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Dodecagonal Space Vector PWM for Two Level Inverter Fed Open End Winding Induction Motor Drive

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Abstract: A dodecagonal space vector pulse width modulation method for a two level inverter fed open end winding induction motor is discussed. Space vector PWM (SVPWM) method is one of the best suited controlling techniques as it reveals better utilisation of dc link voltage, high modulation index and posses only less harmonics compared to other methods. For conventional hexagonal SVPWM, output voltage is not purely sinusoidal which results in more harmonic contents. So to overcome this problem, 12 sided SVPWM is used. Since the 12 sided polygonal structure is near to a circular shape, the output so obtained will be near to sinusoidal. This will reduce the harmonics and a better input is given to the induction motor. It can be seen that fifth and seventh order harmonics is completely eliminated from the output voltage. Dodecagonal SVPWM is achieved by connecting two 2 level inverters on both sides of an open end winding induction motor. Here equal power is fed from both ends of the induction motor and the inverters which are of half the rated machine can be used. Thus the cost regarding the inverters can be reduced. Here, dodecagonal space vector PWM for two level inverter fed open end winding induction motor is simulated in MATLAB and the simulation results obtained shows that the Total Harmonic Distortion (THD) is only 4.34% for an output phase voltage of 415 V with a speed of 1425 rpm.

Keywords: Space Vector Pulse Width Modulation (SVPWM), Dodecagonal SVPWM, Total Harmonic Distortion (THD), Open End Winding Induction Motor, Sinusoidal Pulse Width Modulation (SPWM).

I. INTRODUCTION

Within the last decade, there have been major improvements and advancements in the field of power electronics. One of such advancement is in the case of inverter and its controlling techniques. An Inverter is basically a converter that converts DC to AC power. A voltage source inverter (VSI) is one that takes in a fixed voltage from a device, such as a dc power supply, and converts it to a variable-frequency AC supply. There are many applications for the inverters. One such major application of inverter is the speed control of Induction Motor Drive.

Different Control techniques have been invented and introduced for the inverters. Pulse Width Modulation Technique reveals the best controlling of the inverter. Pulse-width modulation (PWM) is a technique where the duty ratio of a pulsating waveform is controlled by another input waveform [1], [2] called reference waveform. The intersections between the reference voltage waveform and the carrier waveform give the opening and closing times of the switches. The output voltage of the inverter consists of fundamental component and harmonic component. This harmonics should be eliminated to achieve a better output voltage. By using pulse width modulation we can reduce the amount of harmonics in the output, control output voltage without the addition of any external components, reduce switching losses and can maximise the dc bus utilisation. Out of these advantages, the main disadvantage possessed by this scheme is that the switching devices used in the inverter are expensive as it possesses low turn-ON and turn-OFF times [3]. But the PWM is commonly used in applications like motor speed control, converters, audio amplifiers, etc [1], [4] since, the switching harmonics can be filtered out easily. Single Pulse Width Modulation and Multiple Pulse Width modulation techniques are not commonly used for induction motor drives as it introduces more harmonics in the output voltage [5]. Third Harmonic Injection PWM which was developed to improve the performance of inverter does not define the procedure for determining the amount of added third harmonic component [14]. Other modulation techniques like trapezoidal, stair case and stepped possess more harmonics in the output waveform [1]. The most widely used PWM schemes for three-phase voltage source inverters are carrier-based sinusoidal PWM and space vector PWM (SVPWM). Even though sine PWM is easy to implement, due to the variation of sine wave reference value over a PWM period, the relation between reference values and the carrier values is not fixed [3]. Thus the harmonics in the output voltage will be more, resulting in the undesired low frequency torque and speed pulsations. Also output obtained will be low [7]. Recently, Space Vector PWM techniques are used to improve the performance of inverters for the induction motor drive applications due to its high modulation index, maximum utilisation of DC link voltage and presence of less harmonic contents in the output voltage [8]. It directly uses the control variable given by the control system and identifies each switching vector as a point in complex space, useful in improving DC link voltage utilization, reduces commutation losses and THD and is also suitable for DSP implementation and optimization of switching patterns as well.

