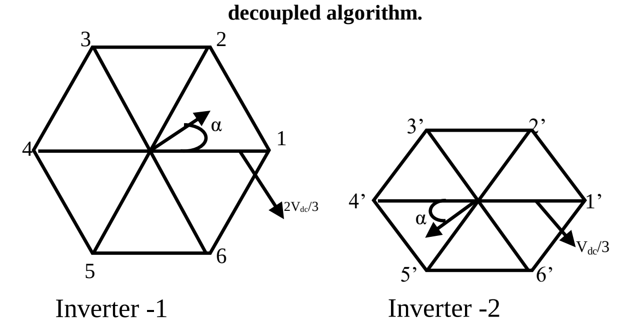

Fig.3 (a): Voltage vectors for (left) inverter-1 and (right) inverter-2. For 4 level decoupled algorithm

The procedure to generate the gating pulses for the individual devices using this algorithm is elaborately explained in [7]. For a dual inverter system, there would be two sets of phase switching times, one for each inverter. The phase switching timings of inverter-1 are denoted by the symbols Tga, Tgb and Tgc , while the symbols T'ga, T'gb and T'gc denotes the same for inverter-2.

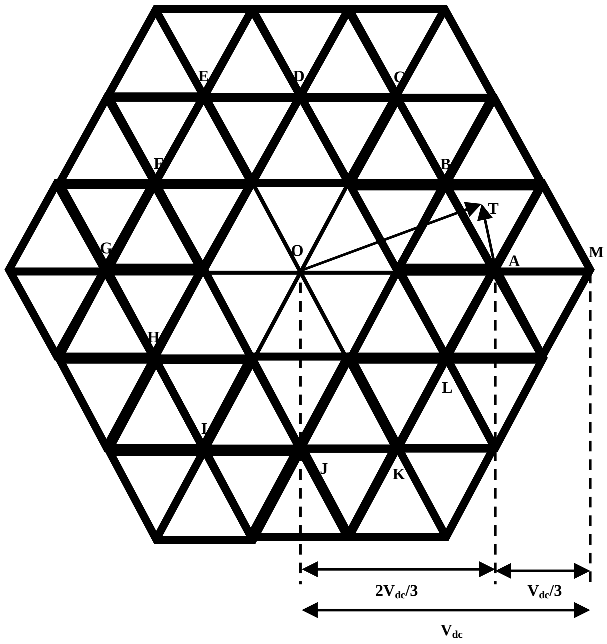

Fig. 3(b): Decoupled PWM strategy for a four –level inverter.

In Fig. 3(b) the vector **OT** represents the actual reference voltage space vector, which is to be synthesized from the dual-inverter system and is given by |Vsr|∠α. This vector is resolved into two opposite components **OA** is ($|2V_{sr}/3|\angle\alpha$) and **AT** is ($|V_{sr}/3| \angle 180^o + \alpha$). The vector **OA** is synthesized by inverter-1 while the vector **AT** is reconstructed by inverter-2. This voltage reference vector of the each inverter can be obtained by just adding the zero sequence voltage to the instantaneous reference voltages by which a new set of voltages can be generated and these voltage wave forms are known as modulating voltage wave forms.

IV. PROPOSED DTC OF OPEN END WINDING INDUCTION MOTOR DRIVE

The electromagnet torque of the open-end winding configuration of induction motor is controlled by controlling the angle between the stator flux and rotor flux vectors. But the rotor time constant is more than the stator time constant so the response of the speed or torque variation is slow so the stator flux is varied according to the required torque variations by keeping the rotor flux vector constant.

The figure 4 show the complete block diagram of the DTC of open end winding induction motor with four level inverter configuration. From the block diagram the outer feedback loop uses the speed feedback and the feedback speed value is converted in to torque value by using the PI controller. The second feedback that is inner first feedback value which is derived from the adoptive motor module is used to derive the torque error value and then by using PI controller the outer loop speed feedback is considered to derive the reference speed value. Now the error is integrated and with the help of the reference flux value and derived flux vector from the adoptive motor module the reference voltage is generated. From the derived reference voltage the SVPWM pulses for the individual inverters with the DC link voltages of 2/3 V_{dc} and 1/3 V_{dc} are generated.

