Australian Journal of Basic and Applied Sciences, 9(2) February 2015, Pages: 53-63

AENSI Journals
Australian Journal of Basic and Applied Sciences
ISSN:1991-8178

Journal home page: www.ajbasweb.com

A Study of Harmonics in Pulse Width ModulationPower Inverter as a Motor Drive

[1]Dr. Fadhil Abbas M. Al-Qrimli and [2]Hussein Takleef Kadhum

[1]University of Baghdad, Iraq, Department of Electrical Engineering, Faculty of Engineering Aljadriya P.O. Box 47183, Baghdad, Iraq.
[2]University of Baghdad, Department of Electrical Engineering, Faculty of Engineering, Aljadriya P.O. Box 47183, Baghdad, Iraq.

ARTICLE INFO

Article history:
Received 25 October 2014
Received in revised form
26 November 2014
Accepted 29 December 2014
Available online 15 January 2015

Keywords:
Pulse Width Modulation, AC Motor Drive, V/f Constant ratio, Total Harmonics Distortion (THD)

ABSTRACT

Methods of Pulse-Width Modulation PWM can be implemented by using two ways direct digital and carrier-based implementation. The carrier-based pulse-width modulation (CB-PWM) is an efficient method used to enhance the performance of the power inverter by reducing the low order harmonics of its output voltage and current. In this paper three types of PWM are studied using CB-PWM method include; Sinusoidal PWM (SPWM), Continuous Space-Vector PWM (CSVPWM), and Discontinuous Space-Vector PWM (DSVPWM). All these types are applied on a 3-phase voltage source inverter (VSI) drive an induction motor. Variable speed control of an induction motor is conceptually very simple. The frequency and amplitude of the drive voltage must be varied to change the motor speed. So that a model is proposed in this paperto stabilize V/f constant ratio for speed variation. The model is derived from the modulation index (M_a) and the inverter output voltage by the curve fitting method.
The results proved that the stabilizing V/f constant ratio is very efficient, resulting in too small error rates (with no more than ±5% tolerance) for all types of PWM mentioned. The study also compared the results with the international standards of current THD, it explained that some of the mentioned PWM method are very reliable in AC machine drive application, and some of them should be avoidable for this purpose. Furthermore, some of PWM mentioned method may be used for lower frequencies (less than rated frequency). All models in this research are built and simulated in MATLAB 2010a /SIMULINK and programming.

ToCite ThisArticle: Dr. Fadhil Abbas M. Al-Qrimli, Hussein Takleef Kadhum, A Study of Harmonics in Pulse Width Modulation Power Inverter as a Motor Drive. ***Aust. J. Basic & Appl. Sci.**, 9(2): 53-63, 2015*

INTRODUCTION

The dc-ac converter also known as an inverter basically converts dc power to ac power. The DC power input of inverter is obtained from the existing power supply network after its rectification. And can be a battery, photovoltaic, wind energy, or other DC sources (B. Ismail 2008). The filter capacitor across the inverter input terminals provide a constant dc link voltage. Therefore the inverter is called a voltage source inverter (VSI) (M. H. Rashid 2005).

The Inverter is a specified arrangement of switches that chops DC input voltage under the influence of control signals to give an output at which the current flows in both directions (i.e. ACvoltage and current). The oldest invented DC-AC inverters are the single pulse width inverters which gives a single positive or negative pulse at one half cycle. Probably, this type can be used for low power applications, but it performs badly when it works with high power applications. This type of inverters has some good properties like its’ high fundamental component, but has a bad current spectrum which causes problems for the load.

With the availability of high-speed switching devices, it was discovered that; chopping the DC voltage into uniform or non-uniform pulses in specified manner improves the spectrum of the output waveform and gives the facility of voltage control, this method is known as Pulse Width Modulation (PWM)(M. Samter 2007).

The most famousmethod of thePWMis asinusoidal pulse-width modulation (SPWM), where it iscompared sine wave signal called themodulating signalwithtriangular wave athigh frequency, called the carrier signal. This is explained in the next section.

The latest methods of the (PWM) used in the present time to control the inverter switching ON/OFF is the Space-Vector Pulse-Width Modulation (SVPWM). This method contains two basic types are continuous SVPWM and discontinuous SVPWM (A. M. Hava 1999, andG. S. Rao 2011).

Discontinuous SVPWM contain many types most famous are DPWMMax, DPWMMin, DPWM0, DPWM1, DPWM2, and DPWM3. The most recent studies focused about these types of PWM.

Corresponding Author: Dr. Fadhil Abbas M. Al-Qrimli, University of Baghdad, Iraq, Department of Electrical Engineering, Faculty of Engineering Aljadriya P.O. Box 47183, Baghdad, Iraq.

(H.W.Broeck, *et al*. 1988), are studied a space vector concept for deriving the switching instants for pulse-width modulated voltage source inverters and compared it with the commonly used established sinusoidal concept. Based an analytical calculation, the current distortions and torque ripples were evaluated and compared with those of established sinusoidal pulse width modulation.

