International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

Dodecagonal Space Vector Generation For Multilevel Inverter Fed Induction Motor Drive

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Abstract

The proposed power circuit that consists of three cascaded two level inverters generates Dodecagonal space vector structure. From this scheme it is possible to control an IM under V/F mode. Harmonics of the order 5^{th}&7^{th}can be eliminated completely.Torque pulsations and losses are reduced due to the reduction in harmonics.

***Index terms*: Dodecagonal, Harmonics, SVPWM.**

I. INTRODUCTION

Ever since the invention of the 3-level inverter [1], multilevel inverters are a major topic of ongoing research. The advantages of multilevel inverters are discussed in literatures.

With the introduction of multilevel converters, switches with lower voltage rating could be used. From the MLI operation, the harmonics in the output waveform can be shifted to higher frequencies which in turn reduce the size of filters. The dv/dt stress on individual device is less and this will help to reduce EMI problems [2]-[4]. Also the switching frequency can be maintained at a lower value in order to reduce switching losses without sacrificing the quality of the output waveform.

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A dodecagonal space vector inverter is a class of multilevel inverter in which 12 voltage space vectors 30° apart are produced along the radii of a 12 sided polygon known as a "dodecagon"**(Fig.2).** The concept of dodecagonal space vectors has been in vogue in the recent past [5-10]. There are some advantages with dodecagonal space vectors structure over the hexagonal structure from conventional two level inverters. By this method 6n±1 (n=odd) harmonics are completely eliminated. There is also an increase in the linear modulation range. The maximum fundamental peak available for a hexagonal structure is 0.577 & for the structure with 12 sides it is 0.644.So 11.6% [0.644/0.577] more linear region is possible from dodecagonal mode structure.

The power circuit is shown in **Fig. 1**, it is the same as in paper [5], but the DC link voltages are different and the combination of switches needed to generate the voltage space vectors are different.There are 12 principal voltage space vectors from this topology.A reference vector lying in a sector can be generated by time averaging the two principal voltage space vectors encompassing the sector.

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II. POWER CIRCUIT AND VOLTAGE SPACE VECTORS

The proposed topology is realized by cascading three conventional two-level inverters, fed from asymmetrical isolated dc voltage sources of value 0.577k V_{dc},0.423k V_{dc}& 0.155V_{dc} as shown in **Fig-1**.(the factor 'k' is selected such that the radii of the 12-sided voltage space vector polygon is the same as that of the conventional hexagonal voltage space vector structure.

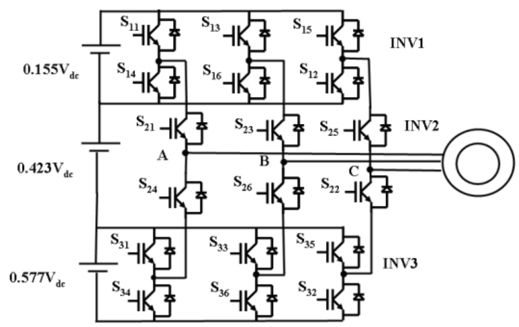

Fig- 1: Power circuit of the proposed scheme.

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The total voltage is 1.155Vdc. Each phase can take four different levels;0.577kV_{dc}, 0.423kV_{dc}&0.155kV_{dc}. The twelve space vectors are formed by combination of voltage space vectors along three phases.

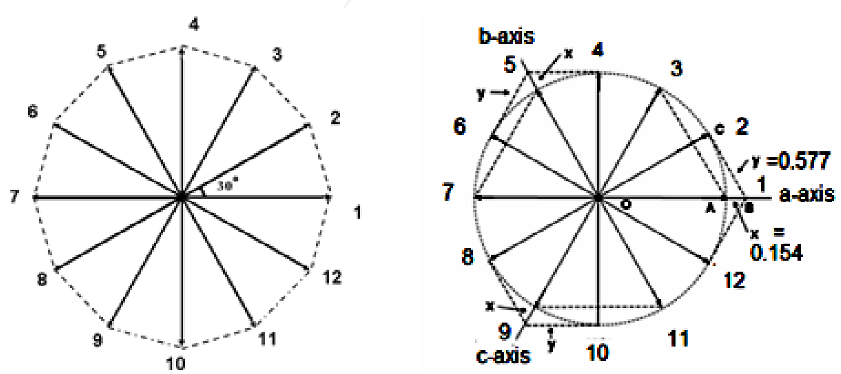

Fig- 2: dodecagonal space vectors & its formation

Table-1: Generation of the 12 voltage space vectors

Vector no.	a-phase	b-phase	c-phase
1	1.0Vdc	0	0
2	1.155Vdc	0.577Vdc	0
3	1.0Vdc	1.0Vdc	0
4	0.577Vdc	1.155Vdc	0
5	0	1.0Vdc	0
6	0	1.155Vdc	0.577Vdc
7	0	1.0Vdc	1.0Vdc
8	0	0.577Vdc	1.155Vdc
9	0	0	1.0Vdc
10	0.577Vdc	0	1.155Vdc
11	1.0Vdc	0	1.0Vdc
12	1.115Vdc	0	0.577Vdc

