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Performance Comparison of Asymmetric Carrier Random and Dual Random PWM Algorithms for Variable Speed Drives

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Abstract-Pulse Width Modulation (PWM) method is one of the most useful technique for controlling the power switches of inverter fed drives. The existing Asymmetric-Carrier Random PWM (AC-RPWM) method has shaft-torque dynamics issue. This paper presents a Dual Random PWM (DR-PWM) for spreading the harmonic spectrum and to solve the above issue. The DR-PWM is used to achieve better performance like noise reduction for different Modulation Index (M.I) values of modulation region. A DR-PWM uses dithered pulse width and zero vector position, which are simulated with complex calculations. This scheme uses Random Pulse Position (RPP) and Random Career Frequency (RCF) PWM. Lead - Lag random bit and random triangular carrier are used. Time for zero voltage is randomized to get enhanced outcomes for vector controlled Induction Motor drives. The proposed DR-PWM with spread spectrum modulation provides less harmonic distortion in the signal compared to the existing AC-RPWM method.

Keywords-Power converter, resonant converter, motor drives, vector control

I. INTRODUCTION

Currently all the modern Power Electronic Converters (PEC), the Voltage Source Inverter (VSI) is probably the most extensively used device among power ratings ranging from fraction of a kilowatt to megawatt level. It converts a fixed DC voltage to three phase AC voltage with controllable frequency and magnitude. To maneuver the power switches from the converter, a number of modulation ways have been proposed from which the PWM approach is perhaps the most used scheme. Power flow is controlled by the inverter switching device gate alerts by generating pulses to obtain high performance, improved efficiency and reliable process. Gate pulses can be obtained by comparing a high frequency carrier signal with a modulating signal. Between the carrier and modulation signals, synchronization was mandatory to achieve high waveform quality with the limited switching frequency capacity of the inverters. Numerous Adjustable Speed Drive (ASD) applications need medium or high bandwidth torque control in order to achieve sufficient control performance. Recent research shows that the Pulse Width Modulation (PWM) is used to provide adjustable frequency sine wave currents to AC machine stators. These drives provide excellent speed control but do not have direct torque control capability.

PWM schemes are categorized into two types such as Current Controlled and Voltage Controlled PWM. Also these schemes are classified as either carrier based or carrier less based PWM schemes.

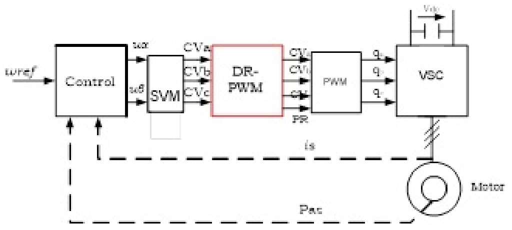

Fig. 1: Block diagram of a motor control using DR-PWM in open and closed loops

For carrier based PWM techniques, a typical harmonic spectrum shows prominent harmonics around the carrier frequency.

When the machines are controlled through such techniques generates acoustic noise. From the current spectrum of the motor, a cost effective strategy to distribute the discrete components is known as Random PWM (RPWM). RPWM also achieves spreading of the energy spectrum through random switching frequency, randomly switching and random pulse position PWM schemes rise to the harmonic spikes and causing unwanted effects in the power converter for example torque ripple, acoustic noise and Electromagnetic Interference (EMI). A variety of RPWM algorithms are reported in the literature [1]–[4]. Till now, research on RPWM schemes was mostly focused on a carrier based implementation [5]. PWM scheme has fixed switching frequency and it causes power spectrum designate and focuses at multiples of the switching frequency.

To obtain effectiveness of PECs, the unwanted effects like torque ripple and EMI need to be reduced. For that reason, this paper is proposed on Dual Random PWM. To reduce the torque ripple time for zero voltage is randomized to get enhanced outcomes. For the torque control of induction motor DTC algorithm was developed and presented by I. Takahashi [6] and it is useful for low and medium power range applications. DTC is produced for very fast torque and flux control and also robust with respect to drive parameters [7], [8]. Though, during steady state process, flux, a notable torque and current pulsations are reflected in speed estimation and it increases acoustical noise. At present, the Space Vector PWM (SVPWM) algorithm is used to overcome these anomalies [9], [10]. SVPWM algorithm is applied to decrease the steady state ripple and to obtain constant switching frequency operation of the inverter DTC in [11]–[13]. Though, the SVPWM algorithm gives good performance, it produces more acoustical noise and harmonic distortion. Existing AC-PWM provides poor performance in torque because of the variation in the frequency components of modulated signal. The peaks are less in the modulated waveform [14]. This problem is reduced in DR-PWM which provides constant variation in the output. The output waveform has many high frequency components. When the operating modulation index is less, the proposed PWM algorithm uses zero voltage as zero voltage vectors. Otherwise, when the operating modulation index is high, the proposed PWM algorithm uses highest voltage as zero voltage vectors. The DR-PWM algorithm is used for Zero Vector Distribution (DRZVD) PWM [15]. It is simple and easy