The two main implementation techniques: Carrier-Based PWM and Direct Digital technique are applied for the Continuous Pulse-WidthModulation (CPWM) and Discontinuous Pulse-Width Modulation (DPWM)(A. M. Hava1999). Output voltage control is an essential feature of adjustable frequency system, and various technique for achieving voltage control within inverter were considered by (P.M.Menghal2003). The Generalized DPWM scheme for 3-phase VSIs has been studies by (O. Ojo 2004). Where this study presents analytical techniques for the determination of the expressions for the modulation signals used in the Carrier-Based non-sinusoidal and Generalized DPWM modulation schemes for two-level, three-phase voltage source inverters. (M. B. AbbuSamter 2007), the thesis projects on the Carrier-Based PWM (CB-PWM) with all its common strategies in both triangular intersection and direct digital implementation methods. Detailed analysis about CPWM and DPWM are involved, containing the derivations for mathematical equations to estimated switching periods for inverter in both direct digital as well as triangular intersection.

The pulse width modulation strategy with, space vector modulation (SVM) was analyzed in detail by(A.Jidin2009). Where the principle of the (SVM) strategy was performed using MATLAB/SIMULINK.

(K. S. Gowri 2009), In this study a novel Space-Vector based Generalized DPWM algorithm is presented without angle estimation based on the concept of imaginary switching times. Where the conventional SVPWM method with equal division of zero state vectors V_0 *and* $V_7$is modified.(R.Rajendran, *et al*. 2010), they were presented the analysis and realization of SVPWM for variable speed control of AC motor drives, employing Xilinx Spartan 3E FPGA device. The selection of zero vectors and space vector sequence are given and the possibilities of realization on FPGA are analyzed in this study. (A. Iqbal, and *et al*. 2010),in this study focuses on step by step development of MATLAB/SIMULATION model of continuous and discontinuous SVPWM followed by their experimental implementation. (K. V. Kumar, and *et al*. 2010),In this study first a model for SVPWM is made and simulated using MATLAB/SIMULINK software and then its performance is compared with SPWM.

Simulation with conventional Continuous Space-Vector PWM (CSVPWM) and various Discontinuous Space-Vector PWM (DSVPWM) techniques are presented and compared by, (G. S. Rao, *et al*. 2011).

In this paper all kinds of PWM mentioned above will be studied in detail as well as how the design of each PWM methods using MATLAB / SIMULINK and MATLAB Programming and then applied each design for the 3-phase inverter drives A 3-phase squirrel cage induction motor. One of the main uses of inverter is to control the speed of induction motors, by changing the frequency of the input power, this method is one of the best methods used to control the speed of induction motors. It is worth mentioning that when the motor speed control by frequency must be maintained on the ratio V/f to be constant i.e. when the value of frequency reduced in turn should reduce the value of the voltage and vice versa. Therefore, in this paper a technique has been proposed to stabilize this ratio by reducing the supply voltage through the modulation index (M_a), and will be mentioned in section IV.

Voltage Control of Inverters:

Some loads, require simultaneous control of voltage and frequency such as induction motor drive. Control output frequency of the inverter cabe achieve by controlling the conduction intervals of the inverter switches. Inverter output voltage may be done by any of the following techniques(P. S. Bimbhra 2007).

1- Control of input DC voltage.
2- External control of inverter AC output voltage.
3- Internal control of inverter.

The first two methods require the use of extra components whereas the third method requires no extra components and it is the most popular method of voltage control of inverterwhere the form of inverter output voltage is a pulse width modulated wave, and the controlling this voltage done by controls the width of these pulses.The popular name of internal control method is the Pulse-Width-Modulation (PWM) method. There are two ways to implement the PWM methods; Direct Digital PWM (DPWM) method and Carrier-Based PWM (CB-PWM) method. As mentioned above the CB-PWM is applied in this paper.

Carrier Based Pwm:

A high-frequency carrier wave and a reference (modulating) wave are compared with each other.The intersection of these two signals determines the switching instants(J. R. Espinoza 2001). The frequency of the reference signal represent the inverter output frequency whereas, the carrier frequency represent the number of pulses per cycle.

Sinusoidal Pulse-Width Modulation (SPWM):

In SPWM of three-phase inverter, there are three sinusoidal reference waves (v_{ra},v_{rb} and v_{rc}) each shifted by 120°. A carrier wave is compared with the reference signal corresponding to a phase to generate the gating signals for that phase as shown in Fig.(1.a) (M. H. Rashid 2005). The intersection of $v_c$and $v_r$waves determines the switching instants and commutation of the modulated pulse.

The ratio of $\frac{|v_r|}{|v_c|}$ is called the amplitude modulation index (M_a). The pulse-width and RMS value of voltage depend upon M_a (Y. R. Manjunatha, *et al.* 2008). The frequency of the reference wave decides the output frequency f_o. The carrier frequency decides number of pulses per half cycle p.In order to use a single carrier signal and preserve the features of the PWM technique, the normalized carrier frequency $m_f$should be an odd multiple of 3.

Continuous Space-Vector Pulse-Width Modulation (CSVPWM):

Space vectors (V_i ,i = 1, 2, . . . , 8) available in VSIs as shown in Fig.(2). The equivalent vector $V_c$rotating in the counter clock wise direction. The magnitude of this vector is related to the magnitude of the output voltage and the time of this vector takes to complete one revolution is the same as the fundamental time period of the output voltage (S. Panda, *et al.* 2009). However, if the modulating signal V_c is laying between the arbitrary vectors V_i and V_{i+1}, only the nearest two nonzero vectors (V_i *and* V_{i+1}) and one zero SV ($V_z = V_7$*or* V_8) should be used.