Figure 2 shows the twelve space vectors as the radii of a dodecagon and how the space vectors are constructed from the three phases. Vectors OA and OC are of magnitude $1V_{dc}$, AB or “x” is of magnitude 0.155 V_{dc} and BC or “y” is of magnitude $0.577V_{dc}$. Vector OC is seen as the resultant of OB along “a” axis and BC along b-axis. Similarly all the 12 principal vectors can be constructed from the components. The **Table-1** gives the voltage levels that need to be in each phase to generate the 12 principal space vectors.

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The harmonics seen in the phase voltage are the 12n±1 (n=integer) harmonics. These are predominant at lower speeds. At high speeds of the order of 50Hz, the harmonics constitute less than 10% of the fundamental.

III. SPACE VECTOR PWM

The voltage space vector is defined by the following expression:

$$V_S = V_a + V_b.e^{\frac{2\pi}{3}j} + V_c.e^{\frac{4\pi}{3}j}$$

If V_a, V_b and V_c are three phase quantities with magnitude $V_m$and phase difference 120^0 then the voltage space vector V_S turns out to be a vector rotating in time with a magnitude of$\frac{3}{2}$ V_m.

In the space vector PWM (SVPWM) technique, one aims at generating a rotating space vector and this is done by time averaging the principal space vectors present in order to emulate the rotating space vector. This results in a PWM pattern in the output phases similar to other PWM techniques such as sine triangle PWM. However SVPWM is far more amenable to implementation using a DSP.

Here T_S is the sampling period, T_1 is the amount of time for which the lower vector in **Fig.3** is kept active and $T_2$is the time duration for which the upper vector is kept active. This is done in every sector in which the resultant space vector V_1 lies at the angleθ. $T_o$is the dead time during which there is no output and it is negative if there is over-modulation.

IV. V/F CONTROL USING THE INVERTER

V_{dc} is so chosen so that at 50Hz operation, the peak phase voltage is 325V, this corresponds to V_{dc}=505V.

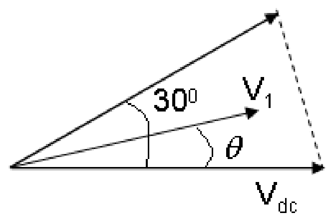

Fig. 3: Time averaging vectors forming a sector

The time duration for which each space vector should be active is given in equation-(1)

$$T_1 = \frac{V_1}{V_{dc}}.T_S.\frac{Sin(30^\circ - \theta)}{Sin(30^\circ)}, T_2 = \frac{V_1}{V_{dc}}.T_S.\frac{Sin(\theta)}{Sin(30^\circ)}, T_s=T_1+T_2+T_o \text{--------(1)}$$

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The number of samples per sector selected for this study is given below.

0<f<=15Hz: 4 samples per sector; 15<f<=30Hz: 3 samples per sector;30<f<=45Hz : 2 samples per sector;45<f<=50Hz: 1 sample per sector

At 50Hz each principal vector is kept active for $\frac{1}{12*f}$=1.667ms and results in a 12 step waveform, in this case $T_1$is 1.667ms, T_2=0 and T_S= T_1, and dead time To =zero. At 47Hz operation, since we are using a constant V/f ratio, $T_1$and T2 are the same but $T_S=\frac{1}{12*f} = \frac{1}{12*47}$=1.77ms, SoTo=0.1064ms.In the 30 to 45 Hz frequency range ,θ = 0° and 15°. Here $T_S=\frac{1}{2*12*f}$.The tables summarize the time durations T_1, T_2 and To that are needed at a particular frequency of operation.

Table- 2: Time durations for frequency between 30 and 45Hz;Table -3: Time durations for frequency between 15 and 30Hz&Table-4: Time durations for frequency 15Hz and below.