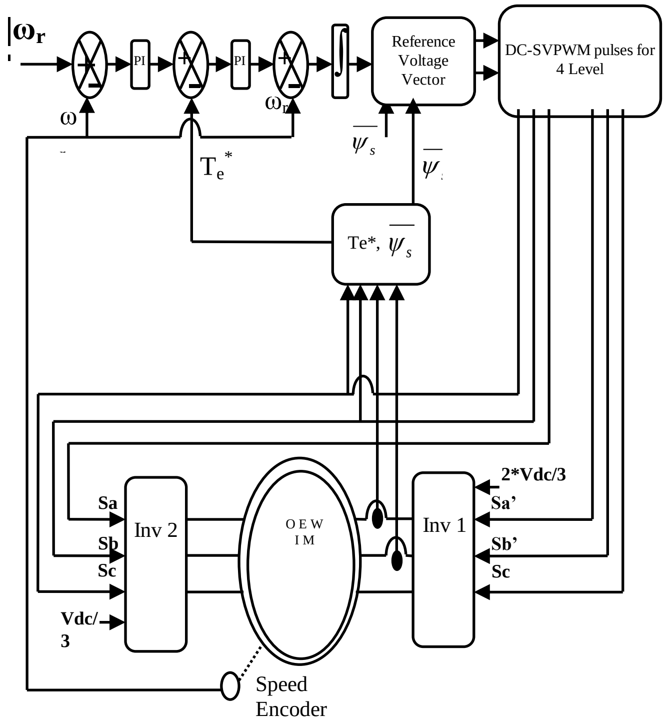

Fig 4: block diagram of the proposed 4-level OEW Induction Motor drive

V. RESULTS AND DISCUSSION

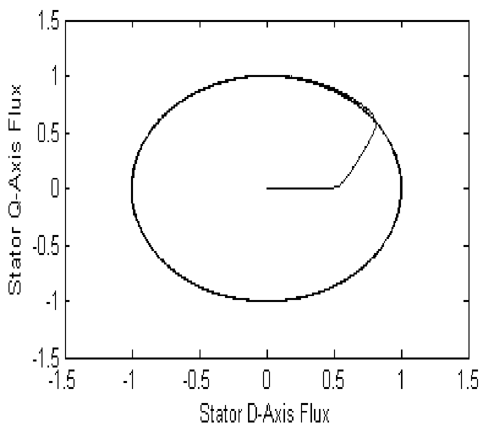

Fig 5: Stator flux space Vector: X-Axis (D- Component), Y-Axis (Q-Component)

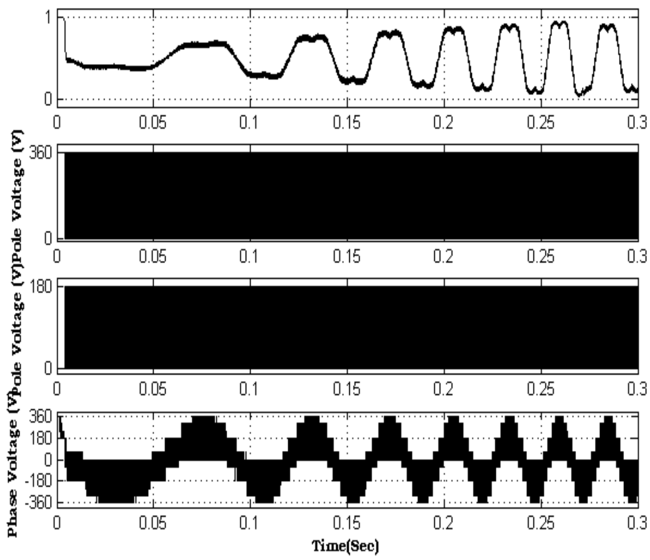

Fig 6: individual inverter pole voltage and effective phase voltages during starting.