To ensure that the generated voltage in one sampling period T_s (made up of the voltages provided by the vectors V_i , V_{i+1}, *and* V_z used during times T_i , T_{i+1}, *and* T_z) is on average equal to the vector V_c, the following expression should hold:

$$V_c.T_s = V_i.T_i + V_{i+1}.T_{i+1} + V_z.T_z \ldots. \qquad (1)$$

The solution of the real and imaginary parts of Eq.(1) for a line-load voltage that features an amplitude restricted to $0 \le \hat{v}_c \le 1$ gives bellow

$$T_i = \frac{\sqrt{3}.T_s.|\overline{V}_c|}{V_{dc}}.sin\left(\frac{i\pi}{3} - \omega t\right) \qquad (2)$$

$$T_{i+1} = \frac{\sqrt{3}.T_s.|\overline{V}_c|}{V_{dc}}.sin\left(\omega t - \frac{(i-1)\pi}{3}\right) \qquad (3)$$

$$T_z = T_s - (T_i + T_{i+1}) \qquad (4)$$

The preceding expressions indicate that the maximum fundamental line-voltage amplitude is unity as $\frac{(i-1)\pi}{3} \le \omega t \le \frac{i\pi}{3}$. This is an advantage over the SPWM technique which achieves a $\frac{\sqrt{3}}{2}$, maximum fundamental line-voltage amplitude in the linear operating region(P. S. Bimbhra 2007).

For a given dc link voltage V_{dc}, the ratio of the fundamental component magnitude of the line to neutral inverter output voltage V_{1m} to the fundamental component magnitude of the six-step mode voltage $V_{1m6step} = \frac{2}{\pi}V_{dc}$, is termed the modulation index M_a(4).

$$M_a = \frac{V_{1m}}{V_{1m\,6step}} \qquad (5)$$

It is found that the normalized sampling frequency f_{sn}should be an integer multiple of 6 (P. S. Bimbhra 2007). This is due to the fact that in order to produce symmetrical line voltages, all the sectors (a total of 6) should be used equally in one period.

The SVPWM can be implemented by using wither sector selection algorithm (also called direct digital method) or by using a carrier based space vector algorithm (S. Panda, *et al.* 2009). The Carrier-Based technique is applied in this paper. The technique is based on the duty ratio profiles, which can be produced by adding the zero-sequence signal to the three-phase reference signals. By comparing the duty ratio profile with a higher frequency triangular carrier the pulses can be generated, based on the same arguments as the sinusoidal pulse width modulation.

The zero sequence signal, which generates by employing the minimum magnitude test compares the magnitudes of the three reference signals and selects the signal with minimum magnitude. Scaling this signal with 0.5, the zero sequence signal of SVPWM is found.

Assume $|v_a^*| < |v_b^*|, |v_c^*|$then

$$v_0 = 0.5 * v_a^* \tag{6}$$

The modulating waveform and the ZSS for this strategy are shown in Fig.(3).

Dsvpwm:

In this PWM scheme, one of the three inverter output legs is clamped to either positive or negative DC bus without any switching's for 120° interval of electrical fundamental period. There are six different schemes are available depending on the variation in the placement of the zero space vectors(A. Iqbalm *et al* 2010).

- ***DPWMMax:***
  The reference signal with the maximum value defines the zero sequence. Assume$v_b^* \leq v_a^* \leq v_c^*$, then

$$v_0 = \frac{V_{dc}}{2} - v_c^* \tag{7}$$

- ***DPWMMin:***
  The reference signal with the minimum value defines the zero sequence. Assume$v_b^* \leq v_a^* \leq v_c^*$, then

$$v_0 = \frac{V_{dc}}{2} - v_b^* \tag{8}$$

- ***DPWM0:***

All three reference modulation signals $v_a^*, v_b^*,$ and $v_c^*$are phase shifted by 30^o (leading), and of the new three signals$v_{ax}^*, v_{bx}^*,$ and v_{cx}^*, the one with the maximum magnitude determines the zero sequence signal. Assume $|v_{ax}^*| \geq |v_{bx}^*|, |v_{cx}^*|$, then

$$v_o = \left(\mathrm{sign}(v_a^*)\right) * \frac{V_{dc}}{2} - v_a^* \tag{9}$$

- ***DPWM1:***
  The reference signal with the maximum magnitude defines the zero sequence signal. Assume$|v_c^*|, |v_b^*| \leq |v_a^*|$, then:

$$v_o = \left(\mathrm{sign}(v_a^*)\right) * \frac{V_{dc}}{2} - v_a^* \tag{10}$$

- ***DPWM2:***

All three reference modulation signals $v_a^*, v_a^*,$ and $v_c^*$are phase shifted by 30^o (lagging), and of the new three signals$v_{ax}^*, v_{bx}^*,$ and v_{cx}^*, the one with the maximum magnitude determines the zero sequence signal. Assume $|v_c^*|, |v_b^*| \leq |v_a^*|$, then

$$v_o = \left(\mathrm{sign}(v_a^*)\right) * \frac{V_{dc}}{2} - v_a^* \tag{11}$$

- ***DPWM3:***
  The reference signal with the intermediate magnitude defines the zero sequence signal. Assume $|v_b^*| \leq |v_a^*| \leq |v_c^*|$, then

$$v_o = \left(\mathrm{sign}(v_a^*)\right) * \frac{V_{dc}}{2} - v_a^* \tag{12}$$

Proposed V/F Constant Ratio:

Changing the frequency of the supply voltage is an ideal method for induction motor speed control. In order to ensure a correct motor magnetization, it is also necessary to change the amplitude of the voltage according to the following equations. The value of active EMF is:

$$E = 4.44\Phi_{max}\, fN \tag{13}$$

Where:
E: Electromagnetic Motive Force (Volt).

f: Supply Frequency (Hertz).
Φ: Flux (Weber).
N: Stator windings turn number.