TABLE-2

	$\theta = 0^\circ$	15^0
T_1	833.3 μ s	431.4 μ s
T_2	0	431.4 μ s

TABLE-3

	$\theta = 0^\circ$	10°	20°
T_1	555 μ s	380 μ s	193 μ s
T_2	0	193 μ s	380 μ s

For15Hz<f<=30Hz, $T_S = \frac{1}{12*3*f} = \frac{1}{36f}$, and for 0<f<=15Hz, $T_S = \frac{1}{12*4*f} = \frac{1}{48f}$

TABLE-4

	$\theta = 0^\circ$	7.5°	15°	22.5°
T_1	416.67 μ s	318.90 μ s	215.68 μ s	108.77 μ s
T_2	0	108.77 μ s	215.68 μ s	318.90 μ s

The entire system is simulated using SIMULINK. The operating frequency is an input to the controller. A counter chooses the sector in which the voltage space vector is located. It also selects the angles at which the space vectors are to be generated. T_1 , T_2 and $\frac{T_o}{2}$ are taken as per the above explanation. The logic is as follows. When the value $\frac{T_o}{2}$ is greater than the carrier triangular value the output (P as shown in **Fig-4**) is high. Similar logic is used for the output Q &R. Q-P = T_1& R-Q= T_2

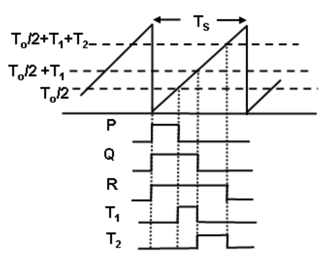

Fig.4: PWM signal generation

A saw tooth waveform as shown in fig. 4 with a time period Ts is used to generate the T_1 and T_2 durations. Look up tables are used to store the pole voltage levels which decide the principal space vector combinations as in table-1.

ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

V. SIMULATION RESULTS

The **fig.5** shows the pole voltage& phase voltage at a frequency of 50Hz .Here the 12 step waveform is clearly seen.**Fig.6** shows the Fourier components in the phase voltage at 50Hz. In this only the 12n±1 harmonics are seen and their amplitudes are less than 10% of the fundamental. Complete absence of the 6n±1 (n=odd) harmonics is observed.The motor current at 50Hz operation is nearly a pure sinusoidal waveform as the harmonics are very low.

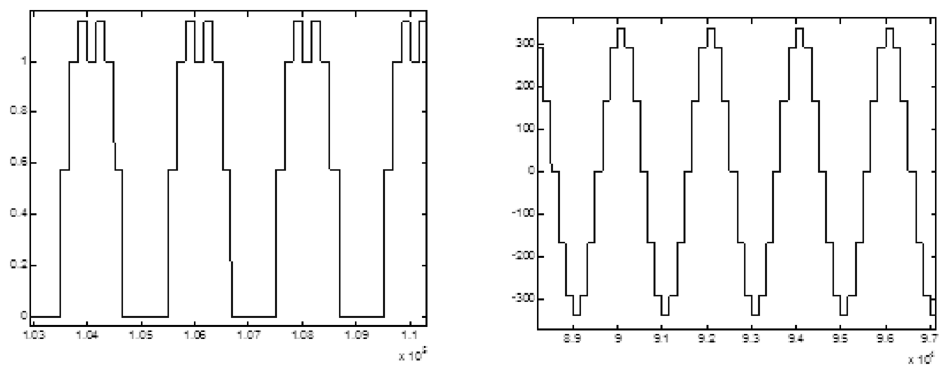

Fig. 5: Pole voltage& Phase voltage at 50Hz

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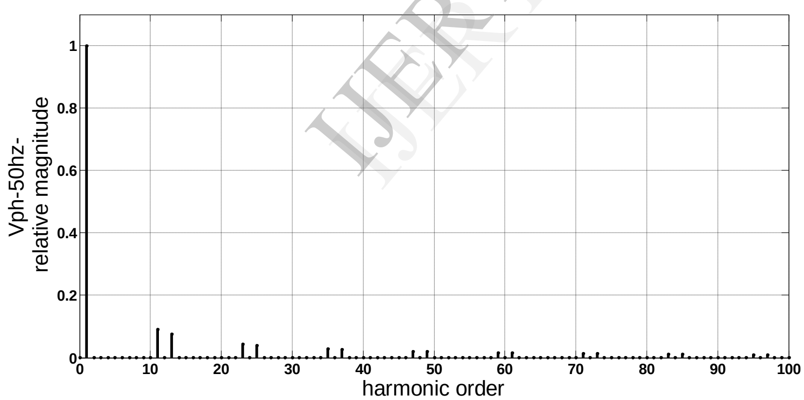

