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A Dual Two-Level Inverter Fed Open-End Winding Scheme with Space Vector PWM

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ABSTRACT: Dual Two-Level Inverter fed Open-end Winding AC Drive is an emerging Multilevel Inverter Topology which is implemented by cascading two standard Three-phase inverters with a six-wire open-end load in between them. Space Vector PWM Technique is implemented considering its various advantages and is selected as a good-performing control strategy to control the dual-inverter. Dual Inverter is equivalent to a Three-level Three-phase converter which produces space vector locations, identical to those of a conventional 3-level inverter. It is well suited for automotive applications in which splitting the batteries bank is possible. The conventional Topology used was Three-Level Neutral Point Clamped Inverter fed Induction Motor Drive with various drawbacks. A new Three-level inverter configuration termed as Dual Two-Level Inverter fed Open-End Winding scheme is introduced. Simulation of a Dual Two-Level Inverter fed Induction motor is done in MATLAB and outputs obtained are verified.

KEYWORDS: Open-end winding AC Drive, Space Vector PWM, Dual Two-Level Inverter.

I.INTRODUCTION

Multilevel inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. The main advantages of multilevel inverters include lower harmonic distortions, smaller common mode voltage and reduced dv/dt stress. Among various multilevel inverter topologies, Three-Level Neutral Point Clamped (NPC) Inverters have found broad applications in high power drives. It offers features such us low THD, static voltage equalization without using additional components and no dynamic voltage sharing problem [1].The proposed scheme is based on the open-end winding configuration with conventional two-level inverters and hence does not experience neutral point fluctuations. It does not require the neutral point clamping diodes and has a simple power circuit. The proposed scheme uses half the dc-link voltage compared to the conventional Three-Level neutral point clamped inverter based scheme and has a lesser device count [2-4]. The dual 2-level inverter is composed by twelve switches driven dually in couples to avoid source shortcuts. This means that the possible states of the system depend on six variables which give the state of each leg. These variables can assume only two values and so the number of all the allowed configurations is obtained as 64 as equivalent to Three-Level NPC Inverter.

II. DUAL TWO-LEVEL INVERTER

A Dual Two-Level Inverter feeding a 6-wire open-end load is shown in Fig.1. The dual 2-level inverter can generate only18 active vectors and 1 null vector. The two inverters composing the converter produce two different systems of line-to-line voltages. The load phase voltages can be obtained as:

$$V_1 = e_{1A} - e_{1B}$$

$$V_2 = e_{2A} - e_{2B}$$

$$V_3 = e_{3A} - e_{3B}$$

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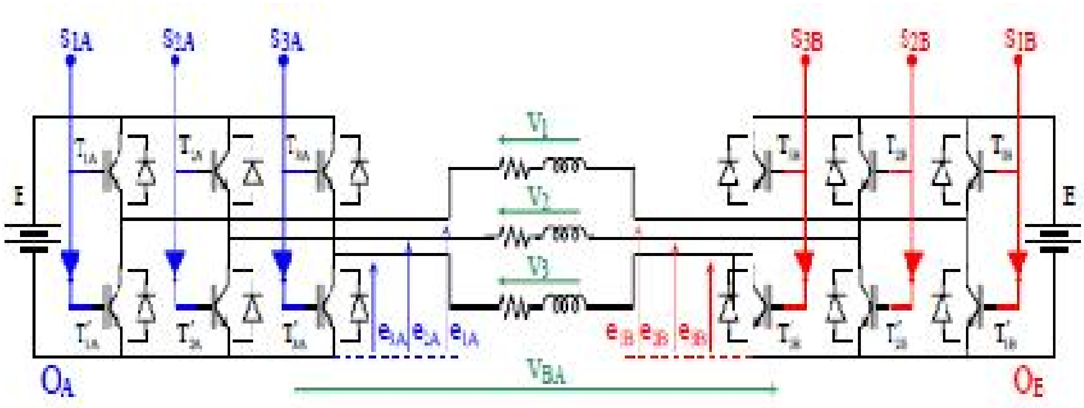

Fig.1 Dual Two-Level Inverter with two DC sources

The converter is composed by six legs; each one can assume two states: high or low. A state function, Sx can be defined to describe the state of each leg. The state function is a real function where the subscript x identifies a specific leg. It is equal to 1 when the leg state is high and the output voltage is equal to source voltage (E). Otherwise its 0 when leg output is zero. Complex vector related to load phase voltages is given by:

$$\bar{V} = \bar{e_A} - \overline{e_B}$$

Where the complex vectors $\bar{e_A}$ and $\overline{e_B}$ are obtained using Park transform as given by the following equations.