Assuming, that the voltage drop of stator circuit is negligible, the relationship between the voltage and the frequency is written as:

$$V = K\Phi f \tag{14}$$

Where:
V: Stator Voltage (Volt).
K: Constant.

Therefore, in order to maintain the motor flux constant, the V/f ratio has to be kept constant. This is known as the constant Volt/Hertz principle. This principle is illustrated in Fig.(5)(S. Panda, *et al*. 2009). If this ratio is kept constant, the stator flux will remain constant, and so the motor torque will only depend on the slip frequency.

When the stator frequency fails under a given frequency threshold (called the boost frequency), the voltage magnitude must be kept at a given level (called the boost voltage) to keep the rotor flux magnitude constant. At the opposite, when the frequency becomes higher than the rated value, the voltage magnitude is also kept to the rated value, to take the saturation of the inverter into account. The rotor flux is no more constant and the torque decreases.

In this paper, a new technique is proposed to control of the V/f ratio. This method controls the value of V/f and fixed it by changing the value of modulation index (Ma). This methodisconstructedby connecting themotorisloaded with full-load tothe Inverter, and builda tableconsists of severalreadings,since eachvalue of modulation index (M_a)takethe correspondingvalue ofthe voltage.Initiallyfeedmotorwithrated voltageandwritethe value of$M_a$and thendecreasethe value of$M_a$and record inverter output voltageto get intominimumvalue ofvoltage, whichisthe value thatthemotor woks at5% of the rated speed. When readings are completed,we take acurve fittingto thetwo rowsand thusappear tohavea generalequationof$M_a$canbe appliedatany valueof thevoltage. It is worthmentioning thatthis equationapplies to the motor, atany valueofload.The readings which recorded are inserted in table(2).

It is known the relationship between fundamental r.m.s of inverter output voltage V_{m1} and M_a, it is close to linear relation so that the polynomial equation will be first order equation and the general shape is:

$$M_a = a_1 V + a_2 \tag{15}$$

After finda_1 *and* a_2, can be design this controller using MATLAB as shown in Fig.(6).

Results:

In accordance withinternational standardsstipulate,the value of theTHDshould be less thanorequal to 5% (IEEE Standard 519-1992, and R. G. Ellis 1996).So that the criterion which taken in this study to test the acceptability for each mentioned PWM types is the current THD% should be less than 5%.

In the beginning a 3-phase induction motor at no-load condition. The no-load current and spectrum are plotted for each type of PWM. TheTHDis calculated for 50 numbers ofharmonics.

Then full-load condition of the induction motor (when the motor is loaded by 25.5 N.m torque), the obtained load current waveforms are illustrated and analyzed to obtain the spectrum of each strategy.

Finally similar results for full load are shown with half-load induction motor

Test Results of Induction Motor at No-Load:

The histogram in Fig.(7) showsthe current THDs when the induction motor at no-load state.

Test result of induction Motor at Full-Load:

The histograms in Fig's.(8) and (9) show the current THDs% at the carrier frequencies3.5KHz and 10KHz respectively, when the induction motor at full-load state.

The results in table (2) shows that the current THD% is decreased with increasing the carrier frequency. The increasing in the carrier frequency should be not exceeded the certain values to avoid some drawback such as increasing in the switching losses.

Test Result of Induction Motor at Half-Load:

The histograms in Fig's.(10) and (11) show the current THDs% at the carrier frequencies 3.5KHz and 10KHz respectively, when the induction motor at half-load state.

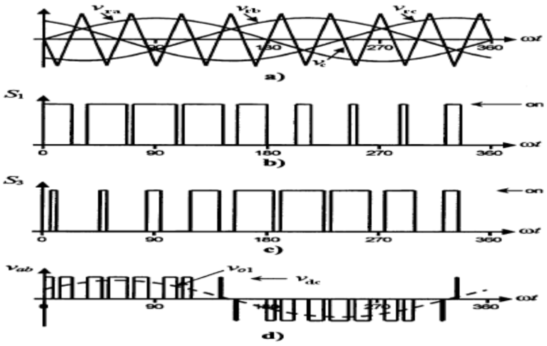


Fig. 1: Sinusoidal pulse-width modulation (SPWM) for three-phase inverter a) Carrier and modulating signals; b) Switch 1 state; c) Switch 3 state; d) ac output voltage.

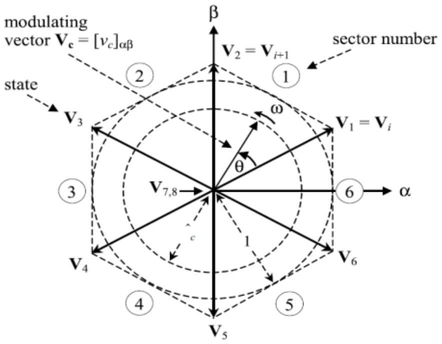


Fig. 2: Space vector representation.

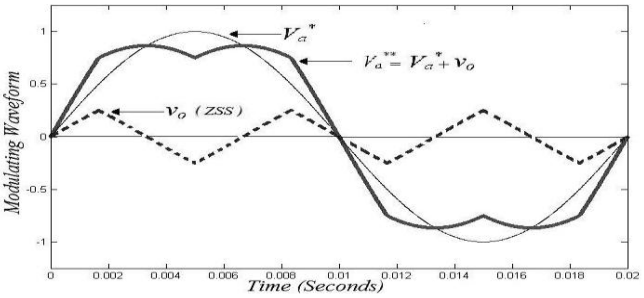


Fig. 3: SVPWM Modulating Waveform and its ZSS(M. Samter 2007).

