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Coupled random PWM technique for dual inverter fed induction motor drive

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ABSTRACT

Dual inverter fed induction motor drives provide more advantages in contrast with other multilevel inverter drives. Coupled PWM techniques provide good standard of output voltage than the decoupled PWM techniques for dual inverter configuration. In this paper analysis of open-end winding induction motor by coupled random PWM signals and decoupled SVPWM signals was carried out. Induction motor by random PWM technique generate low acoustic noise and electromagnetic interference to near by systems. The performance evaluation of the drive wss implemented in MATLAB/simulink and the results were presented.

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1. INTRODUCTION

With the progress in technology electric drives are attaining importance in electrical vehicles. On account of little maintenance and low weight to volume ratio Induction motor fed AC drives are popular when compared with DC motor drives [1]. To increase the dynamic response of these drives for electrical vehicle applications decoupled flux control methods like vector control and direct torque methods are used [2]-[4]. Though vector control involves much of transformations but it gives low steady state ripple. Hence in this paper focus is given on vector controlled induction motor (IM) drives [5].

Regular two-level inverter fed vector controlled IM drives generate poor quality of output voltage, high common mode voltage (CMV) and moreover they are suitable for low power applications [6]-[10]. Multilevel inverter fed IM drives are possible solution for high power applications. Different multilevel inverter configurations like H-bridge, capacitor clamped,diode clamped multilevel invertes and dual inverter configurations are discussed in literature for good quality of output voltage and low CMV [11]-[14]. Among these multilevel inverter configurations dual inverter fed open end IM drive offers many advantages like free from capacitor balancing issues, simple design and operation [15].

Different PWM techniques are employed for the control of dual inverter fed IM drive [16]-[18]. All these PWM techniques are classified and can be performed based on scalar carrier and space vector approaches. Space vector based PWM techniques provide freedom in selecting voltage vectors [19]-[20]. As the PWM techniques are implemented at high switching frequency, high amount of harmonics are observed in harmonic spectrum of output voltage and currents at multiples of switching frequency. This causes acoustic noise and may also cause interference to the nearby systems. To overcome these problems different random PWM techniques were identified for the inverters. In this paper constant switching frequency random PWM technique is implemented for vector controlled dual inverter fed IM drive.

2. FIELD ORIENTED CONTROL OF DUAL INVERTER CONFIGURATION

Separately excited DC motors have fast transient response because of independent control of both torque and flux by armature current and filed current. But these motors have high weight to volume ratio and also require frequent maintenance. On the other side induction motor drives have low weight to volume ratio and does not require frequent maintenance but have poor transient response. To increase the transient performance of the induction motor drive independent control of torque and flux control method need to be introduced by using vector control technique.

In vector control of induction motor drive to generate independent torque and flux components stator current is resolved in d-axis current component (I_{ds}) and q-axis current component (I_{qs}) and rotor flux is to be resolved as d-axis flux component (λ_{dr}) and q-axis flux component (λ_{qr}). The electromagnetic torque expression in the form of d-q quadrants of an induction motor can be expressed as in (1). Block diagram of vector controlled dual inverter fed open end winding induction motor drive as shown in Figure 1.