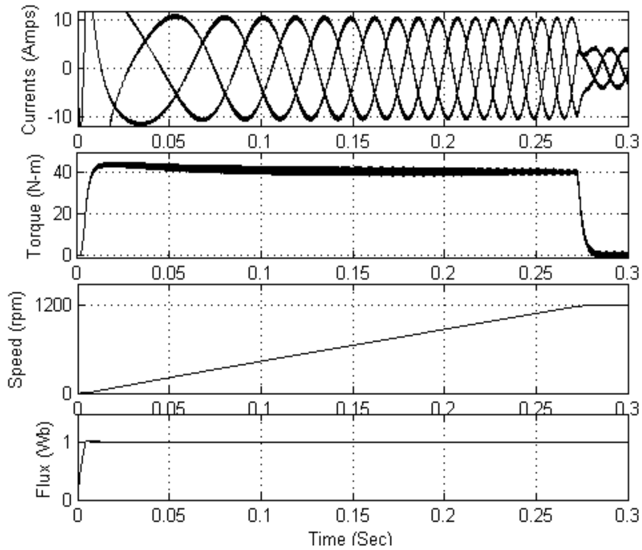

Fig 7: Change in speed from 0 rpm to 1200 rpm during starting transient condition

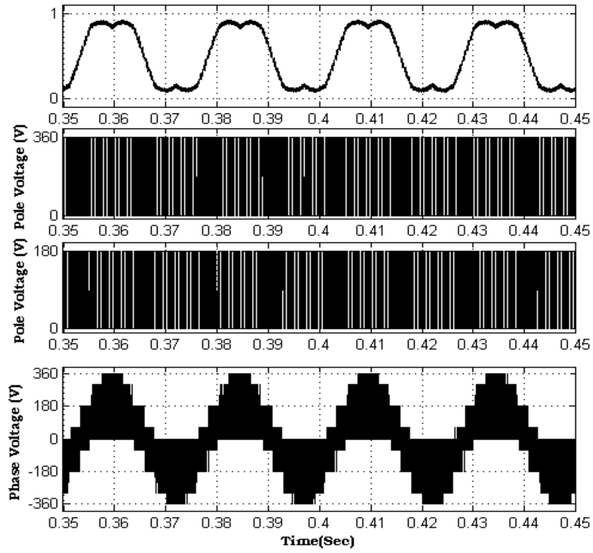

Fig 8: variations in voltage waveform during the steady state condition

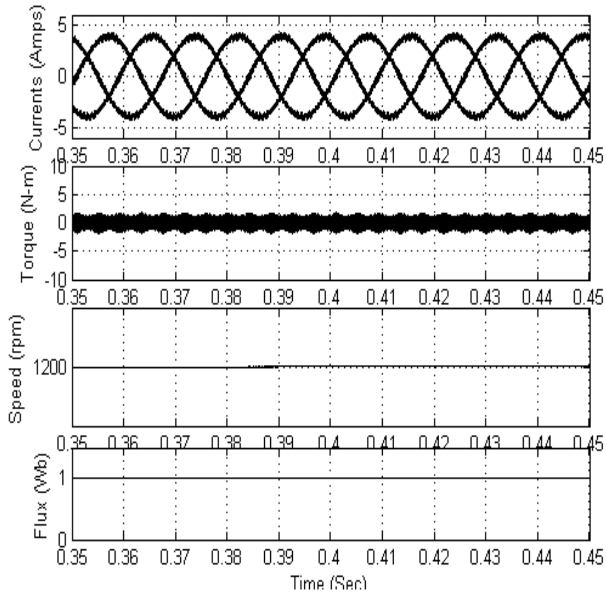

Fig 9: Current and torque waveforms under steady state where speed remains at 1200 rpm.

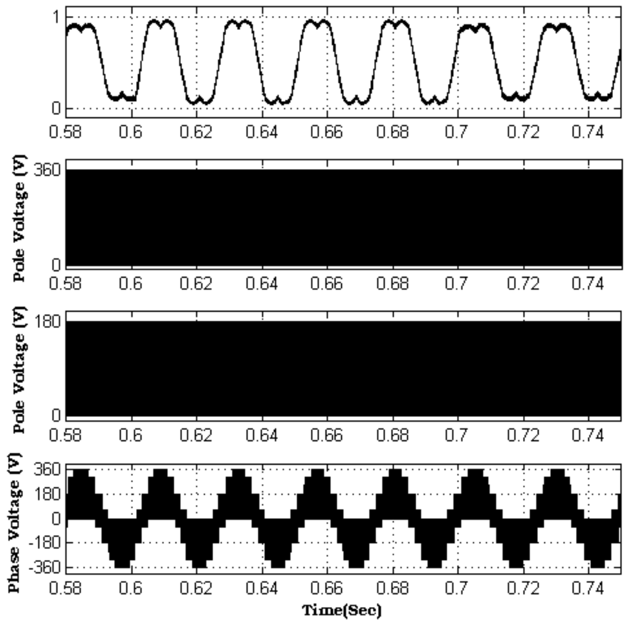

Fig 10: modulation, pole voltages and effective motor phase voltages during the step change in load torque