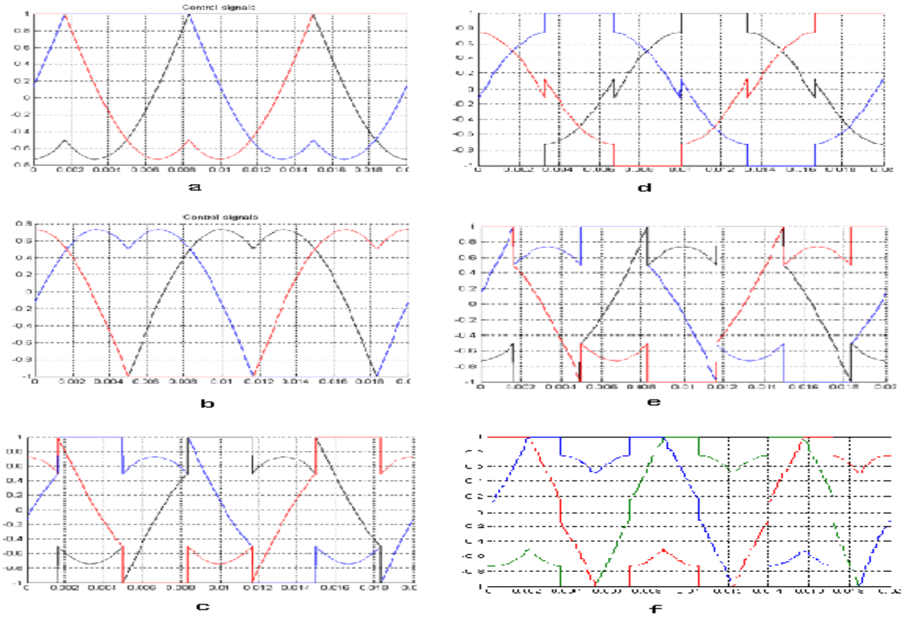


Fig. 4: Discontinuous Space-Vector PWM a) DPWMMax, b) DPWMMin, c) DPWM0, d) DPWM1, e) DPWM2, f) DPWM3.

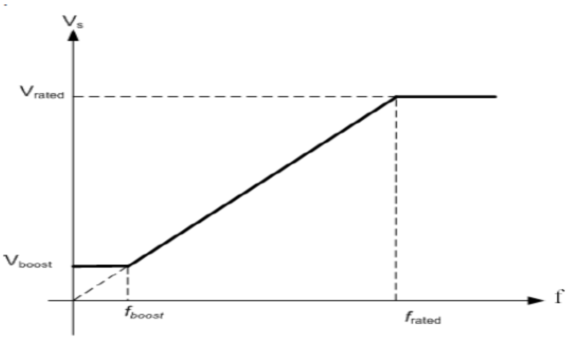


Fig. 5: Stator Voltage Magnitude Versus the Stator Frequency Deduced from the V/f Principle.

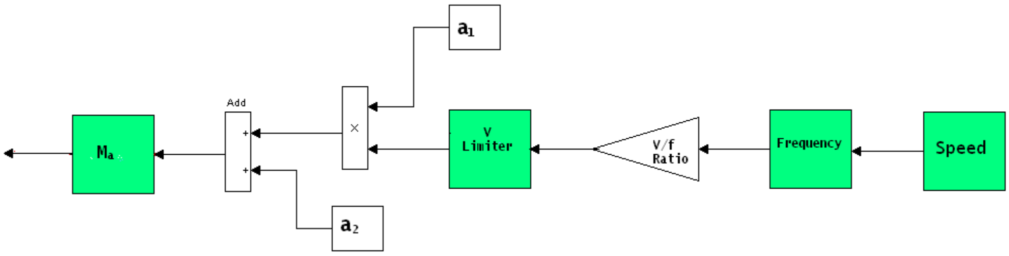


Fig. 6: Proposed model to stabilize V/f ratio for desired speed.

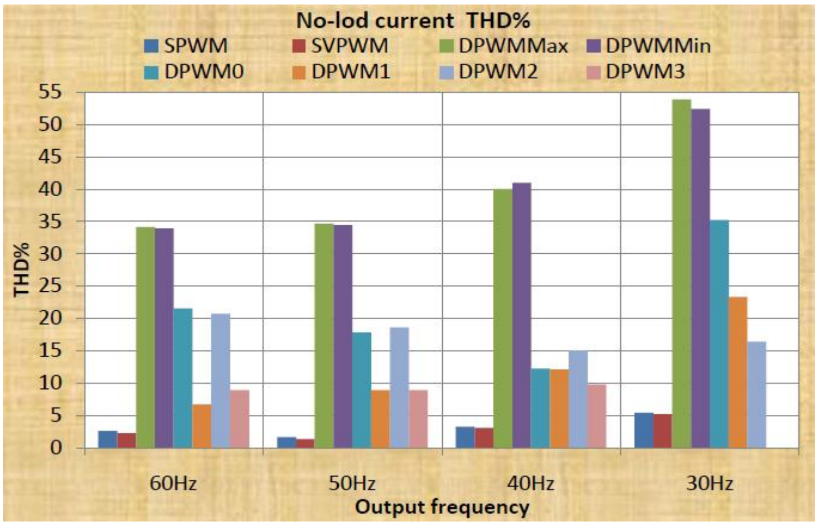


Fig. 7: No-load current THD%.