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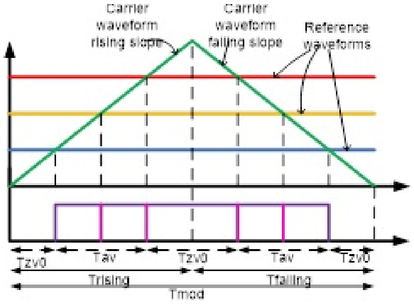


Fig. 2: PWM carrier waveform: symmetrical carrier wave in the modulation period.

for implementation. In this proposed system, whenever the carrier (dithered) signal changes from negative to positive, Random Carrier Frequency PWM technique is used. For opposite direction, Random Pulse Position PWM (RPP-PWM) is used. The digital information contained in the bits need to be mapped to the analog pulses which are transmitted and this is done by the Pulse Position Modulation (PPM).

II. ASYMMETRIC CARRIER RANDOM PWM

In traditional modulation methods like space vector modulation (SVM), called symmetric carrier PWM, the time required for up-counting mode (T_{rising}) is equal to the time required for down-counting mode $(T_{falling})$, as it is shown in the Fig. 2. By changing the ratio between (T_{rising}) and $(T_{falling})$ the resultant voltage vector is generated in the modulation period. This method has a drawback; it gives rise to discrete frequency components in the currents spectrum which leads to EMI [13]. This section presents a new FCF-RPWM technique called Asymmetric-Carrier random PWM technique. The advantage of this method is that, it has good performance for both low and high modulation index values and does not require any external circuits for digital implementation as shown in Fig. 3.

By changing the ratio between (T_{rising}) and $(T_{falling})$, the resultant voltage vectors generated in the conventional and in the AC-PWM is similar in position and magnitude for given modulation period, the only difference is that the voltage vector is created with different modulation frequencies [15]. In this AC-PWM the modulation period is maintained constant, but the distribution of the time length between raising and falling slopes are not equal as it is shown in Fig. 3. By choosing a random time length for raising and falling slopes in every modulation period, the time length for active vector regions will vary randomly. In other words, the voltage vector generated in the raising slope period is generated at different switching frequencies than the voltage vector generated in the falling slope period. The spreading effect of discrete components from the motor current spectrum using this AC-PWM method is good even at high modulation index values. Here the total time spent for generation of active voltage vectors as longer than the time spent for generation of zero vectors. The main advantage of this method is that it is very straightforward to include into an existing closed loop and open loop control algorithms without changing the control structure or adding hardware components, but the problem is that the PWM module has to updated twice during the modulation period and the nonlinearities like minimum dead time and minimum pulse filter have been neglected in the simulation. The AC-PWM is also suffering with shaft torque dynamics issue at low modulation index values are to avoid this problem the sampling period has to be improved. In this paper a new random PWM technique is proposed for reduction of shaft torque dynamics and considering the acoustic noise issue.

III. PROPOSED DUAL RANDOM PWM

A typical motor control structure in open or closed loop block diagram is shown in Fig. 1. In this section, the proposed DR-PWM is discussed. The achievement of efficient spread spectrum modulation is explained as follows.

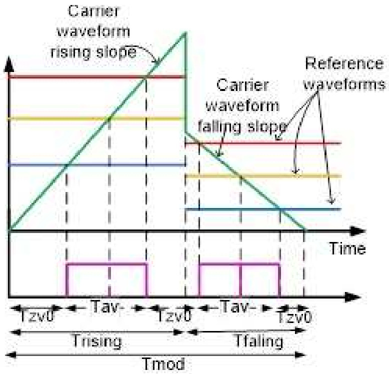


Fig. 3: PWM carrier waveform: Asymmetric carrier wave in the modulation period.