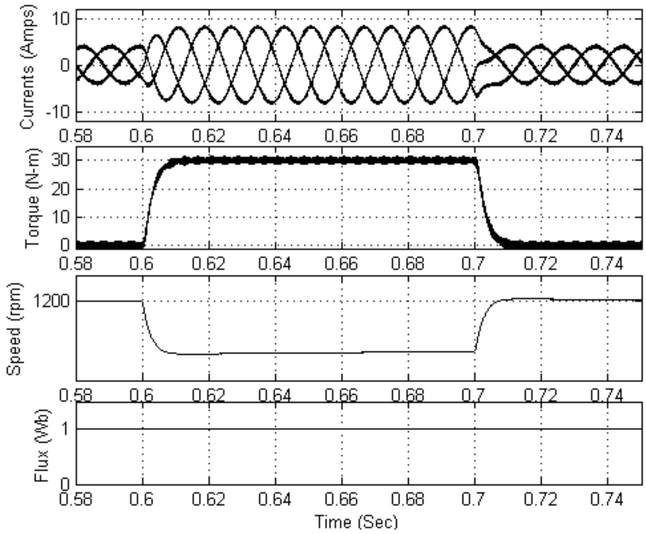

Fig 11: Change in speed from 1200 rpm to 1190 rpm under loaded condition

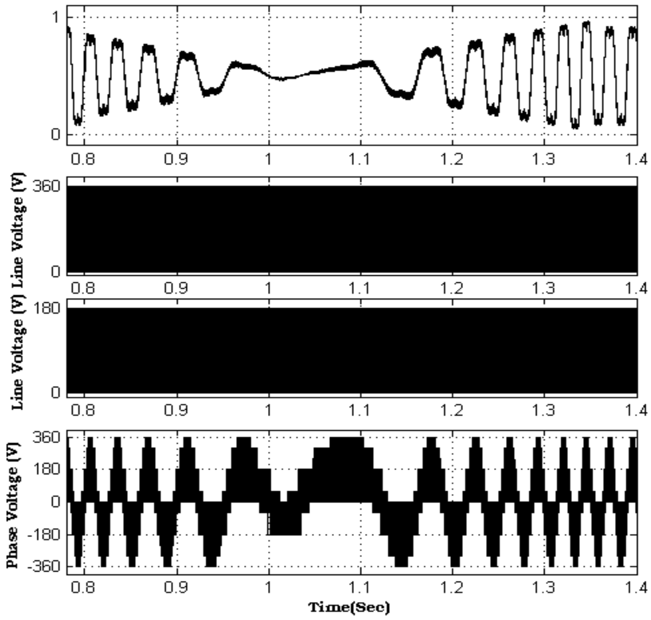

Fig 12: variation in modulation waveform and motor phase voltages during the speed reversal period

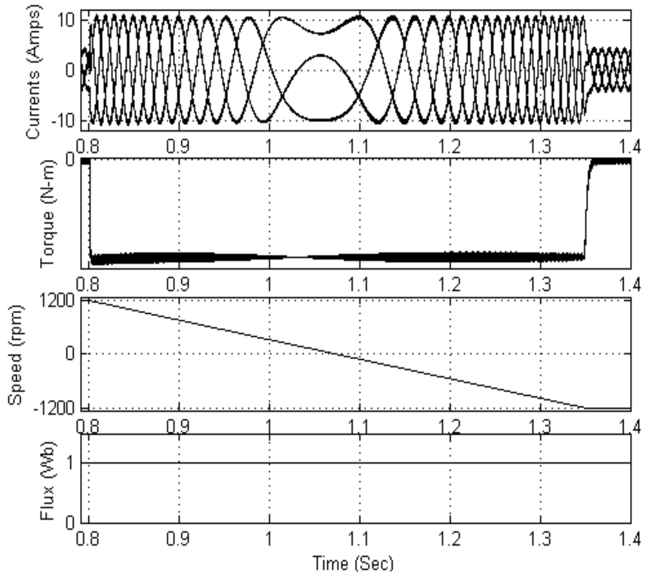

Fig 13: Change in speed from 1200 rpm to -1200 rpm with speed reversal at no-load condition