Fig-6 Fourier of phase voltage at 50 Hz

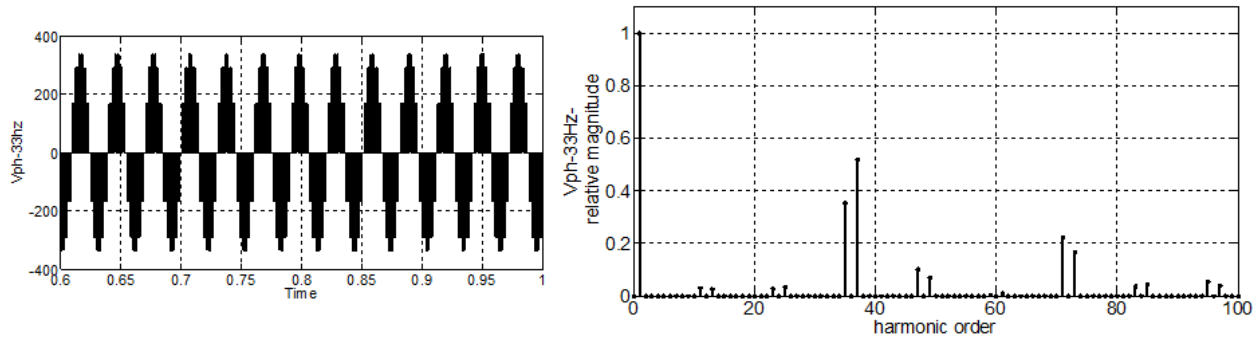

Fig-7 Phase voltage and its FFT spectra at 33Hz

Figures7 showsthephase voltage and itsFFT spectra at 33Hz and observe the absence of 6n±1 (n=odd) harmonics in the FFT spectra.

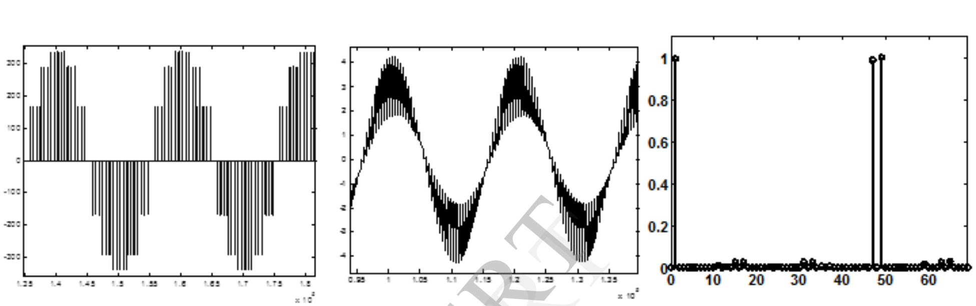

Fig. 8: $V_{ph,}$ current&Fourier components of phase voltage at 5 Hz

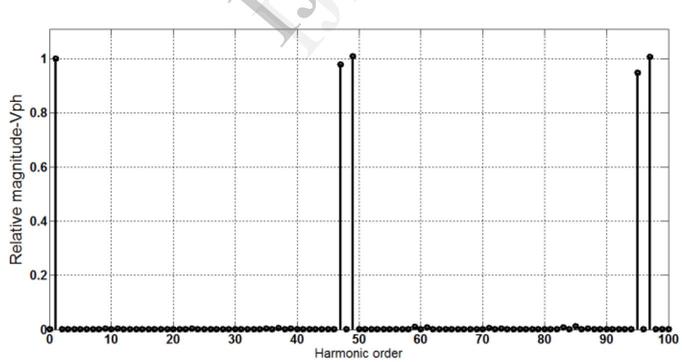

Fig-9 Fourier components of phase voltage at 10 Hz

The current, phase voltageand itsFourier components at5Hz operation are shown in **fig.9.**

Upto 15Hz as the number of samples per sector is 4; the switching frequency is 4x12=48 times the fundamental. As even harmonics are absent due to the symmetry, prominent harmonics of the order of 47^{th}&49^{th} are seen as shown in **fig-8 and 9**. TABLE-5 gives a comparative study of harmonic contents in the phase voltage and current atdifferent frequencies.

TABLE-5

WTHD from dodecagonal SV scheme

Frequency of operation In Hz	WTHD-Phase voltage	WTHD-current
50	.0097	.0144
40	.0177	.0161
33	.0179	.0037
14	.0314	.0032

VI. CONCLUSIONS

The paper introduces one to a dodecagonal space vector based multilevel inverter. There is an increase in the linear modulation range.Torque pulsations and losses can be reduced due to the absence of$6n\pm1$, n=odd harmonics in the entire modulation range.

In this case the switching takes place between the zero vectors and the vector at the boundary of the polygon structure. The disadvantages are the existence of higher dv/dt & increased device rating. Hence a hybrid scheme, which is a combination of hexagonal & dodecagonal structure, is suggested.

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