A. Type sizes

Fig. 1 shows the block diagram of a typical motor control structure in open or closed loop. The result of the control block is calculated with reference voltage vector in the $-$ plane. This output voltage vector U_s from [21] is decomposed into two adjacent active voltage vectors when compared with the values for PWM module using the SVM blocks based calculated values. Within a modulation period, the DR-PWM block is obtained by randomization of the active and zero series vectors time length. In DR-PWM, PR_{rising} and $PR_{falling}$ are also computed with the function ratios are converted into compared values of the PWM module based o existing method and it can be seen from the block diagram in Fig. 1. The main advantage of DR-PWM is easy to implement digitally, without changing the existing control structure and addition of any external hardware modules. This modulation can be used in both open and closed-loop motor control applications. The PWM unit is used for motor control of a commercial microcontroller and it consists of an updown counter, PR and three CRs. For generating the carrier wave for the PWM unit an up-down counter is used. In traditional Space Vector Modulation (SVM), the time required for PR_{rising} up-counting mode is equal to the time required for $PR_{falling}$ down-counting mode, as it is in the existing AC-PWM. The ratio changes between PR_{rising} and $PR_{falling}$, the resultant voltage vectors generated in the first and the second part of the modulation period are similar in position and amplitude, and the difference being the resultant voltage vector which is created with different modulation frequency of active and zero voltage vector times can be calculate from equation (1)-(3).

$$T_1 = \frac{2\sqrt{3}}{pi} M_i sin(60^\circ - \alpha) T_s \tag{1}$$

$$T_2 = \frac{2\sqrt{3}}{pi} M_i sin(\alpha) T_s \tag{2}$$

$$T_z = T_s - T_1 - T_2 \tag{3}$$

where M_i is modulation index and is defined as

$$M_i = \frac{piV_{ref}}{2V_{DC}}$$

In this proposed function, step by step process is explained in system overview section.

B. System Overview

The overall process of DR-PWM system is illustrated in Fig. 1. In this proposed DR-PWM, whenever the dithered signal changes from negative to positive, RPP-PWM technique is used. For opposite direction zero vectors Pulse Position Modulation (PPM) is used. For the digital information contained in the bits needs to be mapped to the analog pulses which are transmitted and it is done by the Pulse Position

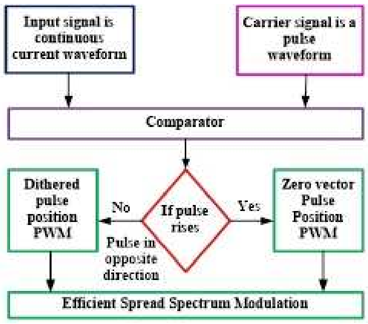


Fig. 4: Overall algorithm of proposed DR-PWM system

Modulation (PPM). The modulation method has randomly updated the frequency, which has the advantage of easy implementation and integration into an existing algorithm of open- or closed loop motor control.

C. Dithering based PWM

Dithering is done by adding noise of a level less than the least-significant bit or signal. The added noise has the significance of spreading the many short-term errors across the signal spectrum as broadband noise Dither is a small ripple frequency that is applied to convert the PWM signal to the current that causes the desired vibration and thereby increases the linearity of the motor and improves motor response.
In proposed method Dither signals are used to perform one part of Random PWM. The popular Dither wave types are triangular, rectangular and three Power modes. In Triangular, default triangular is selected, which is the safest mode for doing additional process of proposed file. Here the triangular based dither wave is used.

Conventional method of dither generation has different dithering frequency ranges with different sweep frequencies which are used to find the best sweep frequency and that would give the minimum peak value of the FFT spectrum of the switch voltage. Here the sinusoidal pulse width modulation is used to simulate the multilevel inverter of three levels. The different dithering frequency ranges for which the inverter is simulated are $19-21kHz$, $18-22kHz$ and $16-24kHz$. The different sweep frequencies considered for each dithering range are $120Hz$, $240Hz$, $480Hz$ and $960Hz$. The above said frequencies are static frequency method. Then in random PWM, dithering frequencies are generated randomly to reduce the high level noise in the form of peak frequency.

D. Zero vector Pulse Position PWM

In PPM modulation, each pulse is delayed or sent in advance of a regular time scale. A binary communication system can be ascertained with a forward or backward shift of the pulse in time. Then the data is encoded with adding an extra time shift θ_{shift} to the impulse. The binary PPM signal is given by equation (4)

$$s(t)=\sum_{k=-\infty}^{\infty}\alpha_k p(t-k_f\pm\theta_{shift}) \tag{4}$$

where the data modulation is done by small shifts in the pulse position shift $p(t)$ is the UWB pulse and T_f is the frame duration.