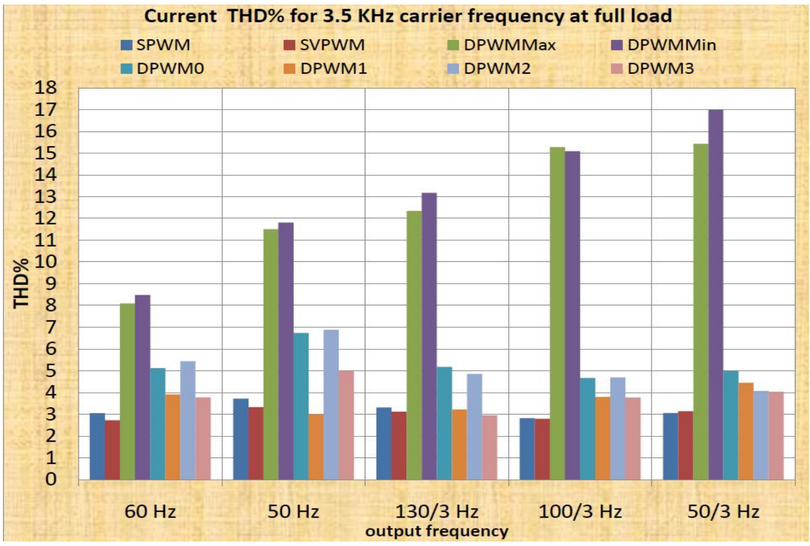


Fig. 8: Current THD% for 3.5KHz carrier frequency at full load.

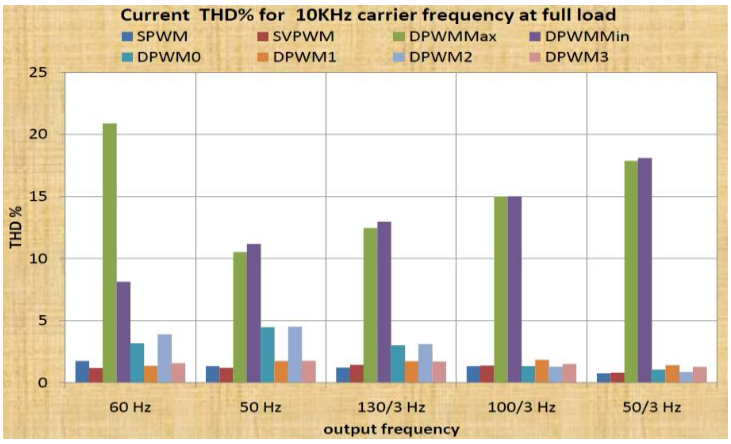


Fig. 9: Current THD% for 10KHz carrier frequency at full load.

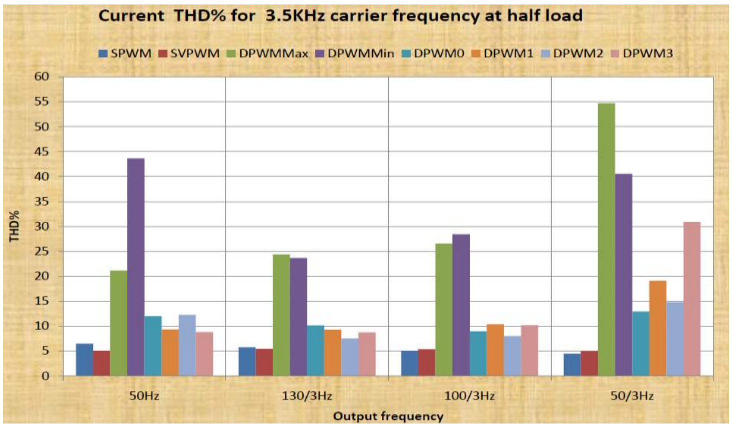


Fig. 10: Current THD% for 3.5KHz carrier frequency at half load.

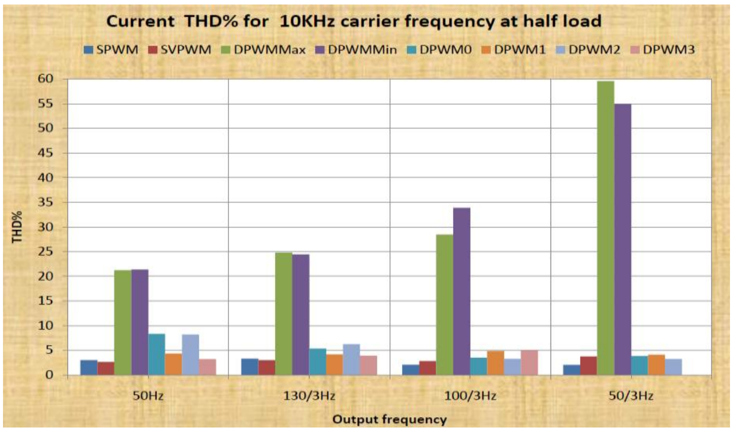
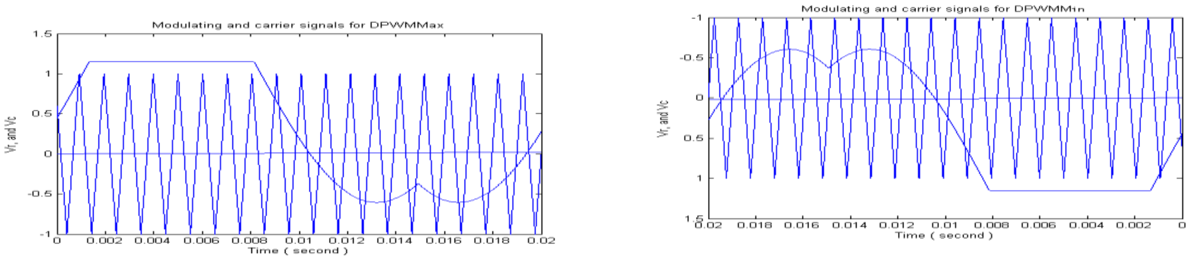