$$\bar{e_A} = \frac{2}{3}(e_{1A} + ae_{2A} + a^2e_{3A})$$

$$\overline{e_B} = \frac{2}{3}(e_{1B} + ae_{2B} + a^2e_{3B})$$

The load phase voltage vector can be expressed using the states of both inverters as:

$$\bar{V} = E(\bar{s_A} - \overline{s_B})$$

$$= \frac{2}{3}E[(s_{1A} + as_{2A} + a^2s_{3A}) - (s_{1B} + as_{2B} + a^2s_{3B})]$$

$$= \frac{2}{3}E[(s_1 + as_2 + a^2s_3)]$$

$$= E\bar{s}$$

Tab.1 shows the individual inverters and combined Dual inverter leg states.

Tab.1 States of each inverter and Dual Inverter

s_{xA}	s_{xB}	s_x
1	**1**	**0**
1	**0**	**1**
0	**1**	**-1**
0	**0**	**0**

Anyway, among the 64 configurations there are a lot of redundant situations. The effect of these redundancies can be seen considering the number of all the possible combinations of the whole converter leg states. This number is 27 which are obviously less than the number of possible configurations. The 18 active vectors and 1 null vector are shown in Fig.2. The 27 switching states are classified in to 4 groups based on the length of the vectors as null, short, medium and large vectors.

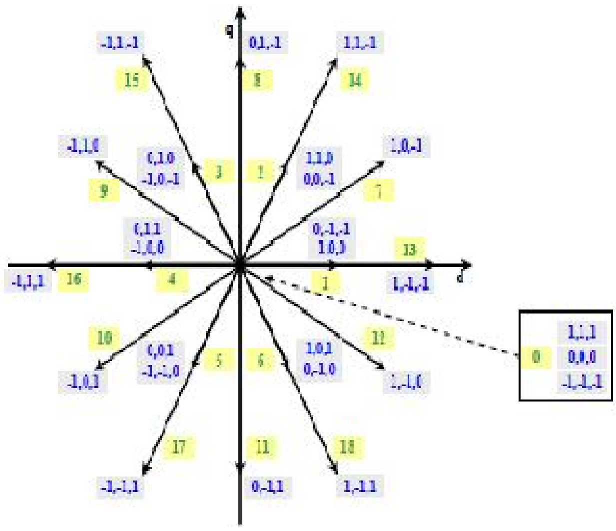

Fig.2 Vectors produced by dual 2-level inverter

III. SPACE VECTOR PWM

Space vector modulation is a powerful PWM technique which treats the inverter as a single unit. The most important feature required for a well-designed PWM technique is that it should not allow different phases to switch simultaneously. It is the only PWM technique which satisfies the above condition. In SVPWM, the three phase sinusoidal voltages are represented using a single space vector. Using suitable transformations the three phase voltages (Van,Vbn,Vcn) are transformed to a single space vector in two dimensions (Vs).

For a three phase PWM inverter, there are 8 possible switching states or vectors which can be arranged in the form of a hexagon in the x-y plane. Out of the 8 switching vectors, there are 6 active vectors (V_1,V_2, V_3, V_4, V_5, V_6) and 2 null vectors(V_0,V_7). The vectors (V_1 to V_6) divide the plane into six sectors. The reference space vector, Vref is generated by two adjacent non-zero vectors and two zero vectors as shown in Fig.3. The important condition to be satisfied while we synthesize a reference space vector is the volt-second balance principle.

Considering the sector 1 in the space vector diagram with two active vectors V_1 and V_2 and two null vectors V_0 and V_7 and according to Volt-second balance principle, if V_1 is applied for a time T_1,V_2 applied for time T_2 and Vz for a time T_0.

$$V_1T_1+V_2T_2+VzT_0= Vref\ T$$

Where $T=T_1+T_2+T_0$

The entire 360 degree is divided in to six sectors. Suppose initially the switching state is (000) which corresponds to V_0 applied for time $T_0/2$. Now the upper switch of phase a is turned on which corresponds to V_1 (100) for a time interval of T_1, then the upper switch of phase b is turned on corresponding to V_2(110) applied for a time T_2 and finally the upper switch of phase c turned on corresponding to V_7 (111) for $T_0/2$. The above procedure is repeated for another half cycle to complete one full cycle and the switching patterns are generated as shown in Fig.4.