IV. SIMULATION RESULTS

In this section, the proposed Dual Random PWM is evaluated and simulations have been carried out for both the PWM algorithms AC-RPWM and DR-PWM in MATLAB/Simulink software for different M.I values. Fig. 5 shows the periodogram power spectrum estimation. Fig. 6(a) show the phase voltage Van Fig. 6(b) and Fig. 6(c) shows the motor currents spectrum of AC-PWM and DRPWM for a modulation index of 0.1. When m.i is 0.1 there are some spikes concentrated at 4, 8 and 12 kHz in the AC-PWM but these are completely disappeared in the proposed DR-PWM. The current ripple is increased in the AC-RPWM, by eliminating the discrete components from the currents spectra, the acoustic noise in the case of DR-PWM becomes close to white noise. Fig. 7(a) show the phase voltage Van Fig. 7(b) and Fig. 7(c) shows the magnitude response of AC-PWM and DRPWM for a modulation index of 0.5. Fig. 8(a) shows the phase voltage Van. Fig. 8(b) and Fig. 8(c) shows the magnitude response of AC-PWM and DRPWM for a modulation index of 0.8. When m.i value increases the spikes in the motor currents spectrum are also increases when it is controlled by AC-RPWM. These discrete components completely disappeared when it is controlled by DR-PWM. Fig. 9 shows the wave forms for t_{ga}, t_{gb} and t_{gc}. Fig. 10 shows the comparison of total harmonic distortion for different values of modulation index. The THD is less for all values of m.i in the proposed DRPWM in comparison with AC-PWM. It shows that the proposed DRPWM technique gives superior performance in comparison with the existing random PWM techniques.

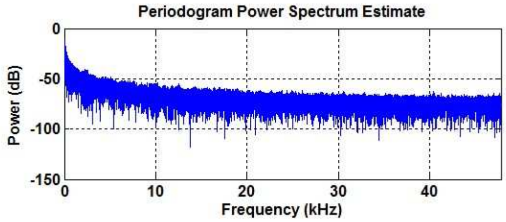
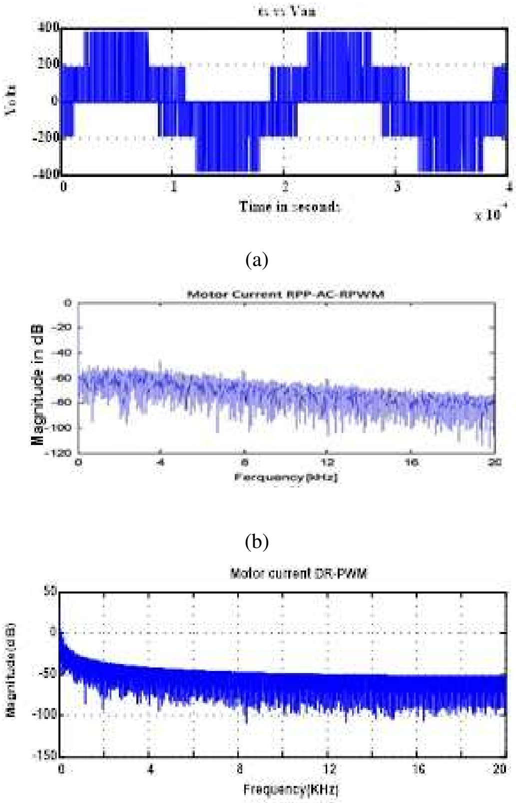


Fig. 5: Periodogram Power Spectrum estimation

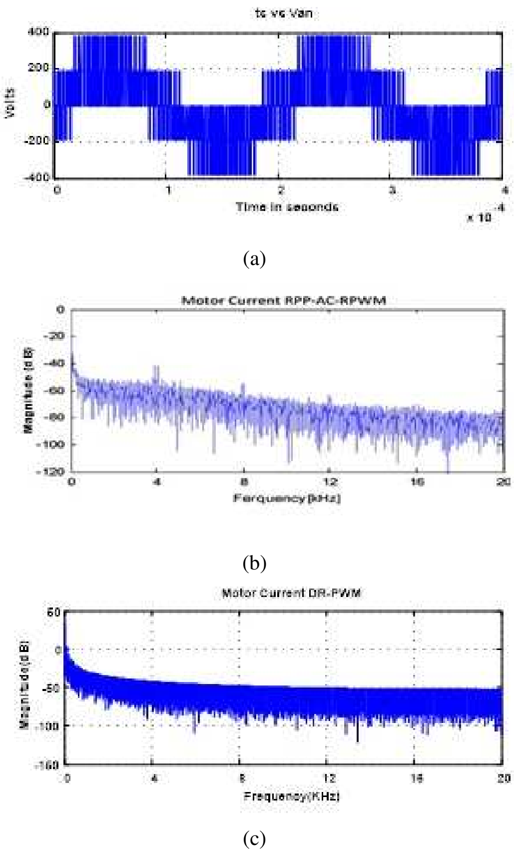


(a)