Fig. 11: Current THD% for 10KHz carrier frequency at half load.



Modulating and carrier signals of DPWMMax. (b) Modulating and carrier signals of DPWMMin.

Fig. 12: The comparing states of DPWMMax and DPWMMin.

Table 1: Recorded reading of proposed method to control v/f ratio.

M_a	M_{a1}	M_{a1}-0.02	M_{a1}-0.04	M_{a1}-0.06	………….	$M_{a\text{ (at boost voltage)}}$
V	V_{rated}	V_1	V_2	V_3	………….	V_{boost}

Table 2: Measured values of mentioned PWMs at 3.5KHz carrier frequency and full loaded induction motor.

	Synchronous Speed(r.p.m)	Rotor Speed(r.p.m)	Slip%	Frequency (Hz)	V_{L-L} (volt)	V/f ratio	M_a	Current THD%
SPWM	1800	1623	9.83	60	401.8	6.696	0.9577	3.05
	1500	1387.5	7.5	50	401.8	8.036	0.9577	3.724
	1300	1186	8.76	43.333	348.3	8.037	0.8321	3.314
	1000	879.6	12.04	33.333	268	8.04	0.6401	2.819
	500	431	13.8	16.666	134.1	8.046	0.3201	3.059
SVPWM	1800	1627.5	9.58	60	403.1	6.718	0.8404	2.734
	1500	1390	7.33	50	403.1	8.062	0.8404	3.332
	1300	1188.5	8.57	43.333	348.2	8.035	0.7284	3.118
	1000	882.5	11.75	33.333	269	8.07	0.5604	2.794
	500	434	13.2	16.666	134.4	8.064	0.2804	3.142
DPWMMax	1800	1604.5	10.86	60	399.3	6.655	0.9002	8.09
	1500	1378	8.13	50	399.3	7.986	0.9002	11.5
	1300	1175	9.61	43.333	338.5	7.811	0.7735	12.35
	1000	868	13.2	33.333	260.1	7.803	0.6135	15.27
	500	425	15	16.666	130.2	7.812	0.3469	15.43
DPWMin	1800	1618.5	10.08	60	399.1	6.651	0.9006	8.481
	1500	1378	8.13	50	399.1	7.982	0.9006	11.81
	1300	1176	9.53	43.333	337.9	7.797	0.7739	13.18
	1000	868.5	13.15	33.333	260.4	7.812	0.6139	15.09
	500	426	14.8	16.666	130.3	7.818	0.3473	16.991
DPWM0	1800	1618.5	10.08	60	400.2	6.67	0.9808	5.118
	1500	1378.5	8.1	50	400.2	8.004	0.9808	6.737
	1300	1180	9.23	43.333	344.7	7.954	0.8288	5.173
	1000	883	11.7	33.333	272.6	8.178	0.6368	4.664
	500	435.5	12.9	16.666	132.8	7.968	0.3168	4.981
DPWM1	1800	1625	9.72	60	407.7	6.795	0.9602	3.914
	1500	1387.5	7.5	50	407.7	8.154	0.9602	3
	1300	1186	8.76	43.333	348.2	8.035	0.8322	3.22
	1000	870.5	12.95	33.333	262.5	7.875	0.6402	3.8
	500	427	14.6	16.666	134.4	8.064	0.3202	4.45
DPWM2	1800	1626	9.66	60	402.8	6.713	0.9967	5.44
	1500	1377	8.2	50	402.8	8.056	0.9967	6.881
	1300	1176	9.53	43.333	341.8	7.887	0.8231	4.849
	1000	881	11.9	33.333	270	8.1	0.6311	4.688
	500	432	13.6	16.666	130.5	7.83	0.3111	4.083
DPWM3	1800	1620.5	9.97	60	400.3	6.671	0.9599	3.784
	1500	1388	7.46	50	400.3	8.006	0.9599	4.998
	1300	1186	8.76	43.333	350.6	8.09	0.8319	2.95
	1000	886	11.4	33.333	274.2	8.226	0.6399	3.77
	500	438	12.4	16.666	134.5	8.07	0.3199	4.033

Table 3: Suitable and unsuitable states for each PWM mentioned.