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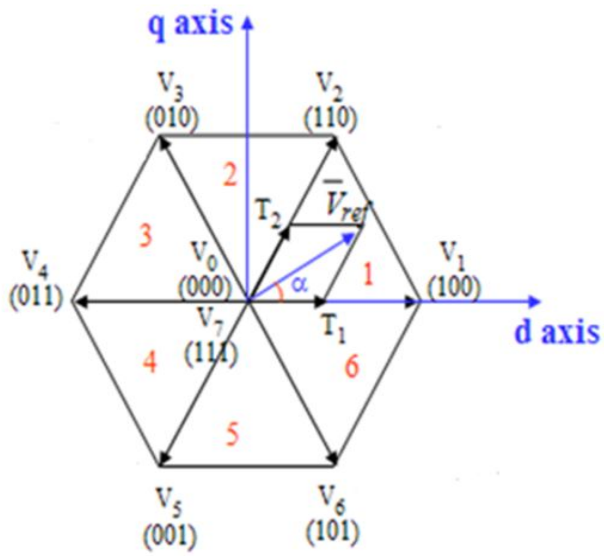

Fig.3 Switching Vectors and Sectors

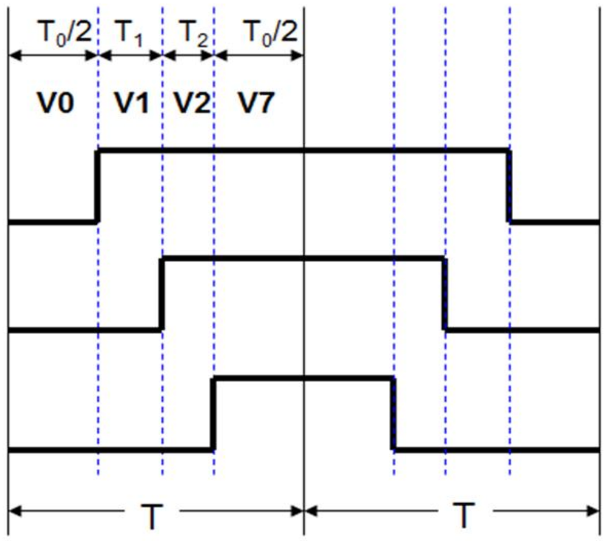

Fig.4 Space Vector PWM switching patterns at sector I

Space Vector PWM generates less harmonic distortion in the output voltage or currents in comparison with sine PWM. Also Space Vector PWM provides more efficient use of supply voltage in comparison with sine PWM. Voltage Utilization for Space Vector PWM = 2/√3 times of Sine PWM since locus of space vector for sine PWM is a circle with radius ½Vdc whereas for SVPWM is a circle with radius 1/√3Vdc as shown in Fig.5.

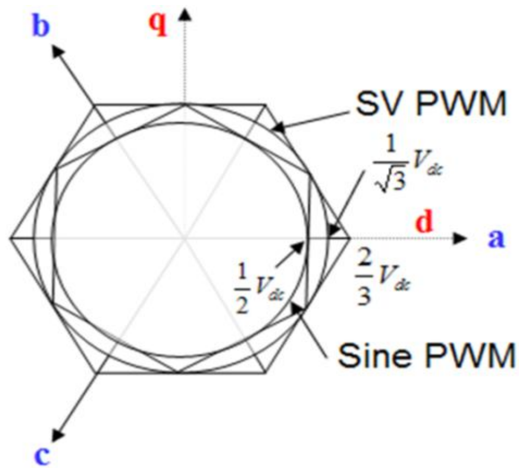

Fig.5 Locus comparison in SPWM and SVPWM

IV.SIMULATION

Implementation of space vector modulation for multilevel inverters is complex and computationally intensive. Therefore a two-level inverter based SVPWM algorithm for a multilevel inverter is used for developing the model for a Three-level NPC inverter fed Induction motor [6]. Simulation of Dual Two-Level inverter fed open-end winding induction motor is done in MATLAB. SVPWM is implemented using Matlab Function block where the pulses for upper switches of the inverter are obtained as shown in Fig.6. The pulses for lower switches are obtained by taking the compliment of corresponding upper switches. Depending up on the switching patterns in each sector the switching times for upper switches are obtained as shown in Tab.2 [5].