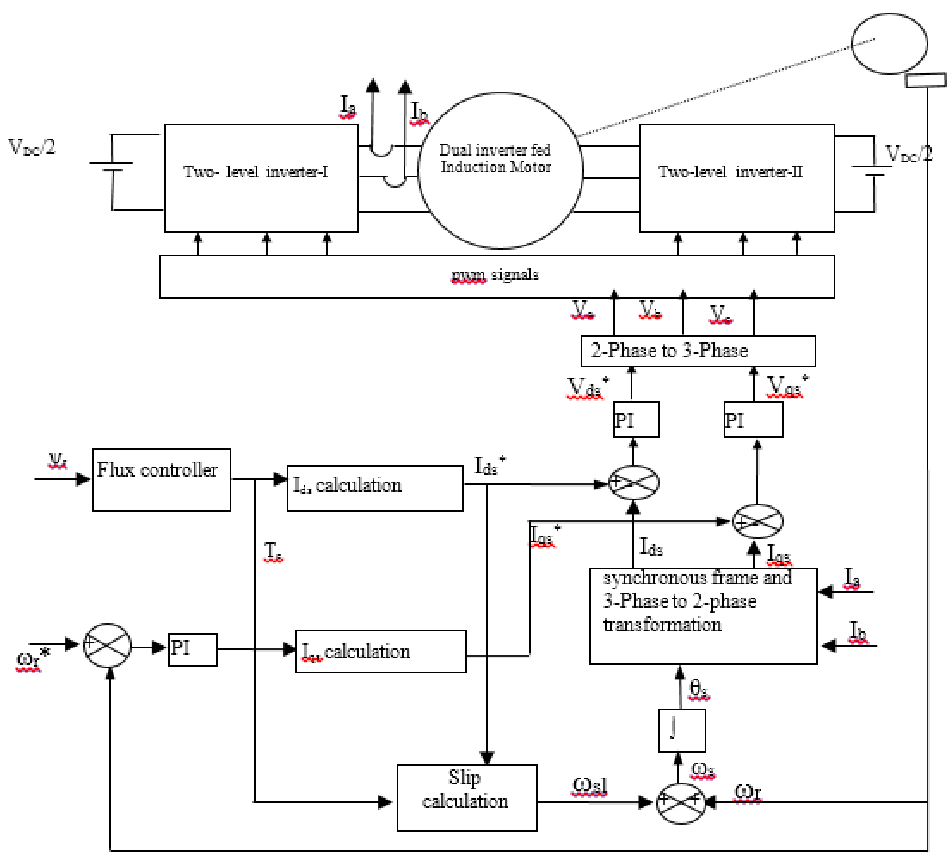


Figure 1. Block diagram of vector controlled dual inverter fed open end winding induction motor drive

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\lambda_{dr} i_{qs} - \lambda_{qr} i_{ds}\right) \qquad (1)$$

In separately excited DC motor drive both the current components (torque and flux controlling current components) will be in orthogonal and will be in DC quantities. Hence induction motor quantities expressed in synchronous reference frame will appear in DC form and both are made to be in orthogonal. When the rotor flux is aligned to synchronous reference frame rotor q-axis flux $\lambda_{qr} = 0$ becomes zero.

Hence the torque expression can be modified as in (2)

$$T = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\psi_r i_{qs}) \quad (2)$$
$$\text{where}\, \psi_r = L_m I_{ds}$$

From (2) it is observed that by controlling I_{ds} flux can be controlled and by controlling I_{qs} torque can be controlled. Hence independent control of torque and flux can be achieved in vector controlled IM drive.

For the reference frame transformation phase angle (θ_s) need to be estimated. Based on the estimation of this phase angle vector control techniques are divided into two types as direct vector control and indirect vector control. In direct vector method θ_s is generated using hall sensor and in indirect vector control it is calculated from rotor position angle and slip as in (3).

$$\theta_s = \theta_r + \theta_{sl} = \int (\omega_r + \omega_{sl})dt = \int \omega_s \quad (3)$$

The block diagram of the dual inverter fed IM drive is shown in Figure.1. In Figure.1 reference I^*_{ds} and I^*_{qs} are calculated from the speed and flux controllers. These are compared with actual I_{ds} and I_{qs}. I_{ds} and I_{qs} are obtained from the actual three phase currents, which are then transformed in to synchronous reference frame. The current error command generates input reference signals for PWM. In PWM block different coupled PWM techniques can be implemented for dual inverter configuration as in section 3.

3. COUPLED PWM TECHNIQUE FOR DUAL INVERTER CONFIGURATION

To generate space vector PWM pulses for dual inverter two approaches are generally followed. One way is to directly synthesize pulses for two inverters in a decoupled manner in which the space plane of the two inverters forms a conventional two level space plane each with 8 possible switching states. So 64 switching state combinations are possible to synthesize required voltage for the induction motor. In the second approach, PWM pulses are synthesized treating both inverters in a coupled manner. That is, switching pulses for the two inverters are synthesized from three level pulses. A total of 27 switching states are possible to generate three level output voltage. The 27 switching states of a three-level inverter in a d-q axis space vector plane are shown in Figure 2. The switching states of inverter for generating a reference voltage V_{ref} in an instantaneous fashion using nearest voltage vectors in all the six sectors are to be synthesized based on an algorithm. The salient features of space vector algorithm are i) starting and ending state in every sampling period must be same, ii) not more than one state should change during every state transition.

There are different ways to synthesize the nearest switching states. In the present method the switching states for the two inverters are synthesized from three level switching states in a coupled fashion. The approach reduces the inherent complexity involved in selecting the three level switching states by shifting the V_{ref} into an appropriate two-level sub hexagon. There are six outer sub hexagons with centres as V_7, V_8, ..., V_{12} (H_1, H_2,......, H_6) and one inner sub hexagon with centre V_0 (H_0).