It was found that, there will be substantial amount of low frequency harmonics, mainly fifth and seventh harmonics in the motor phase if we are using PWM based on conventional hexagonal voltage space vector structure (as in Fig.1) in an inverter fed induction motor drive [15]-[20].

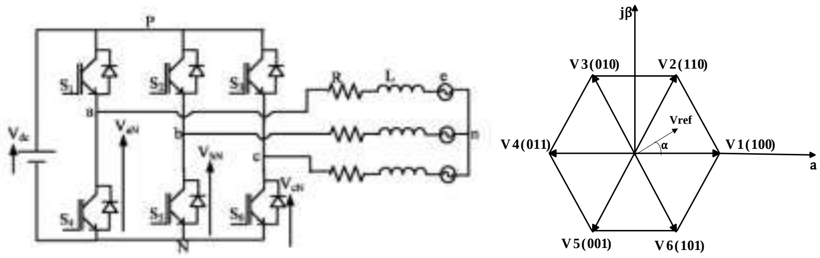

Fig.1. Hexagonal space vector structure from a two level inverter

These harmonics increases the torque pulsations and makes the current control schemes inaccurate. Thus complex compensation techniques are required for smooth current control. Dodecagonal Space Vector PWM based inverter is an improvement over the conventional hexagonal space vector PWM based inverters in this respect. This Dodecagonal Space vector PWM based inverter can eliminate the lower order harmonics like fifth and seventh and make the output more sinusoidal in nature. In this paper, a carrier based Dodecagonal Space vector PWM based two level inverter is discussed for the smooth control of an open end winding induction motor drive [21], [22].

II. DODECAGONAL SPACE VECTOR PWM

Dodecagonal SVPWM is a special switching scheme which is used for the proper controlling of the inverter.

A. Dodecagonal SV structure

For obtaining a 12 sided polygonal space vector structure, two 2 level inverters should be connected on both sides of an open end winding induction motor. Induction motor drives are becoming popular for low and medium power in various industry applications. However, a single 2-level inverter is not suitable to supply the power to the high power motor. This is due to the limitation of the device ratings. Multilevel inverters can overcome this problem. These inverters increase the complexity in the control algorithms. Open-end winding configuration of induction motor fed by two separate conventional inverters with IGBT as switching devices reduces these problems. An induction motor can be made open ended by disconnecting the neutral point. The circuit configuration for 12 sided polygonal PWM for inverter for the speed control of induction motor is shown in Fig.2 [11]-[15].

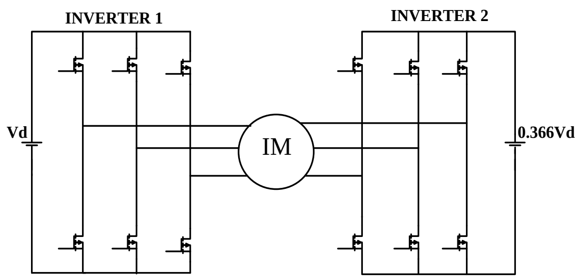

Fig.2. Basic circuit diagram of an open end winding induction motor fed two level inverters for obtaining Dodecagonal SV structure

The circuit in Fig.2 generates dodecagonal SV structure using the combinations of two hexagonal SV structures obtained from each inverter. As shown in Fig.2, inverter-1 and inverter-2 feed the motor from two isolated dc-link sources. The voltage ratio of the two dc-link sources is 1: 0.366. In the present case the dc-link voltage of inverter-1 is 1 V and the dc-link voltage (V_d) of inverter-2 is 0.366 V. The voltage space vector positions of the individual inverters

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(inverter-1 and inverter-2) are shown in Fig.3. Here the voltage magnitude of hexagonal structure from inverter 2 is 0.366 times that of the inverter 1.