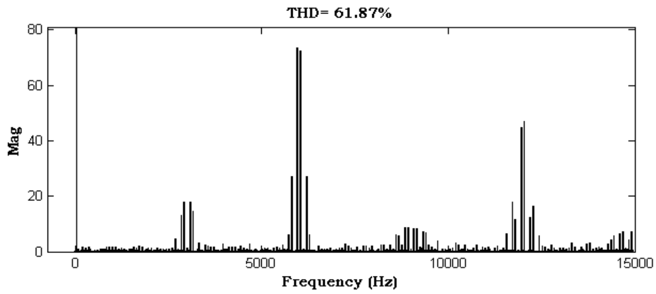

Fig 14: Normalized harmonic spectra of voltage waveform under steady state.

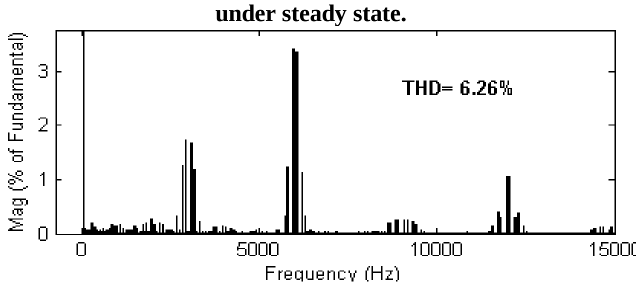

Fig 15: Normalized harmonic spectra of current waveform under steady state.

The generated SVPWM pulses will be fed to the inverters to feed on either ends of the induction motor. To validate the proposed method, simulation studies have been carried out by using MATLAB /SIMULINK. The motor parameters are as follows 4 KW, 400V, 30 N-m, 1470 rpm,

4-pole, 50 Hz, 3-phase, stator resistance Rs = 1.57ohm, rotor resistance Rr = 1.21ohm, stator inductance Ls=0.17H, rotor inductance Lr=0.17H, mutual inductance Lm=0.165H, moment of inertia J=0.089Kg-m^2. The proposed method shows four-level voltages are generated by two two-level inverters. Various conditions such as starting, steady state, step change in load and speed reversal are simulated. The locus of stator D-Q axis flux is plotted in fig 5, while in fig 7; it is observed that the speed changes from zero rpm to 1200 rpm during the starting transient condition. In fig 6, the starting transients are shown for the modulation waveform, the pole voltages of individual inverters and the effective phase voltage. The modulation waveform and the individual inverters pole voltages and the effective motor voltages are shown during the motor operation with no load condition with a constant speed is shown in fig 8 and effective motor phase current, torque, speed and constant flux during the steady state can be viewed in fig 9. A change in speed from 1200 rpm to 1190 rpm under loaded condition at the time of 0.6 sec and the load is removed from the machine at the time of 0.7 sec after removing the load the speed is attained back to no load speed can be observed in fig 11. During the step change in motor load torque there are no variations in the voltage waveform viewed in fig 10. A speed reversal command is applied to at time of 0.8 sec and the machine speed completely reversed which is initially run at 1200 rpm and finally it reaches to -1200 rpm as shown in fig 13. In fig 12 the modulation waveform and effective phase voltages are shown during the speed reversal period.

The steady state voltage and current THD are shown in fig 14 and fig 15. The total V_{dc} selected for the drive system is 540 Volts only.

VI. CONCLUSION

An effective and simple multilevel configuration for the direct torque control of the open end winding induction motor drive with asymmetrical dc link voltages is presented in this paper. This proposed method is very simple and is extension of the DC-SVPWM three level OEWIM configuration. The algorithm in [7] is used for the generation of the SVPWM pulses. The described PWM scheme uses only the three instantaneous phase reference voltages for the implementation and do not require either sector identification or lookup tables.

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