MRAS BASED SENSORLESS INDUCTION MOTOR DRIVE USING VARIABLE STRUCTURE CONTROL

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ABSTRACT

Induction motor drives are widely used in industries for its simple and easy control. Variable structure controller (VSC) for an induction motor drive is an effective method of control in case of non linearities and uncertainties to enhance robustness. Dynamic performance of Induction motor drives is an essential characteristic for many industrial applications. Quality of the product is an industry and the profit of the industry are mainly depends on the performance of the induction motor drive. Transient state performance of the VSC based an induction motor drive to be improved. Since conventional VSC based induction motor drive has PI controller based speed controller. To enhance the performance of the system this paper proposes Model reference Adaptive System based speed controller in VSC. The design is simple and easy to be implemented. The entire system is simulated using Matlab / Simulink to analyze the performance of a drive. Performance of a drive using Model reference Adaptive System VSC is analysed and compared with conventional Proportional and Integral VSC. To analyze the dynamic performance of the system machine is subjected to constant and variable load in this paper.

Keywords: Induction Motor, variable structure controller, Model reference Adaptive System, PI controller.

1. INTRODUCTION

In many industries induction motors plays vital role like backbone of an industry. it is used for its reliability and low cost. performance of an induction motor drive decides the efficiency of an industry. so many researchers analysed to enhance the performance of a drive. recently, many researchers presented the advanced control strategies for pwm inverter fed induction motor drive. particularly, the vector control, which guarantees high dynamic and static performances like dc motor drives, has become very popular and has been developed and improved. fast digital processor and power devices in the vector control drives provides the possibility of achieving high performance induction motor drive control. there are many works devoted to the vector control, but only few deals with the improving the performance of controller structure [1]. classical control theory using conventional pi controllers provides good performance only in case of linear processes whose exact model is known. however, it is not possible to deal always with linear process. to achieve effective control using pi controller needs precise knowledge of motor and load parameters this is not possible in always.

Variable structure controller (VSC) is a system to deal with nonlinearities [2]. The variable structure system is inherently aimed at dealing with system uncertainties, lead to good performances even in presence of strong and fast variations of the motor parameters. Many authors analyzed the performance of variable structure systems with a sliding mode [3-5]. The VSC works on the principle of imposing the system motion to occur on a given manifold in the state space, which is defined according to the control tasks. VSC is more advantageous for its robustness, insensitivity to parameter variations, fast dynamic response. In the conventional VSC based induction motor drive PI controller is used [6][7]. Again it leads to all drawbacks by the PI controller in the VSC system too. Fuzzy logic controller (FLC) and Fuzzy Gain Scheduling (FGS) Controller are analyzed many researchers for the speed control in the induction motor drive [8-9]. Since then, fuzzy logic control has become an active and fruitful research area with
many theoretical works and industrial applications being reported [10] [11] [12-14]. Still to obtain the complete adaptive nature, specific adaptive control techniques are needed. Adaptive control changes the control algorithm coefficients in real time to compensate for variations in environment or in the system itself. It also varies the system transfer function according to situation. Out of many adaptive control schemes, this paper mainly deals with the model reference adaptive control approach. In MRAC [15-19], the output response is forced to track the response of a reference model irrespective of plant parameter variations. The controller parameters are adjusted to give a desired closed-loop performance.

2. VARIABLE STRUCTURE CONTROL ALGORITHM DESCRIPTION

The vector controlled induction motor drives are easily adoptable to VSC algorithm. In a sliding mode (SM) control, the reference model is stored in the form of a predefined phase plane trajectory, and the system response is forced to follow or slide along the trajectory by a switching control algorithm [20]. Sliding surface or sliding line is defined as the starting point of a sliding mode control design [21]. Ensuring the ability of the system to reach or cross the chosen sliding line is the next stage of a control algorithm. After the system crossing the Sliding line, it will be able to cross it again for an infinite number of times.

In this paper, the motor speed is controlled in order to obtain a constant motor speed. So, the vector control task is to impose the convergence of the motor speed magnitude to a reference one. This goal can be fulfilled applying the VSC synthesis procedure to the error speed system equation.