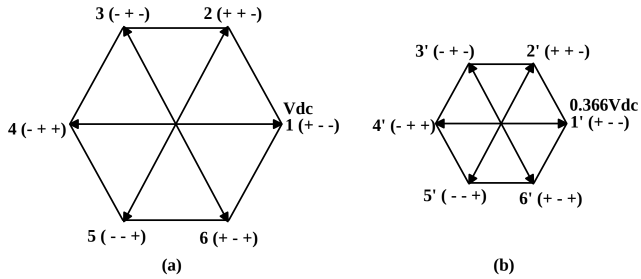

Fig.3. Hexagonal Space Vector structure from inverter 1 and inverter 2

The combinations of the vectors of two hexagonal SV structures provide the dodecagonal SV structure for synthesising the reference vector. The different combination of vectors (see Fig.4) for producing dodecagonal structure are (1,3'), (1,5'), (2,4'), (2,6'), (3,5'), (3,1'), (4,6'), (4,2'), (5,1'), (5,3'), (6,2'), (6,4'). Since the switching vector magnitude of a two-level inverter is proportional to the value of its dc-link voltage, a dc-link voltage ratio of 1: 0.366 between inverter-1 and inverter-2 is needed to realize a resultant 12-sided polygonal voltage space phasor location of Fig.4. The set of certain space vector combinations of (1,3'), (1,5'), (2,4'), (2,6'), (3,5'), (3,1'), (4,6'), (4,2'), (5,1'), (5,3'), (6,2'), (6,4') makes a 12–sided polygon at their vertices with a dc-link voltage ratio of 1 : 0.366 between the inverters.

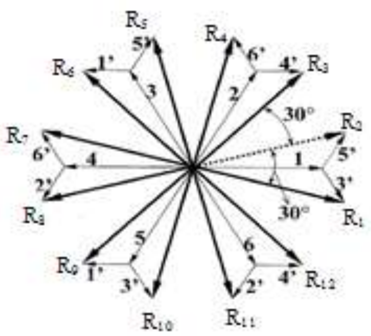

Fig.4. Selected combinations of the vector positions from inverter-1 and inverter-2.

By using vector positions at the vertices of the 12–sided polygon (adjacent vectors are 30 separate), appropriately for PWM operation, all the 5th and 7th order harmonics can be cancelled from the motor phase voltage. This set of 12 space vectors can be divided into two sets, one consisting of vectors (1,3'), (2,4'), (3,5'), (4,6'), (5,1'), (6,2') and the other consisting of vectors (1,5'), (2,6'), (3,1'), (4,2'), (5,3'), (6,4') separated by 30°. Therefore, if these two sets of vector are switched (clockwise direction) with a 30° phase delay in time, the fundamental component of both these sets add up because the fundamental of the leading set of vectors move by 30° clockwise in space when lagging set of vectors are switched. However, the 5th order harmonics (negative-sequence components , etc.) of the leading set of vectors move by 150° anticlockwise in space when lagging set of vectors are switched, and comes exactly in opposition to the 5th harmonics of the lagging set of switching vectors and cancel each other. Hence, the 5th order harmonics of both sets of vectors cancel each other. This is also true with the 7th order harmonic components produced by the leading set of vectors, which rotate by 210° clockwise and comes in exact opposition to that of the lagging set and, hence, cancel each other. Thus, a 30° vector disposition of switching vectors (seeFig.4), cancels all the 5th and 7th order voltage harmonics from the motor phase.
Table 1 shows the switching states for inverter 1 and inverter 2. In Fig. 4, the vector ‘1’ of inverter-1 and vector ‘3'’of inverter-2 is combined together to obtain the resultant vector ‘R_1’. Likewise, to obtain the resultant vector R_2, a combination of the vector ‘1’ of inverter-1 and vector ‘5'’ of inverter-2 is considered as per table 1.

