SPEED CONTROL OF INDUCTION MOTOR USING PREDICTIVE CURRENT CONTROL AND SVPWM

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ABSTRACT:

In this paper work, sensorless speed control of three phase induction motor is to be carried out using predictive current method and space vector PWM. A closed loop estimation system is proposed with robustness against motor parameters variation is used for the control approach. The novelty of the presented solution is the integration of a simple observer for both speed/flux and current control purposes, and the obtained results have been improved in comparison to the previous works.

KEYWORDS:

Adjustable speed drives (ASD), Electromotive forces (EMF), Induction motor (IM), Field oriented control (FOC), Predictive current controllers (PCC), Proportional-integral (PI), Space Vector Pulse width modulation (SVPWM).
1. INTRODUCTION

In sensor control of induction motor, speed sensor produces noise signals. These noise signals produce interference in the control circuit and hence precise control cannot be obtained. To overcome this problem in Adjustable speed drives (ASD) employing Induction Motors, this sensorless control methodology is proposed in [1]-[3].

In ASD, the mature control approach of IM is FOC method, which is widely used in modern industrial drives. The integral part of numerous FOC systems is the stator current controller [8]. In the classical FOC solution, PI or hysteresis controllers are generally used. FOC is very sensitive to the disturbances. So it is inaccurate in real time systems.

2. PROPOSED SYSTEM

In this paper, the real-time system of the electric drive is presented. The system has Predictive current control (PCC) implemented in the IM speed sensorless system with a field oriented control method [3].

In the proposed scheme, FOC is used along with PCC and space vector PWM to insure a constant switching frequency. The predictive current control algorithm is modified by using an observer system instead of a simple load model [6]. The use of the observer avoids the problems associated with system start up. To simplify the control algorithm, the proposed PCC is combined with the speed/flux observer for an FOC IM drive.

The proposed sensorless control scheme of induction motor system is simple, robust, and can operate with a very wide speed range, including extremely low and very high speeds.

Advantages of sensorless drives:

a) Lower cost.

b) Reduced size of the drive machine.

c) Elimination of the sensor cable.

d) Increased reliability.

2.1 Basic Scheme

The structure of the proposed system is shown in Fig 1. The IM is supplied from a frequency converter, which consists of a diode rectifier and transistorized voltage source inverter. The FOC is used for a decoupled motor speed and flux control with PI controllers. Instead of a PI or hysteresis stator current is controllers; The PCC is used in the proposed scheme. The commanded motor current, transformed from the d,q to the α,β coordinates, is controlled by PCC. Simultaneously, the PCC cooperates with the space vector PWM, which assures a constant switching frequency of the inverter. The inverter with SVPWM and PCC works as a controlled current source. The system works without a speed sensor, while only the inverter input voltage and output currents are measured. Other variables required by the control system are calculated in a closed-loop observer system.

2.2 Predictive Current Control
The constant switching frequency predictive current controller [7] calculates the voltage vector command every sampling period, which will force the current vector to its command value. A new real-time predictive current control, which will give the active voltage vectors that can give the minimum current error every sampling time, will be described. Now, the problem is to find the appropriate voltage vector which will decrease the current error to zero as fast as possible.

The operation of the system (motor model) is described by the following equation,

\[ v_s(t) = R_s i_s(t) + \frac{d}{dt} + e_m(t) \]  

(1)

Here; \( e_m(t) \) (the counter emf vector) is expressed by

\[ e_m(t) \equiv \frac{l_m}{l} \frac{d}{dt} \psi \]  

(2)

It is desirable to estimate the rotor flux because of the difficulty in measuring it directly and above equation can be written in a differential form as follows

\[ v_s(k) = R_s i_s(k) + \frac{\sigma L_s}{T_s} [i_s(k + 1) - i_s(k)] + e_m(k) \]  

(3)

Where \( T_s \) is the sampling period.

The reference inverter voltage vector that will force the current vector to follow its command value is calculated every sampling period. It is assumed that the inverter voltage and counter emf vector of the motor are assumed to be constant over the sampling period. The voltage vector \( v_s^*(k) \) is calculated by changing the current \( i_s(k + 1) \) to follow the reference value \( i_s^*(k + 1) \) as given by the following equation,

\[ v_s^*(k) = R_s i_s(k) + \frac{\sigma L_s}{T_s} [i_s^*(k + 1) - i_s(k)] + e_m(k) \]  

(4)

The angle of the command voltage vector can be calculated from the following relation.

\[ \alpha = \tan^{-1} \frac{v_{sy}}{v_{sx}} \]  

(5)

Using the voltage angle the location of the voltage vector can be determined with respect to the sector number. Now, three possibilities are considered. The first one is to use the location of the voltage vector and the nearest voltage vector for the whole modulation period, and this can be easily determined with respect to the sector number. The second one is to calculate the switching times for the power devices using space vector modulation. The third one is to use the direction of the command voltage itself and to insert its magnitude multiplied by the modulation index and a simple ramp modulator. The control method described until now does not solve the problem of current ripple. Now, the new proposed method with decreasing stator current ripples is explained.

A new method for reducing the stator current ripples has been presented. Our goal is to make the average output current for one period equal to the current command. The tolerance band around the current command which gives indication about current ripples can be calculated. So, the areas between actual current oscillations and its command are minimized to reduce the current ripple. If the derivative of these areas with respect to the switching time is set equal to zero, then the switching instants of the power devices are obtained. For one sample time, the stator current discrete equation can be expressed as follows:

\[ i_{sd}(k + 1) = i_{sd}(k) + \left( \frac{1}{\sigma l_s} v_s(k) - \frac{R_s}{\sigma l_s} i_{sd}(k) + \frac{L_s^2 \rho w_r}{\sigma l_s L_T} i_{sd}(k) \right) T_s \]  

(6)

\[ i_{sq}(k + 1) = i_{sq}(k) + \left( \frac{1}{\sigma l_s} v_s(k) - \frac{R_s}{\sigma l_s} i_{sq}(k) + \frac{L_s^2 \rho w_r}{\sigma l_s L_T} i_{sq}(k) \right) T_s \]  

(7)

The foregoing equation includes the influence of the applied voltage vector on the current variation, taking the operating condition into considerations.

The ripple areas can be calculated based on the values of the sampling time, and the positive and negative slopes of current equations. The on-time of the active voltage vector can be obtained according to minimization of ripple areas by the following
Where \( dI \) is the maximum difference value between the actual and command current, \( M^+ \), and \( M^- \) are the positive and negative slopes of the stator current wave. In abbreviation, the on durations of the active voltage vector and the zero vectors are \( T_{onz} \) and \( (T_s - T_{onz}) \) respectively and for every new cycle the time must be reset to zero. It should be noted that if the time < 0 or > \( T_s \) the active voltage vector must be turned on during the whole sampling period.

2.3 Space Vector Pulse Width Modulation

Space Vector PWM [9]-[12] supplies the AC machine with the desired phase voltages. The SVPWM method of generating the pulsed signals fits the above requirements and minimizes the harmonic contents. Note that the harmonic contents determine the copper losses of the machine which account for a major portion of the machine losses.

Taking into consideration the two constraints quoted above there are eight possible combinations for the switch commands. These eight switch combinations determine eight phase voltage configurations. The diagram below depicts these combinations.
Table 1: SVPWM switching table

<table>
<thead>
<tr>
<th>Voltage Vectors</th>
<th>Switching Vectors</th>
<th>Line to neutral voltage</th>
<th>Line to line voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>V_0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>V_1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>V_2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>V_3</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>V_4</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>V_6</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>V_7</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

(Note that the respective voltage should be multiplied by \( V_{dc} \))

The vectors divide the plan into six sectors. Depending on the sector that the voltage reference is in, two adjacent vectors are chosen. The binary representations of two adjacent basic vectors differ in only one bit, so that only one of the upper transistors switches when the switching pattern moves from one vector to the adjacent one. The two vectors are time weighted in a sample period \( T \) to produce the desired output voltage.

Assuming that the reference vector \( V_{ref} \) is in the 3° sector, we have the following situation:

![Fig 5: Reference vector as a combination of adjacent vectors](image)

Where \( T_4 \) and \( T_6 \) are the times during which the vectors \( V_4, V_6 \) are applied and \( T_0 \) the time during which the zero vectors are applied. When the reference voltage (output of the inverse park transformation) and the sample periods are known, the following system makes it possible to determine the uncertainties \( T_4, T_6, \) and \( T_0 \):

\[
T = T_4 + T_6 + T_0 \\
\bar{V}_{ref} = \frac{T_4}{T} \bar{V}_4 + \frac{T_6}{T} \bar{V}_6
\]

Under these constraints the locus of the reference vector is the inside of a hexagon whose vertices are formed by the tips of the eight vectors. The generated space vector PWM waveforms are symmetrical with respect to the middle of each PWM period. The diagram shows the waveforms in the example presented above.
The following diagram shows the pattern of SVPWM for each sector:

In conclusion, the inputs for the SVPWM are the reference vector components \((V_{\alpha_{sr}}, V_{\beta_{sr}})\) and the outputs are the times to apply each of the relevant sector limiting vectors.

