HYBRID PWM BASED MRAS SPEED OBSERVER FOR SENSORLESS CONTROL OF INDUCTION MOTOR DRIVE

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Abstract- This paper presents a novel method of Hybrid pulse width modulation (HPWM) algorithm for control of induction motor drive based on model referencing adaptive system (MRAS). In the conventionally used space vector pulse width modulation (CSVPWM) scheme the duration of zero voltage application is equally distributed in each and every sampling period. In this paper a HPWM is presented for sensorless control of induction motor using MRAS to reduce steady state ripples. The proposed method is developed on stator flux ripple notion which is nothing but a measurement for ripple in line current. The proposed HPWM method for induction motor is developed by using the expressions for mean square flux ripple over a sub-cycle for each switching sequence. By using the proposed method the performance of the drive is improved at different modulation indices. The simulations have been carried out and the results are presented and analyzed.

Keywords - MRAS, modulation index, HPWM, Sensorless control.

I. INTRODUCTION

The recent developments for control of induction motor is mainly focused on using fast switching power devices which has led to increased interest of researchers in the area of voltage source inverters (VSI) with pulse width modulation (PWM) control. There are several PWM techniques present in literature which are summarized in [1].

Triangular control and space vector approach finds a lot of attention and are mainly implemented PWM methods [2]. Conventional space vector pulse width modulation strategy is the widely used method [2], [3] which utilizes two zero and two active voltage vectors in each sector to obtain the reference voltage vector. The complexity in the SVPWM increases and to reduce this complexity a simplified approach was presented in [4] which use the concept of offset time and in [5] imaginary switching time SVPWM was used to reduce the complexity. A single expression with conventional space vector approach was presented in [6] which increase the complexity of the algorithm. In [7]-[10] different types of SVPWM schemes were developed to enhance the performance, improve the efficiency and waveform. In [11]-[14] different types of hybrid PWM algorithms have been developed for reduced current ripple at all modulation indices.

In this paper a simplified hybrid PWM algorithm based MRAS speed observer is proposed. The proposed method utilizes the concept of imaginary switching times which reduces the complexity of the scheme at the same time improving the performance of the drive.

II. MODELING OF INDUCTION MOTOR

Before starting the analyzing of any motor we have to first develop its mathematical model. The mathematical model of 3 phase induction motor is developed in stationary frame of reference by using the following equations.

\[ v_d^* = R_i i_d^* + p \psi_d^* \]
\[ v_q^* = R_i i_q^* + p \psi_q^* \]
\[ 0 = R_i i_d' + p \psi_d' + \omega_i \psi_q' \]
\[ 0 = R_i i_q' + p \psi_q' - \omega_i \psi_d' \]

where \( \psi \) is flux linkages and is given as

\[ \psi_d^* = L_i i_d^* + L_m i_d' \]
\[ \psi_q^* = L_i i_q^* + L_m i_q' \]
\[ \psi_d' = L_i i_d' + L_m i_d^* \]
\[ \psi_q' = L_i i_q' + L_m i_q^* \]

and the electromagnetic torque equation of the induction motor is given as

\[ T_e = \frac{1.5P}{2} (\psi_d' i_d^* - \psi_q' i_q^*) \]

and the electromechanical equation of the induction motor drive is given as

\[ T_e = T_L + J \frac{d\omega_m}{dt} = T_L + \frac{2}{P} J \frac{d\omega_r}{dt} \]
III. PRINCIPLE OF CONVENTIONAL MRAS

In MRAS scheme there are basically two models one known as reference model and the other as adaptive model. The reference model is used to determine the required state is usually represented by voltage model representing the stator equations. The adaptive model also known as adjustable model provides the estimated values of the states is usually represented by current model describing the rotor equations where in the rotor flux is expressed in terms of rotor speed and stator current components. The error obtained between the reference and adaptive model is given to an adaptation mechanism which adjusts the adaptive model by generating the estimated value of rotor speed. The basic rotor flux MRAS speed observer for induction motor drive was first developed by Schauder in 1992[15] and is shown in Fig. 1. A lot of effort is being focused on improving the performance of this scheme. The main problems that are associated with this scheme are pure integration and stator resistance sensitivity.

The reference rotor flux components that are obtained from the reference model are given as [15]-[17]

\[ p\psi'_d = -\frac{L_m}{L_r} \left( R_i i'_d + \sigma L_r p_i'_q - v'_d \right) \] (5)

\[ p\psi'_q = -\frac{L_m}{L_r} \left( R_i i'_q + \sigma L_r p_i'_q - v'_q \right) \] (6)

Where \( \sigma \) is leakage coefficient and is given as

\[ \sigma = 1 - \frac{L_m^2}{L_d L_r} \] (7)

The rotor flux components that are obtained from the adaptive model are given as [15]-[17]

The speed tuning signal of the adaptation mechanism which is used to reduce the error between the rotor flux and the reference rotor flux there by reducing the error between the reference model and adjustable model speeds is given as

\[ e_\omega = \psi'_q \dot{\psi}'_d - \psi'_d \dot{\psi}'_q \] (10)

and the estimated speed is given as

\[ \hat{\omega}_r = \left( k_p + \frac{k_v}{p} \right) e_\omega \] (11)

IV. PROPOSED SWITCHING SEQUENCE

Eight switching states are possible for a 3-phase, two-level VSI that are depicted as voltage space vectors in Fig. 2. The space vector locations form the vertices of a regular hexagon, forming six symmetrical sectors. Its voltage vector of sector I is shown in Fig. 3.

V. CONCLUSION

The turn-on time of two active states and zero states is used to find the duty cycle information for active switching gate signals. An average vector equal to Vref is generated in each sampling period T_s. For a given Vref and angle \( \alpha \) in sector I the expression for timing durations for active and zero states in the are first sector is given as:

\[ T_1 = 1.154(\sin(60^\circ - \alpha))M_i T_s \] (12)

\[ T_2 = 1.154(\sin(\alpha))M_i T_s \] (13)

\[ T_z = (T_1 + T_2 - T_s) \] (14)

Where \( M_i \) is Modulation index which is given as \( \frac{3V_{\text{ref}}}{2V_{\text{dc}}} \)
V. HYBRID SVPWM METHOD

The conventional SVPWM uses 0127-7210 sequence in sector I and 0327-7230 in sector II and so on. The possible switching sequences which can be obtained by using the freedom of active state vector division can be used with in the sub-cycle to generate $V_{ref}$ vector are shown in Fig. 4. The symmetric bus clamping sequences 012-210 and 721-127 use one zero state and the remaining two asymmetrical bus clamping sequences 0121-1210 divide the vector time in to two equal halves with in a sub-cycle[2], [7], [12], [18]. Stator flux ripple vector is a measure of the ripple in line current which is obtained by taking the time integral of voltage ripple vector [2], [7], [12], [18]. The values of $d$, $q$ axes ripples at the switching instants are given as [18]

$$Q_1 = T_s \left( \frac{2}{3} V_{dc} \cos \alpha - V_{ref} \right)$$

$$Q_2 = T_s \left( \frac{2}{3} V_{dc} \cos \left(60^\circ - \alpha\right) - V_{ref} \right)$$

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$$D = T_s \left( \frac{2}{3} V_{dc} \sin \alpha \right)$$

We can determine the appropriate $V_{ref}$ space vector by using flux error and stator ohmic drop and it is given as

$$V_d^{ref} = \frac{T_s}{T_s} \left[ R_d \frac{\Delta \psi_d}{T_s} + \Delta \psi_d^{ref} \right]$$

$$V_q^{ref} = \frac{T_s}{T_s} \left[ R_q \frac{\Delta \psi_q}{T_s} + \Delta \psi_q^{ref} \right]$$

The block diagram of the proposed scheme is shown in fig. 6. In the proposed method, the position of the reference stator flux vector ($\psi_s^{ref}$) is derived by the adding slip speed and actual rotor speed. After each and every sampling duration actual stator flux vector ($\psi_s$) is adjusted by the error and it tries to attain the reference flux space vector. The errors in the $d$ and $q$ axes stator flux vectors are obtained as

$$\Delta \psi_d = \psi_d^{ref} - \psi_d$$

$$\Delta \psi_q = \psi_q^{ref} - \psi_q$$

$$\Delta \psi_d^{ref} = \psi_d^{ref} - \psi_d$$

$$\Delta \psi_q^{ref} = \psi_q^{ref} - \psi_q$$

Fig. 4 Possible switching operations in sector I

In this paper the space vector base HPWM method is presented for sensorless control of induction motor using conventional MRAS who’s switching sequence are divided into seven parts in each sector as shown in Fig. 5.

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$$\Delta \psi_q^{ref} = \psi_q^{ref} - \psi_q$$

Fig. 5 Space vector based HPWM showing seven parts of a sector.

Fig. 6 Block diagram of Proposed HPWM based MRAS speed observer

Where, $T_s$ is sampling period also known as the duration of sub-cycle and it is a half of period of the switching frequency. It means that the torque and flux are controlled for each switching half cycle or controlled twice per switching cycle.

VI. SIMULATION RESULTS AND DISCUSSION

The proposed scheme is verified by performing simulations in Matlab/Simulink. Simulations are performed on 3-phase 2 pole induction motor having following parameters: $R_r = 3.55 \ \Omega$, $R_s = 4.15 \ \Omega$, $L_r = L_s = 0.76 \ \text{mH}$, $L_m = 0.646 \ \text{mH}$ and moment of inertia of 0.33 $\text{Kg/m}^2$. In Fig. 7 the response of the drive for the conventional MRAS scheme is shown for 1300 rpm without load and Fig. 8 shows the response for the proposed MRAS scheme using HPWM. As can be observed from the waveforms the speed performance is better with the proposed scheme. Also the pulsations are reduced in with the proposed scheme. The stator current is also made smooth with the proposed scheme. In Fig. 9 and 10 the response of the drive for both
conventional and proposed MRAS scheme are shown for 1300 rpm.

Fig. 7 No load plot of conventional MRAS at 1300 rpm

Fig. 8 No load plot of proposed MRAS at 1300 rpm
Fig. 9 Plots of conventional MRAS with load of 10 N-m applied at 1 sec

Fig. 10 Plots of Proposed MRAS with load of 10 N-m applied at 1 sec
VII. CONCLUSION

The conventional MRAS is simple and most widely used sensorless control scheme but considerable amount of ripples in the torque are present and the stator current is not so smooth. Hence to reduce the pulsations in the torque and to make the stator current waveform smoother a novel method of HPWM based MRAS speed observer is proposed for the sensorless control of induction motor. From the simulation results it can be observed that the ripples present in the torque are minimized and the waveform of the stator current is also improved. The simulations are performed for 800 and 1300 rpm which show that the proposed scheme gives improved performance over a wide range of speeds.

REFERENCES