B. PWM timing calculations
The PWM timings can be calculated by volt-sec balance equation. The volt-sec balance equations for Fig. 5 are,

$$V_{R1} T_s = V_1 T_1 + V_2 T_2 \quad (1)$$

$$V_{R1} T_s = T_1 V{<}15^{\circ} + T_2 V{<}{-15}^{\circ} \quad (2)$$

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$$T_s = T_1 + T_2 + T_0 \tag{3}$$

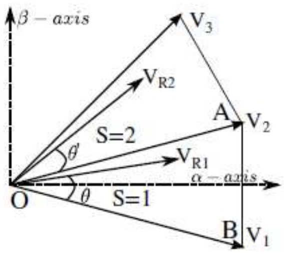

Fig.5. Position of reference vectors in sector S=1 V_{R1} and V_{R2} in sector S=2

V_{R1} is the reference vector in Sector-1, V is the magnitude of V_1, V_2 and the radius of the dodecagon as given in Fig. 5.

TABLE I SWITCHING STATES OF INVERTER 1 AND INVERTER 2

Vectors	Inverter 1 switching state	Inverter 2 switching state
R_1	100	010
R_2	100	001
R_3	110	011
R_4	110	101
R_5	010	001
R_6	010	100
R_7	011	101
R_8	011	110
R_9	001	100
R_{10}	001	010
R_{11}	101	110
R_{12}	101	011

The above equation can be written in terms of complex variables as given below.

$$\frac{T_s}{V}(V_\alpha + j\,V_\beta) = T_1\,(\cos 15° - j\,sin15°) + T_2\,(\cos 15° + j\,sin15°) \tag{4}$$

By separating the real and the imaginary parts, the above equation is represented as a matrix equation as given below.

$$\frac{T_s}{V}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} cos15° & cos15° \\ -sin15° & sin15° \end{bmatrix}\begin{bmatrix} T_1 \\ T_2 \end{bmatrix} \tag{5}$$

T_1 and T_2 can be calculated as follows.

$$\begin{bmatrix} T_1 \\ T_2 \end{bmatrix} = \frac{\frac{T_s}{V}\begin{bmatrix} sin\,15° & -cos\,15° \\ sin\,15° & cos\,15° \end{bmatrix}}{2 sin\,15° cos\,15°}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{6}$$

Now the timing calculation for sector 1 is obtained as,

$$T_1 = 2\text{m}\,T_s \sin\left(\frac{\pi}{6} - \alpha\right) \tag{7}$$

$$T_2 = 2\text{m}\,T_s \sin(\alpha) \tag{8}$$

$$T_0 = T_s - (T_1 + T_2) \tag{9}$$

Where, m is the modulation index. Similarly, the timings for other 12 sectors can be calculated.

III. SIMULATION RESULTS

A 1HP, 415 V, 50 Hz open end winding induction motor is used for MATLAB simulation. Two inverters are fed from two separate DC sources of 600V and 220V for obtaining the dodecagonal structure for generating the dodecagonal PWM. First, the system is analysed using an RL load of R=100Ω and L=1mH. Fig.7 shows the simulation results with output voltage of 415 V for a 50 Hz frequency with the corresponding gating signals (see Fig. 6).