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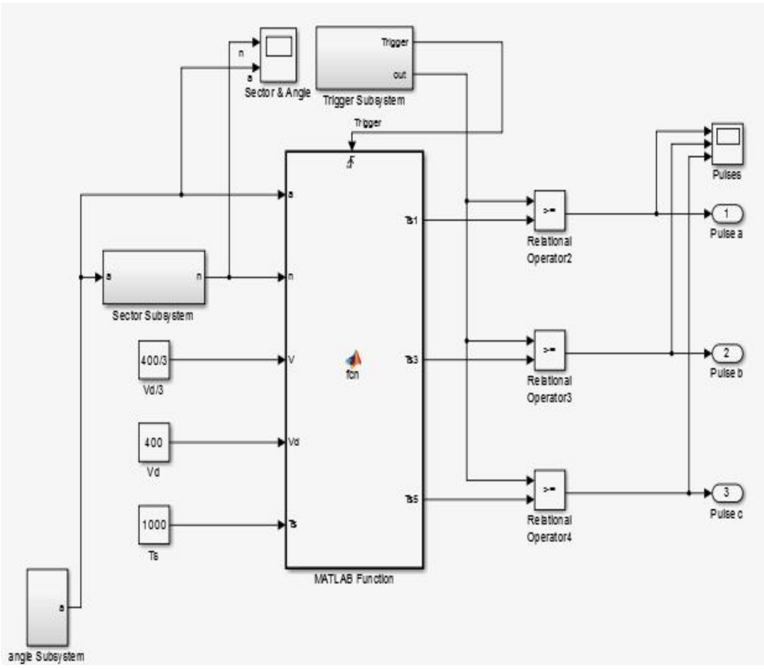

Fig.6 SVPWM Implementation using Matlab Function

The control pulses for inverter switches are generated using SVPWM program code which is to be typed in Matlab function block as shown in Fig.6. Angle subsystem and Trigger subsystem are basically ramp function generators. In the Space Vector PWM, the three-phase output voltage vector is represented by a reference vector that rotates at an angular speed of ω = 2πf. Trigger is used for repeating the ramp after every cycle where the carrier frequency can be specified. Sector subsystem determines, in which sector reference vector lies. It is necessary to know in which sector the reference output lies in order to determine the switching time and sequence.

Tab.2 Switching sequence table for each switch in each leg

Sector	Upper Switches (S1,S3.S5)
1	S1 = T1 + T2 + T0 / 2 S3 = T2 + T0 / 2 S5 − T0 / 2
2	S1 = T1 + T0 / 2 S3 = T1 + T2 + T0 / 2 S5 = T0 / 2
3	S1 = T0 / 2 S3 = T1 + T2 + T0 / 2 S5 − T2 + T0 / 2
4	S1 = T0 / 2 S3 − T1 + T0 / 2 S5 = T1 + T2 + T0 / 2
5	S1 = T2 + T0 / 2 S3 = T0 / 2 S5 − T1 + T2 + T0 / 2
6	S1 = T1 + T2 + T0 / 2 S3 = T0 / 2 S5 = T1 + T0 / 2

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Dynamic model of induction motor is implemented in MATLAB to study the transient as well as steady state behaviour of the drive system. The d-q equivalent circuit is used for obtaining the model equations in terms of flux linkage using one of the popular induction motor models known as Krause's model [7]. Dynamic or d-q equivalent circuit in synchronously rotating reference frame where d-q axes rotate at synchronous speed for modelling induction motor is shown in Fig.7.