The error between the motor speed and its reference can be obtained as follows;

\[ \omega_{err} = \omega_r - \omega_r(t) \]  
\[ \omega_{err}^0(t) = \left( -\frac{B}{J} + \frac{3p}{2} \frac{Lm}{Lr} k \right) \omega_{err}(t) \]

Where, \( k \) is a linear feedback-gain, \( B \) is the viscous friction, \( J \) is the moment of inertia, \( p \) is the number of pair poles, \( Lm \) is the mutual inductance, and \( Lr \) is the self inductance of the rotor per phase of the induction motor. So, the equivalent dynamic behavior of control system can be rewritten as [1];

\[ \omega_{err}^0(t) = (a + bk) \omega_{err}(t) \]  
\[ S(t) = \omega_{err}(t) - \int_0^t (a + bk) \omega_{err}(\tau) d\tau \]

Where, \( \xi = -\frac{B}{J}, \eta = \frac{3p}{2} \frac{Lm}{Lr} \), \( k \) is a feedback gain, and \( (\xi + \eta k) \) is designed to be strictly negative. The switching surface with an integral component for the sliding mode speed controller is designed as follows [1];

\[ I_q(t) = k \omega_{err}(t) - \beta \text{sgn}(S(t)) \]

It is obvious from the equation (3) that the speed error will converge to zero exponentially if the pole of the system is strategically located on the left-hand plane. Thus, the overshoot phenomenon will not occur, and the system dynamic will behave as a state feedback control system. Based on the developed switching surface, a switching control law, which satisfies the hitting condition and guarantees the existence of the sliding mode, is then designed. So, the variable structure speed controller is designed as the following;

**Fig. 1. MRAS Based VSC For Vector Controlled Induction Motor Drive**

Where, \( \beta \) is denoted as switching gain, with the following assumption, \( \beta \geq 0 \), \( I_q \) is the reference torque component current, and \( \text{sgn} (\cdot) \) is a signum function defined as,
The derivatives of this lyapunov candidate function in thus:
\[
\frac{dV}{dt} = e^T [(A - GC)^T + (A - GC)] e - 2
\] (9)
\[
e^T [(A - GC)^T + (A - GC)]
\] (10)

With \( Q = \varepsilon I_e \) and \( \varepsilon > 0 \)

The stability of adaptive observer has proved if we respect two conditions as follows:

The eigen-value of the observer is selected to have negative real parts so that the states of the observer will converge to the desired states of the observed system. The term in factor of \( (\omega_e - \omega_r) \) the equation (9) must be zero. The expression of the derivative of estimated speed becomes then:

\[
K (e_{isd} \hat{\omega}_{rd} - e_{isq} \hat{\theta}_{rd}) - \frac{1}{\lambda} \frac{d}{dt} \hat{\omega}_r = 0
\] (11)

\[
\frac{d}{dt} \hat{\omega}_r = \lambda K (e_{isd} \hat{\theta}_{rd} - e_{isq} \hat{\theta}_{rd})
\] (12)

However this adaptive law of the speed

\[
\hat{\omega}_r = K_i \int_0^t (e_{isd} \hat{\omega}_{rd} - e_{isq} \hat{\theta}_{rd}) dt
\] (13)

Has obtained for the satatorique frame his dynamic has adjusted by \( K_i \) (finite positive constant). For augmented the dynamic of this observer during the transitory phase of rotor speed, we estim the speed by large PI regulator; we added a supplementary term proportional of error. Then

\[
\hat{\omega}_r = K_p (e_{isd} \hat{\omega}_{rd} - e_{isq} \hat{\theta}_{rd}) + K_i \int_0^t (e_{isd} \hat{\theta}_{rd} - e_{isq} \hat{\theta}_{rd}) dt
\] (14)

Where \( SZ \) and \( S' \) are adaptive gains for speed estimator. An identification system for speed is shown in Fig.2, which is constructed from a
linear time-invariant forward block and a nonlinear time-varying feedback block.

4. PI CONTROLLER IN VSC

PI controller is the simple method of control and widely used in industries. Proportional plus Integral Controller increases the speed of response of the system [22]. It produces very low steady state error. Two PI controllers are proposed in this paper for \( k \) and \( \beta \). In this paper speed Error \( (e) \) is given as input to both PI controllers. General equation of the PI controller is

\[
U(s) = K_p E(s) + \frac{K_i}{s} E(s)
\]  

(15)

Where \( K_p \) is proportional gain, \( K_i \) is the integral gain, \( E(s) \) is the controller input and \( U(s) \) is the controller output.