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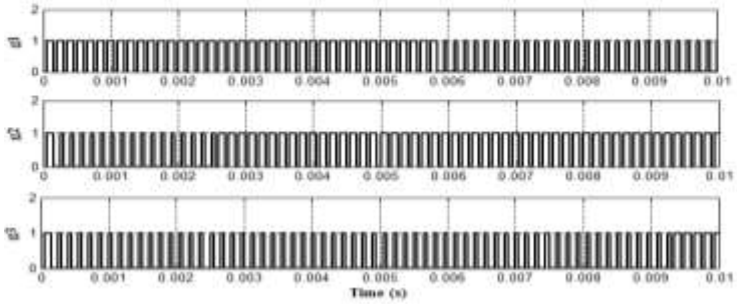
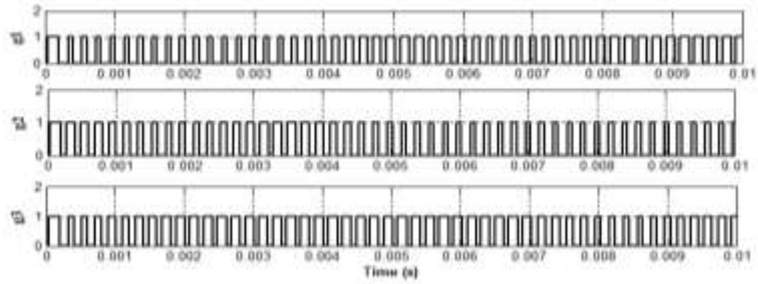


(a)



(b)

Fig.6. (a) Gating pulses for inverter 1 (b) Gating pulses for inverter 2

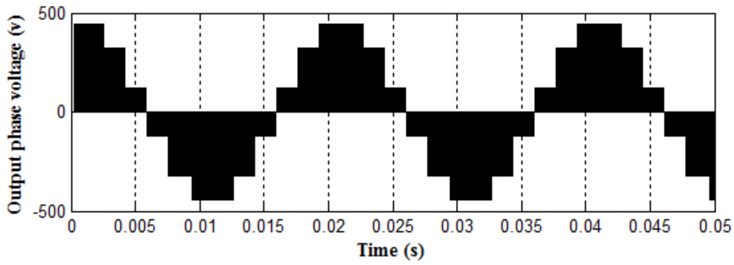
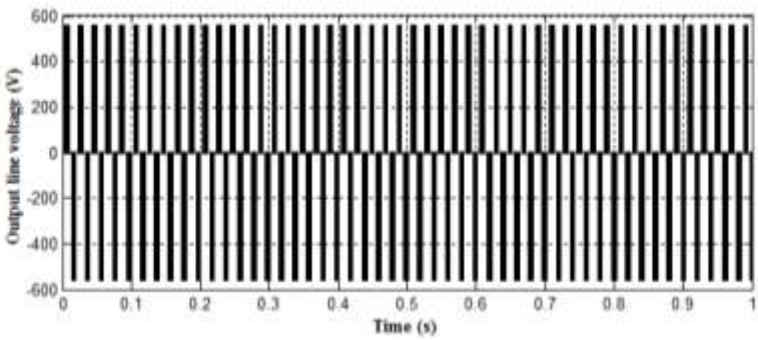
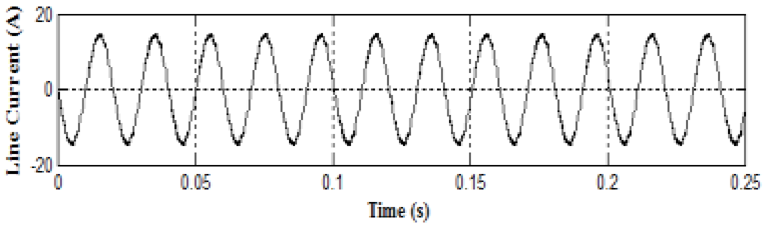


Fig.7. Output phase voltage for phase ‘A’

The corresponding output line voltage and line current is obtained as shown in Fig. 8.



(a)



(b)

Fig.8. (a) Output line voltage (b) Output line current

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The FFT analysis of the output phase voltage is shown in Fig.9. The analysis shows that the 5th and 7th harmonics is completely eliminated which reduces THD and makes the waveform more sinusoidal.