### 2.4 Svpwm Predictive Current Control

Predictive control schemes calculate the voltages required to reach the desired currents after a sampling period. A Pulse Width Modulation (PWM) is used to translate these desired voltages into switching orders. This approach, sometime called Dead Beat Control, is noted PWM Predictive Control (PPC) in this paper. It has been used in current control for inverters where the duty cycles are calculated by using classical Space Vector PWM (SVPWM). In this paper, we present an algebraic method to determine the duty cycle values for each leg of the inverter. A special care has been given to the real time implementation, by reducing the amount of calculations needed compared to classical SVPWMs. In this class of PCC the system behaviour is predicted over more than one sampling period. It can improve performances at the expense of increased computation times making this technique incompatible with a standard industrial microcontroller board. In this paper an IM fed by a three-phase two-level voltage-source inverter is used as a common base in order to compare different predictive current controls. It should be noted that the methods that are described in this paper can be applied to other alternative-current machines and with various power converters. The parameter sensitivity of each approach is studied by simulation.

### 3. EXPERIMENTAL SETUP
The three phase induction motor is controlled by voltage source inverter circuit. The power device in the inverter is controlled using PCC and SVPWM operation obtained in controller design. The controller can be DSP processor or PIC microcontroller. The hall sensor is used to detect stator current from induction motor and fed the digital signal to the controller for control operation.

In source side, the step down transformer is connected with four step diode rectifier and then connected with capacitor (220uf). The type of diode used in rectifier is IN4007. Motor side inverter consists of six switches MOSFET IRF250. Each switch leg is connected parallel with a capacitor (0.1uf) and resistor (420ohms). PIC 16F877A controller is used to control the inverter switching pulse. MCT2E-Single Channel Opto Isolator is used between the power circuit and driver circuit.

### Table 2: Parameters of 3φ induction motor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_n$</td>
<td>1.5 kW</td>
</tr>
<tr>
<td>$U_n$</td>
<td>380 V 50 Hz</td>
</tr>
<tr>
<td>$I_c$</td>
<td>1.810A</td>
</tr>
<tr>
<td>$n_a$</td>
<td>1400 rpm</td>
</tr>
<tr>
<td>$\eta_c$</td>
<td>85.9 %</td>
</tr>
<tr>
<td>$T_a$</td>
<td>11 Nm</td>
</tr>
<tr>
<td>$J$</td>
<td>0.04 kgm²</td>
</tr>
<tr>
<td>$R_s$</td>
<td>7.48 Ω</td>
</tr>
<tr>
<td>$R_r$</td>
<td>3.68 Ω</td>
</tr>
<tr>
<td>$L_m$</td>
<td>0.4114 H</td>
</tr>
<tr>
<td>$L_s$</td>
<td>0.0221 H</td>
</tr>
<tr>
<td>$L_r$</td>
<td>0.0221 H</td>
</tr>
</tbody>
</table>

### 4. SIMULATION RESULTS

The closed loop estimation with predictive current control and space vector PWM is developed using Matlab/Simulink. Using back emf, speed is calculated. The speed and flux are estimated in PCC and constant switching pulse is generated in SVPWM toolbox.
The three phase induction motor speed control with sensorless operation is designed. The constant back emf is calculated in induction motor. The back emf is depend upon stator voltage and stator current of the induction motor. The pulse generated in SVPWM is depends upon the flux and speed calculation in PCC.

The speed of the motor is calculated using back emf and stator current in speed controller. The constant stator voltage and frequency maintained throughout the operation. The speed of the motor is starts controlled after 3ms time.

5. CONCLUSION

A new observer system was discussed and used for sensorless induction motor drive under FOC control. The wide speed range was obtained including very low as well high speeds. The proposed observer system does not demonstrate essential sensitivity to motor parameters. In this approach, only easily measurable values, such as stator current components, have been used for implementing the observer system, e.g. stator current and DC bus voltage. This substantially improved the reliability and robustness of the whole drive system. The presented results show that the discussed system maintains stability at wide speed range as well. Even an exaggerate change of motor parameters did not affect the stable operation of the sensorless drive. The effect of the dc drift and changes in the PI controller parameters were also demonstrated. This is a result of the low dependency on these parameters and on strong and fast self-adaptation of the speed observer system. Nevertheless, the observers are relatively very simple and require little computational power of the processors in contrary to other observers. The extensive experimental investigation validates the claim of simple and robust observer system.

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