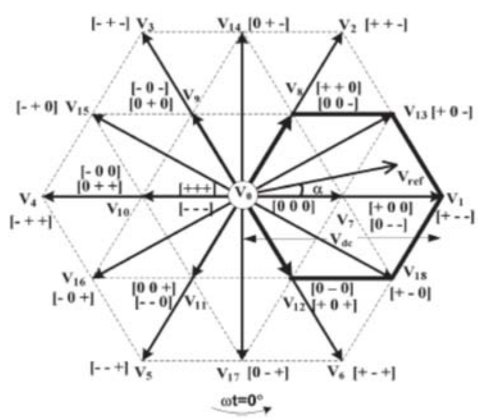


Figure 2. Switching states and their space vector locations of a coupled inverter

The process of synthesizing the switching states of the two inverters is as follows. Due to the symmetry of all sub hexagons the same explanation is valid for V_{ref} located in any of the outer sub hexagons. It is assumed that the tip of the V_{ref} lies in sector-1 of H_1. The sub hexagon in which V_{ref} lies is identified from d-q axis components (V_d, V_q) of V_{Ref} using (4). Here α is the angle made by V_{ref} with respect to d-axis. Once the sub hexagon is identified, the tail of the V_{ref} is shifted from V_0 to V_7. The shifted or new reference vector $V_{ref,,n}$ defined by (5) is decomposed into its direct and quadrature axis components (V_{dn}, V_{qn}). Now sector identification is done in a similar way as done for identifying the sub hexagon. Knowing the sector, sub hexagon the optimal switching states (for a given PWM sequence) to synthesize the reference vector in an average switching period are identified from the look-up Table 1.

$$H_i = 1 + fix(rem\left(\frac{\alpha}{60}\right)) \tag{4}$$

$$V_{ref,n}{=}V_{ref} - V_7 \tag{5}$$

In conventional space vector PWM method, four nearby switching states generally referred as active state 1, active state 2 and two zero states are synthesized based on the position of the shifted reference vector, $V_{ref,n}$. The time to be dwelled in a switching state is calculated maintaining the principle of volt-second balance and are given by (6), (7) and (8). The synthesis of the switching states for the two inverters from three level inverter switching states is explained through Table 2. Table 2 shows the synthesis of coupled PWM pulses when V_{Ref} lies in sector -1 of H1.

Table 1. Synthesis of coupled inverter switching states (switch on-1, off-0)

Three Level Inverter Switching states	Switching states of inverter-I	Switching states of inverter-II
+	1	0
0	0 or 1	0 or 1
-	0	1

$$T_1 = \frac{V_{ref}}{0.5{*}V_{dc}}\frac{sin(60^0-\beta)}{sin(60^0)}T_s \tag{6}$$

$$T_2 = \frac{V_{ref}}{0.5{*}V_{dc}}\frac{sin(\beta)}{sin(60^0)}T_s \tag{7}$$

$$T_Z = T_s - T_1 - T_2 \tag{8}$$

Here T_1, T_2 are the times to be dwelled by the two inverters in active state 1 and 2 respectively as given in Table 2. In random PWM generation the zero-state distribution factor a_0 is randomly generated. The time to be lapsed in zero state 1 (T_{Z1}) and zero state 2 (T_{Z2}) is divided in the ratio of $a_0\ and\ (1 - a_0)$ among two zero states, given in (9) and (10). Hence a_0T_Z is the time to be dwelled by the two inverters in zero state 1 and zero state 2 respectively. Ts is the time period of half the switching cycle. Division of zero state times generate numerous PWM methods. For instance, conventional space vector PWM pulses are generated with equal division of zero state duration, $a_0 = 0.5$.

$$T_{Z1} = a_0T_Z \tag{9}$$

$$T_{Z1} = (1 - a_0)T_Z \tag{10}$$

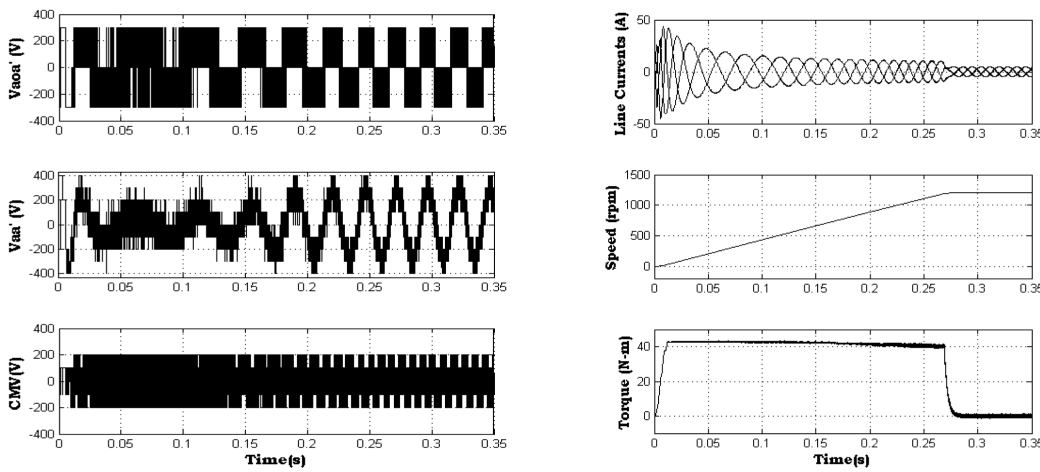
Table 2. Random distribution of zero state inverter switching times