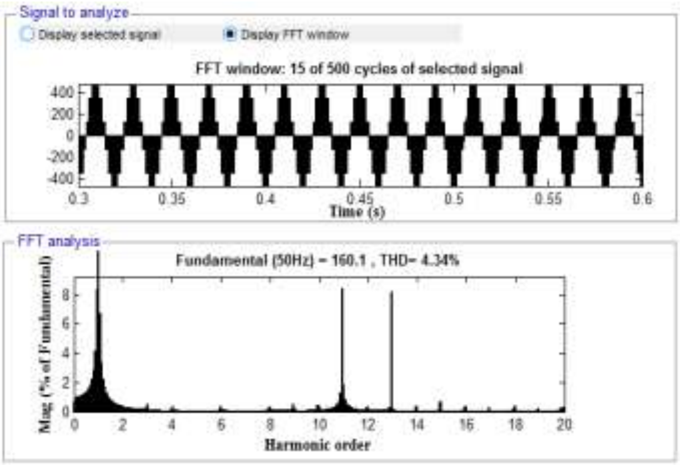

Fig.9. FFT analysis of output phase voltage obtained from dodecagonal SVPWM

Here, THD obtained is 4.34% which is as per the IEEE standard.
The output phase voltage and the corresponding FFT analysis obtained from conventional hexagonal SVPWM are shown in Fig.10 for a comparison with the dodecagonal SVPWM.

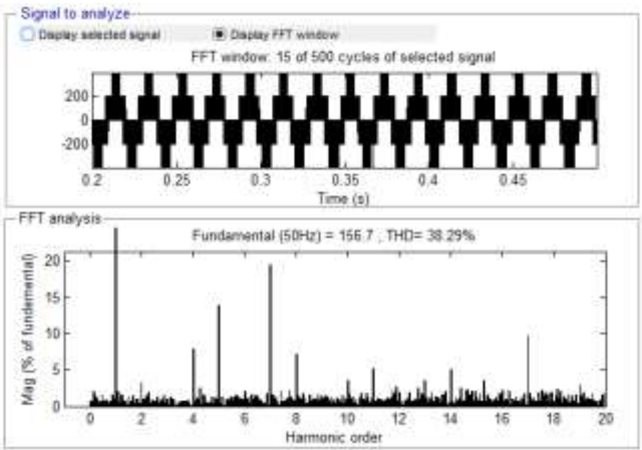

Fig.10. FFT analysis of output phase voltage obtained from hexagonal SVPWM

Here we can see the presence of 5th and 7th harmonics and the THD is on the higher side which is 38.29%.
The two dodecagonal SVPWM inverters are connected to the open end winding induction motor and the speed, current and torque relations are obtained as shown in Fig. 11.

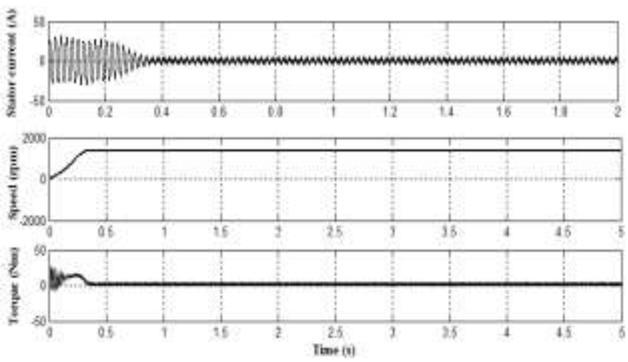

Fig.11. Stator current, speed and torque of open end winding induction motor

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The speed of the open end winding induction motor is obtained as 1425 rpm.

IV. CONCLUSION

The space vector diagram used in this study, characterised by dodecagonal space vectors eliminates the lower order fifth and seventh harmonics and makes the output voltage waveform more sinusoidal. This results in the smooth operation of the induction motor drive with a speed of 1425 rpm. Here, the obtained output voltage THD is 4.34% which is as per the IEEE standard. In comparing the dodecagonal and conventional hexagonal SVPWM, it is found that dodecagonal SVPWM gives better performance in controlling of the inverter and also the induction motor drive. The discussed topology with the synchronous PWM operation may be extended to higher power levels for high power electronic applications.

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