	Induction motor at full-load		Induction motor at half-load	
	f_c = 3.5KHz	f_c = 10KHz	f_c = 3.5KHz	f_c =10KHz
SPWM	Suitable	Suitable	Unsuitable	Suitable
SVPWM	Suitable	Suitable	Unsuitable	Suitable
DPWMMax	Unsuitable	Unsuitable	Unsuitable	Unsuitable
DPWMMin	Unsuitable	Unsuitable	Unsuitable	Unsuitable
DPWM0	Suitable for $f_r \leq 40$Hz	Suitable	Unsuitable	Suitable for $f_r \leq 40$Hz
DPWM1	Suitable	Suitable	Unsuitable	Suitable
DPWM2	Suitable for $f_r \leq 45$Hz	Suitable	Unsuitable	Suitable $f_r \leq 40$Hz
DPWM3	Suitable	Suitable	Unsuitable	Suitable

Conclusion:

- Throughthe resultsshownin table(2), it is notedthat theproposed methodto stabilized the$\frac{V}{f}$ constant ratiogive us high accuracyresults.
- The types SPWM, SVPWM,DPWM3 and DPWM1 can be usedfor anyfrequency because the percentage of current THD is less than the values that set forth in international standards (less than 5%). And also note that the SVPWM is better than the other types because it has less current THD.
- Results shown that the two methods DPWMMax and DPWMMin are not suitable for such uses because the current THD much more than the values stipulated in international standards.
- The DPWM0 technique can be used only when the frequencies less or equal to 40Hz.
- The DPWM2 technique can be usedforfrequenciesless than or equal to 45Hz.
- DPWMMax and APWMMin have number of pulses of almost 40% lower than the other types of PWM and this leads to the switching losses will be reduced by the same percentage.Increasing incarrier frequencyare not givenany improvementof thecurrent THDand the reasonis that themodulating signal in DPWMMax and DPWMMin are compared with thecarrier signalonly innegativepartforDPWMMaxandthe positivepartfor theDPWMMinAsshown in Fig. (12).
- Tale (3) gives the suitable and unsuitable state for each PWM mentioned.

REFERENCES

Bimbhra, P.S., 2007. Power Electronics, 4th Edition, Delhi, Published by: R. C. Khanna for Khanna Publishers, pp: 414-403.

Broeck, H.W., H.C. Skudelny and G.V. Stanke, 1988. “Analysis and realization of a pulse width modulation based on voltage space vector,” IEEE Trans. Ind. Appl., 24(1): 142-150.

Ellis, R.G., 1996. “Harmonic Analysis of Industrial Power Systems,” IEEE Trans. Industry Applications, 32(2): 417-421.

Espinoza, J.R., 2001. “Inverters,” In Power Electronics Hand Book, Ed. M. H. Rashid, Canada: Academic Press, pp: 225-269.

Gowri, K.S., T.B. Reddy and C.S. Babu, 2009. “ Novel space vector based generalized discontinuous PWM algorithm for induction motor drives,” Asian Research Publishing Network (ARPN), 4(1): 76-88.

Hava, A.M., R.J. Kerkman and T.A. Lipo, 1999. “Simple analytical and graphical methods for carrier-based PWM-VSI drives,” IEEE Trans. On power electronics, 14(1): 49-61.

IEEE Standard 519-1992, “IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power System”, IEEE, New York, NY, 1992.

Iqbal, A., S.M. Ahmed, M.A. Khan and H. Abu-rub, 2010“Generalized simulation and experimental implementation of space vector PWM technique of a three-phase voltage source inverter,” International Journal Of Engineering Science and Technology (IJEST), 2(1): 1-12.

Ismail, B., 2008. “ Design and development of unipolar SPWM switching pulses for single phase full bridge inverter application,” Master’s thesis, Electrical and Electronic Engineering, University Sains Malaysia, Penang, Malaysia.

Jidin, A. and T. Sutikno, 2009. “MATLAB/SIMULINK Based analysis of voltage source inverter with space vector modulation,” TELKOMNIKA Journal, 7(1): 23-30.

Kumer, K.V., P.A. Michael, J.P. John and S.S. Kumer, 2010. “ Simulation and comparison of SPWM and SVPWM control for three phase inverter,” Asian Research Publishing Network (ARPN), 5(7): 61-74.

Manghal, P.M. and A.S. Sindekar, 2003. “Harmonic analysis for some prominent PWM strategies in inverters,” IE (I) Journal. EL, 84: 79-85.

Manjunatha, Y.R. and M.Y. Sanavullah, 2008. “Comparative study of PWM inverters fed 3-phase induction motor,” Asian power electronic journal, 2: 2.

Ojo, O. and P. Kshirsagar, 2004. “ The generalized discontinuous PWM modulation scheme for three-phase voltage source inverters,” In 29th IEEE Industrial Electronics Society annual conference, pp: 1629-1636.

Panda, S., A. Mishra and B. srinivas, 2009. “ Control of voltage source inverters using PWM / SVPWM for adjustable speed drive applications,” Bachelor dissertation, Dpt. Electrical engineering, National institute of technology Rourkela university, Rourkela, India.

Rajendran, R. and N. Devarajan, 2010. “ Analysis and FPGA realization of a pulse width modulator based on voltage space vectors,” International Journal of computer Application, 2(6): 46-51.

Rao, G.S. and K.C. Sekar, 2011. “ A comprehensive analysis of space vector PWM technique based on placement of zero-space vector,” International Journal Of Engineering Science and Technology (IJEST), 3(4): 2728-2739.

Rashid, M.H., 2005. Power electronics circuit devices and applications, (3rd edition). New Delhi: A. K. Ghosh, Prentic-Hall of India private limited.

Samter, M., 2007. “Spectral analysis for non-sinusoidal PWM with variable switching frequency for harmonic reduction in inverters,” Master’s thesis, Dept. Electronic and communication engineering / Electronic circuits and systems, Nahrain university, Baghdad, Iraq.