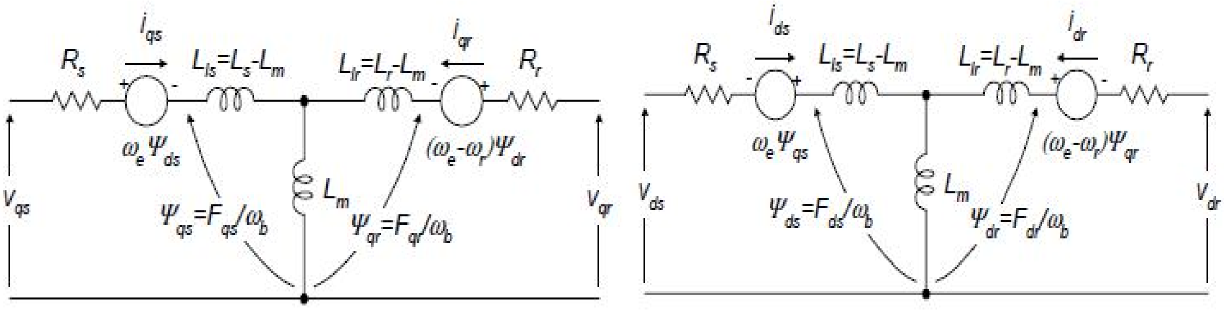

Fig.7 d-q equivalent circuit of an induction machine

The conventional d-q model of a normal 3-phase induction motor is modified to compute the motor phase current of the open-end winding induction motor drive as shown in Fig.8. Inverters are modelled using basic output voltage equations. The pole voltages of the individual inverters are then computed. Subtracting the pole voltages of inverter-2 from those of inverter-1, the difference of pole voltages is obtained and is impressed onto the conventional d-q model of induction motor to compute the motor phase currents.

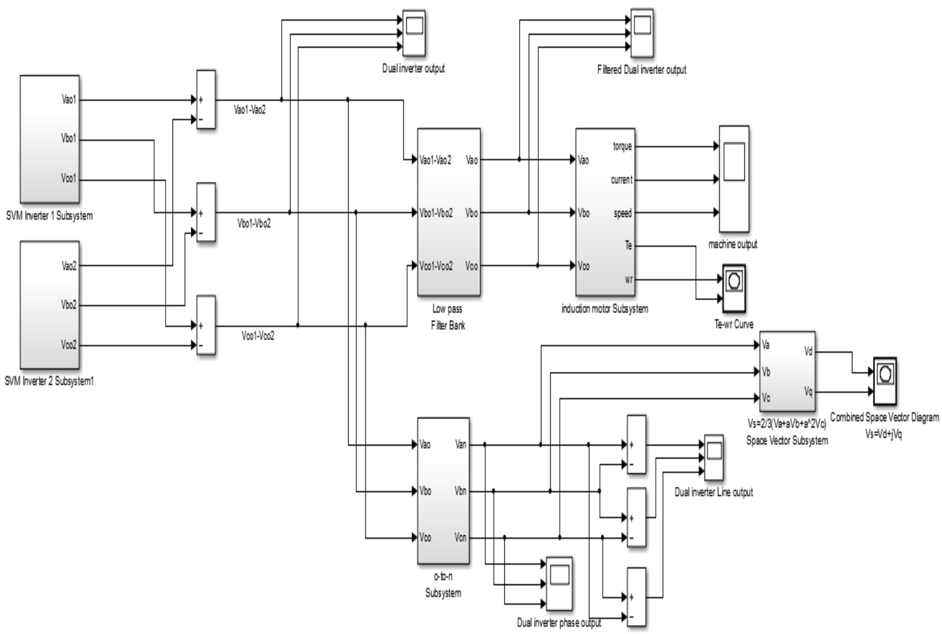

Fig.8 Simulink model of an open-end winding induction motor

V. RESULTS AND DISCUSSION

The proposed SVPWM scheme is simulated in MATLAB for a 2Hp open-end winding induction motor with a single power supply. The output voltages of the Three-level NPC inverter and Dual Two-level inverter are shown in Fig.9 and Fig.10. The space vector diagram obtained at the output of X-Y plot of Dual Inverter is shown in Fig.11. Fig.12 shows Torque-Speed Curve of machine in motoring region where the machine almost accelerates freely to synchronous speed (ωe=314.2rad/sec). Program code for SVPWM is implemented based on the switching time equations in each sector as shown in Tab.2.

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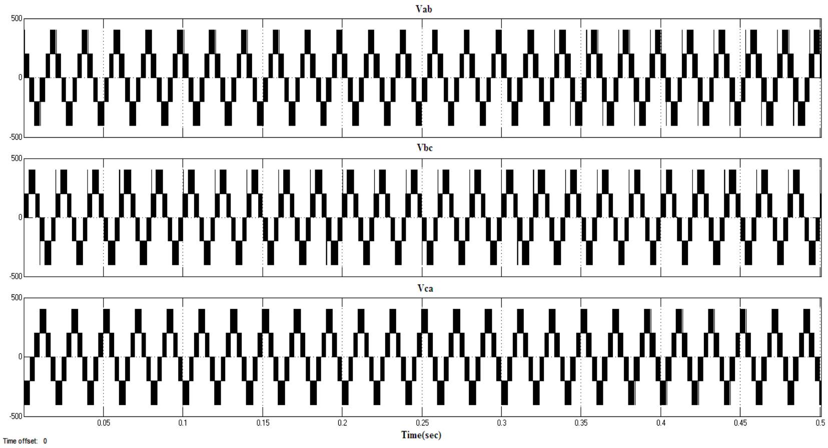

Fig.9 Three-level inverter line output

From Fig.9 and Fig.10 it can be observed that open-end configuration with a dc-link voltage of 200V produce the same three-level inversion at the output similar to the conventional three-level NPC topology with a dc-link voltage of 400V. Therefore the proposed work utilizes only half the dc-link voltage compared with conventional scheme.