Switching Times	Three Level Inverter Switching states	Switching states of inverter-I	Switching states of inverter-II
T_1	0 -1 -1	0 0 0	0 1 1
T_2	1 -1 -1	1 0 0	0 1 1
a_0T_Z	1 -0 -1	1 0 0	0 0 1
$(1-a_0)T_Z$	1 -0 -0	1 0 0	0 0 0

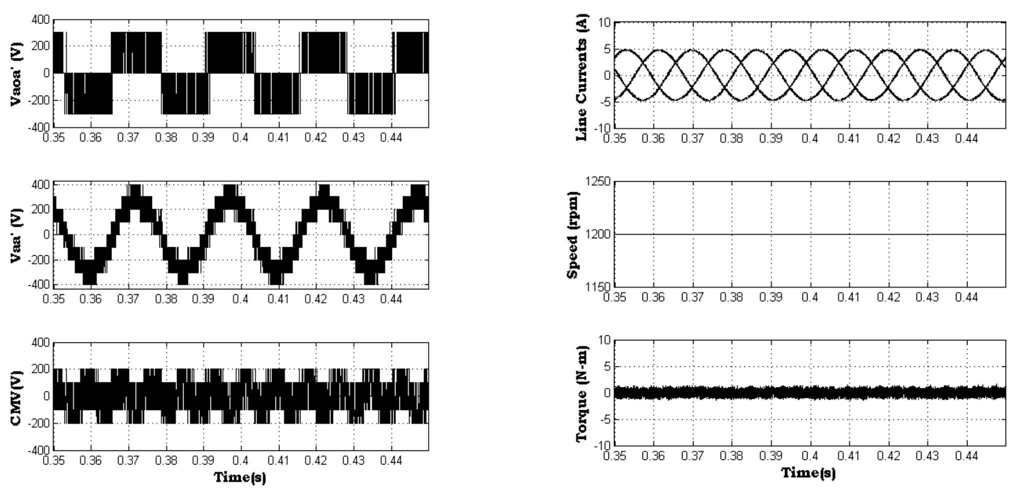
4. RESULTS AND DISCUSSION

The analysis and simulation of coupled PWM technique for vector controlled dual inverter fed induction motor drive was performed in MATLAB/Simulink and results were presented. The parameters used for simulation studies are input DC voltage of 600V which is shared as 300V to each inverter, Induction motor parameters are R_s=1.57Ω, R_r =1.21Ω, L_s=0.17H, L_r=0.17H, L_m =0.165 H, J = 0.089 Kg.m^2. The control signals of both SVPWM and RPWM are generated with a switching frequency of 3 kHz.

The transient and steady state results of pole voltage, resultant phase voltage, CMV, three phase currents, speed and torque with SVPWM and Random PWM at a reference speed of 1200 RPM are shown in Figure 3. From the results shown in Figure 4 it is perceived that magnitude of voltage levels generated in all the voltage plots is same with both the PWM techniques. Because of Random PWM technique only change in pulse position is observed. Hence only slight change in total harmonic distortion is observed where as SVPWM technique generate more THD at nearby harmonics of switching frequencies both in voltage and current magnitudes than the Random PWM techniques, but the THD at other harmonic frequencies may increase or decrease. Because of reduction THD at nearby harmonics of switching frequencies acoustics noise and electronic magnetic interference to nearby systems also decreases.