(b)

(c)

Fig. 6: (a) Phase voltage Van of DR-PWM Inverter at 0.1 M.I (b) Motor currents spectrum with RPP-AC-RPWM at 0.1 M.I (c) Motor current spectrum with DR-PWM at 0.1 M.I



(a)

(b)

(c)

Fig. 7: (a) Phase voltahe Van of DR-PWM inverter at 0.5 M.I (b) Motor current spectrum with RPP-AC-RPWM at 0.5 M.I (c) Motor current spectrum with DR-PWM at 0.5 M.I

V. CONCLUSION

A new Random PWM method called Dual Random PWM is compared with the simulation results of existing AC-PWM method. This scheme uses random pulse position and random carrier frequency PWM to reduce the acoustical noise and the shaft torque dynamics. Time for zero voltage is randomized to get enhanced outcomes for vector controlled Induction Motor drive. The simulation results show that the proposed Dual Random PWM method effectively spreads the discrete components of the current with less noise for various values of modulation index values; it gives less total harmonic distortion and reduces the shaft torque dynamics when compared with the existing AC-RPWM algorithm.

VI. ACKNOWLEDGMENT

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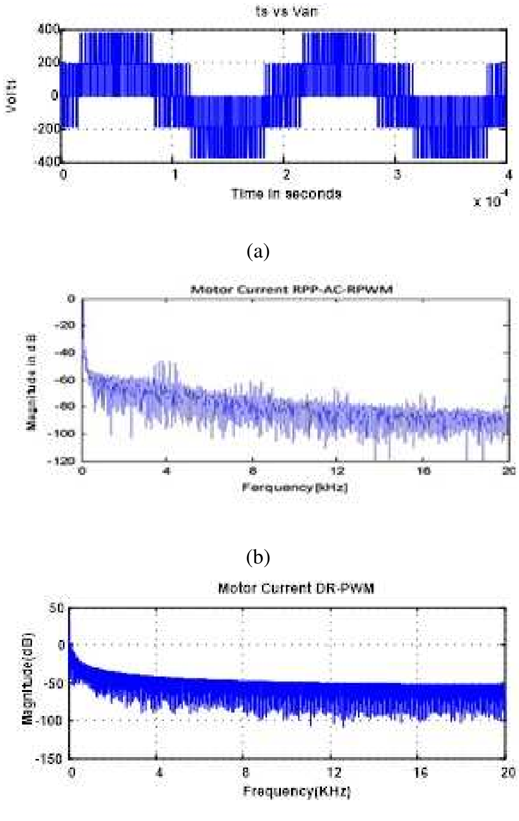

(a)

(b)

(c)

Fig. 8: (a) Phase voltage Van of DR- PWM inverter at 0.9 M.I (b) Motor current spectrum with RPP-AC-RPWM 0.9 M.I (c) Motor current spectrum with DR-PWM at 0.9 M.I

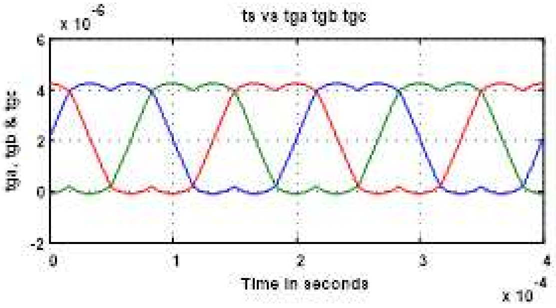

Fig. 9: Time vs t_{ga}, t_{gb} and t_{gc}

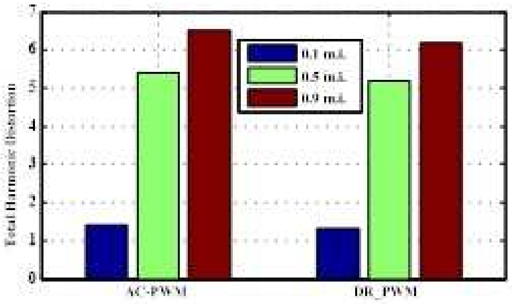

Fig. 10: Total Harmonic Distortion comparison

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