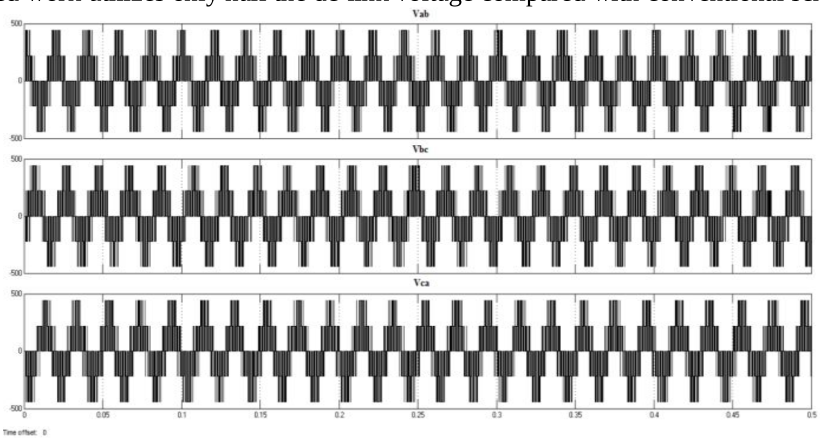

Fig.10 Dual inverter Line output

The space vector diagram of Dual inverter fed open-end configuration as shown in Fig.11 contains 27 switching states with 19 distinct voltage vectors as similar to Three-Level NPC Inverter.

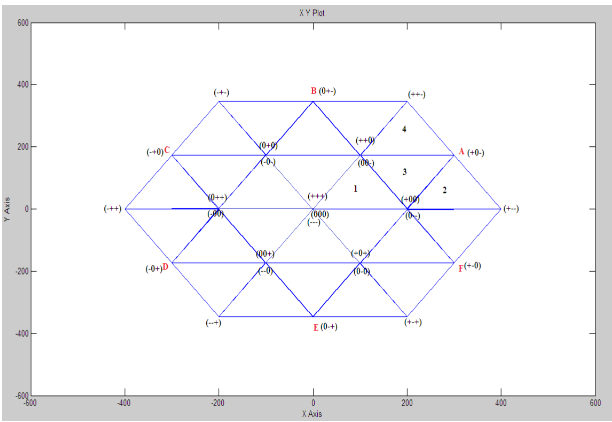

Fig.11 Space vector diagram of Dual Inverter

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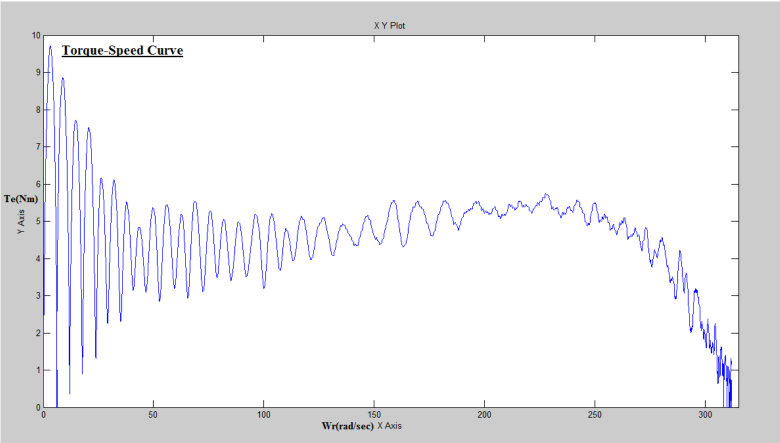

Fig.12 Torque-Speed Curve of Induction Machine in Motoring mode

VI.CONCLUSION

Simulation of a Dual Two-level inverter fed induction motor Drive is done in MATLAB and concluded that Dual Two-level inverter fed open-end winding scheme produce the same three-level inversion as that of a conventional three-level NPC multilevel inverter topology without any drawbacks and it can be extended for higher levels.

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BIOGRAPHY

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