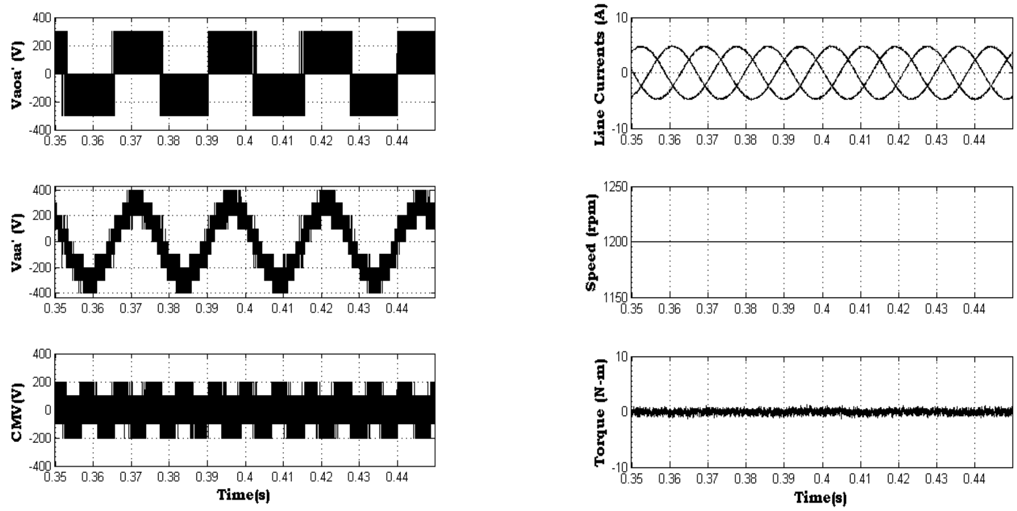


(i)



(ii)

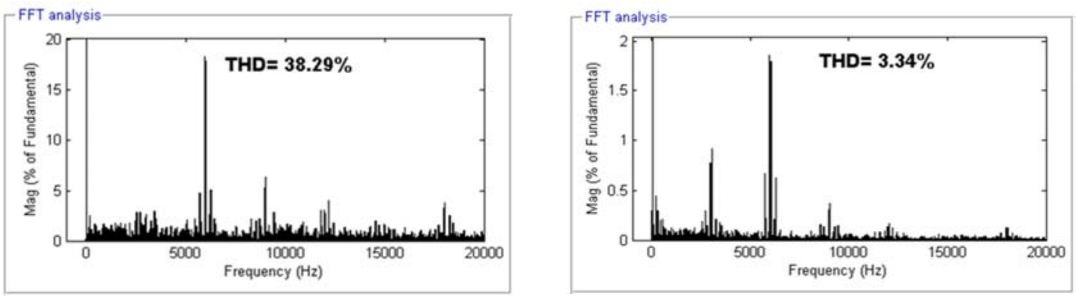
Figure 3a. Results of dual inverter fed induction motor drive with coupled PWM technique, SVPWM; (i) stating transients (ii) steady state



(i) (ii)

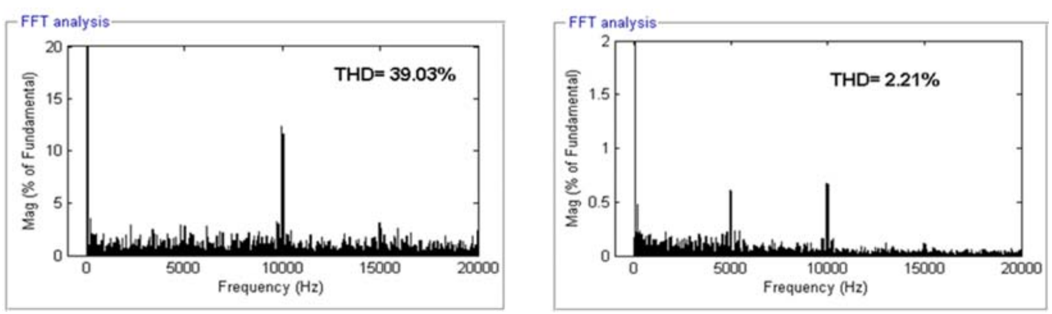
(b)

Figure 3b. Results of dual inverter fed induction motor drive with coupled PWM technique, RPWM; (i) stating transients (ii) steady state



(i) (ii)

Figure 4a. Results of dual inverter fed induction motor drive with coupled PWM technique SVPWM; (i) voltage THD (ii) current THD



(i) (ii)

Figure 4b. Results of dual inverter fed induction motor drive with coupled PWM technique, RPWM; (i) voltage THD (ii) current THD

5. CONCLUSION

The dual inverter fed induction motor drives offers many advantages like free from neutral point fluctuations and capacitor balancing issues when compared with other multilevel inverter topologies. During failure of any inverter the dual inverter fed induction motor drive operates with reduced output voltage. Moreover, the vector control technique also provide fast transient response of the drive. From the results it is inferred that with the coupled random PWM techniques for dual inverter fed induction motor drive THD at nearby switching frequency harmonics are reduced. This leads to the lowering in acoustic noise and electro magnetic interference to nearby systems.

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