In this paper Ziegler Nichols’ method of tuning is implemented to find the optimum value of \( K_p \) & \( K_i \) values. But the drawback of this controller is, it produces the high overshoot and long settling time.

5. SIMULATION RESULTS AND ANALYSIS

To analyze the performance of variable structure controlled induction motor 5 HP squirrel induction motor is taken. It is analyzed using various controllers such as PI and MRAS under various speeds and loads. Parameters of induction motors are shown in table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Voltage</td>
<td>415</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Stator Resistance</td>
<td>1.15Ω</td>
</tr>
<tr>
<td>Rotor Resistance</td>
<td>1.083Ω</td>
</tr>
<tr>
<td>Stator inductance</td>
<td>5.974 mH</td>
</tr>
<tr>
<td>Rotor inductance</td>
<td>5.974 mH</td>
</tr>
<tr>
<td>Mutual inductance</td>
<td>0.2037H</td>
</tr>
<tr>
<td>Moment of Inertia</td>
<td>0.02 Kg m²</td>
</tr>
<tr>
<td>Number of poles</td>
<td>4</td>
</tr>
</tbody>
</table>

Simulation model of MRAS based VSC controlled induction motor drive is shown in fig. 3.

Fig. 3. Simulation Model Of MRAS Based VSC Controlled Induction Motor Drive

The performance of the motor using PI based VSC are shown in fig. 4. The performance is analyzed under a load while the machine is running. The reference speed of the machine is set at 1500 rpm.

Fig. 4. Speed Performance Of PI Based VSC Control

The performance of the motor using MRAS based VSC is shown in fig. 5. Conditions for analyses are same as a PI controller test.

Fig. 5. Speed Performance Of MRAS Based VSC Control

Three phase stator current and flux of MRAS based VSC controlled induction motor drive is shown in fig. 6 and 7.
Fig. 6. Three Phase Stator Current Of MRAS Based VSC Control

Fig. 7. D And Q Axis Flux Of MRAS Based VSC Control

Fig. 8 and Table 2 shows the comparative performance of PI and MRAS based VSC under step change in load at 0.6 seconds and reference speed as 1500 rpm.

Fig. 8. Comparison Of Speed Performance Of PI And MRAS Based VSC Control

Fig. 9. Comparison Of Speed Performance During Starting Using PI And MRAS Based VSC Control

Table 2: Performance Comparison Of PI And MRAS Controller

<table>
<thead>
<tr>
<th>Controllers</th>
<th>Peak overshoot in %</th>
<th>Rise time in Sec</th>
<th>Settling time in Sec</th>
<th>Steady state error in %</th>
<th>Change in speed during load change in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>5.67</td>
<td>0.082</td>
<td>0.2</td>
<td>2.667</td>
<td>0.4</td>
</tr>
<tr>
<td>MRAS</td>
<td>4</td>
<td>0.05</td>
<td>0.15</td>
<td>0.4</td>
<td>0.26</td>
</tr>
</tbody>
</table>

From the table it is obvious that the MRAS method improves performance of induction motor drive in all aspects such as peak overshoot, rise time, steady state error and drop in speed during change in load.

6. CONCLUSIONS

Induction motors are widely used in many industries in daily applications. Performance enhancement of it is necessary to improve quality of product. The Variable structure control is proposed in this for induction motor drive for its high robustness. It means that the system is completely insensitive to parametric uncertainty and external disturbances. Variable structure controlled Induction motor is analyzed in this paper with PI and Model reference Adaptive System. Simulation is done using Matlab. Performance of VSC based IM using both controllers are analyzed under various speeds and loads. From the simulation results it is obvious that PI controller
gives almost quick response but it produces large overshoot, steady state error and high fluctuation in speed while sudden change in load. The Model reference Adaptive System controller performs well in all aspects such as overshoot, steady state error and change in speed while sudden change in load. Therefore it is optimum to use Model reference Adaptive System controller for VSC based Induction motor control.

REFERENCES:


