2011 International Conference on Mechatronic Science, Electric Engineering and Computer
August 19-22, 2011, Jilin, China

Sensorlesse Variable Structure Adaptive Speed Control of an Induction Motor

Yang Zhiping
Department of Mechanical and Electrical Engineering,
Chongqing College of Electronic Engineering
Chongqing, China
E-mail: yzp@cqnu.edu.cn

Zang Jinchun
Department of Mechanical and Electrical Engineering,
Chongqing College of Electronic Engineering
Chongqing, China
E-mail: 235759408@qq.com

Wu Deming
Department of Mechanical and Electrical Engineering,
Chongqing College of Electronic Engineering
Chongqing, China
E-mail: 925086422@qq.com

Zhou Bin
Department of Mechanical and Electrical Engineering,
Chongqing College of Electronic Engineering
Chongqing, China
E-mail: 389392976@qq.com @qq.com

***Abstract*- This paper presents an algorithm for speed controlled of the induction motor under sensorless. According to the Lyapunov stability theory, applying the vector analysis method, through the stator current and the rotor flux are calculated then rotor speed is estimated. In order to overcome the uncertainty of system parameters and the external load disturbance, the sliding mode surface is designed based on robustness requirements. Variable structure adaptive control to track motor speed is fulfilled finally. The simulation result shows that the control scheme is effective.**

Keywords- Induction motor control; Vector control theory; Sliding surface; Variable structure control; Adaptive control

I. INTRODUCTION

In high-risk situation, for induction motor to implement speed control, it is not suitable that using speed sensor detects output speed of the motor, when the motor are running at the low speed and the extremely low speed that the speed sensor is used to sample rotor speed, which measuring error is largely, there are different influences to control the speed of the induction motor these. To improve control of induction motor, some beneficial research results are appeared already, such as nonlinear control [1] and the adaptive control [2] and the optimal control [3], etc. This paper presents research plan that is a new attempt. First of all, speed sensor is not used to detect the rotor speed, while vector analysis method is used based on Lyapunov stability theory, through a simplifying algorithm is applied to estimate the stator voltage and the rotor flux, and then the correlative data is sampled to calculate rotor speed online; sliding surface of the switching control to track motor speed is designed, it satisfies robustness requirements; the variable structure adaptive control law to meet the global stability condition is fulfilled lastly.

II. ESTIMATION OF THE ROTOR SPEED

The stator voltage and the current equations of d-q axial are given below [4]

$$\dot{\psi}_{dr} = \frac{L_r}{L_m}[v_{ds} - R_s i_{ds} - \sigma L_s \frac{d}{dt} i_{ds}] \qquad (1)$$

$$\dot{\psi}_{qr} = \frac{L_r}{L_m}[v_{qs} - R_s i_{qs} - \sigma L_s \frac{d}{dt} i_{qs}] \qquad (2)$$

Where ψ is the flux linkage, L is the inductance, v is the voltage, R is the rotor resistance, i is the current, $\sigma = 1 - L_m^2 / (L_r L_m)$ is the leakage coefficient of the motor. The subscripts r and s denote the rotor and the stator values respectively, and the subscripts d and q denote the d - q axis components in the stationary reference frame.

The relation to the rotor flux and motor speed, the stator currents are represented as:

$$i_{ds} = \frac{1}{L_m}[\psi_{dr} + w_r T_r \psi_{qr} + T_r \dot{\psi}_{dr}] \qquad \text{（3）}$$

$$i_{qs} = \frac{1}{L_m}[\psi_{qr} + w_r T_r \psi_{dr} + T_r \dot{\psi}_{qr}] \qquad \text{（4）}$$

Where w_r is the rotor electrical speed and $T_r = L_r / R_r$ is the rotor time constant, when equations (3) and (4) are used to estimate the motor speed, then stator current $\hat{i}_{ds}$ and $\hat{i}_{qs}$ are the estimated value referred to the i_{ds} and i_{qs}, and $\hat{w}_r$ is the estimated value of the rotor electrical speed. The difference between the stator current and the estimated stator currents are obtained as:

$$i_{ds} - \hat{i}_{ds} = \frac{T_r}{L_m} \psi_{qr} (w_r - \hat{w}_r) \qquad \text{（5）}$$

$$i_{qs} - \hat{i}_{qs} = \frac{T_r}{L_m}\psi_{dr}(w_r - \hat{w}_r) \qquad (6)$$

Equation (5) is multiplied by ψ_{qr} and Equation (6) is multiplied by $-\psi_{dr}$ and then added together it is obtained：

$$\begin{aligned}&(i_{ds} - \hat{i}_{ds})\psi_{qr} - (i_{qs} - \hat{i}_{ds})\psi_{dr} \\ &= \frac{T_r}{L_m}(w_r - \hat{w}_r)(\psi_{qr}^2 + \psi_{dr}^2)\end{aligned} \qquad (7)$$

From Equation (7), the rotor speed error is obtained as follow:

$$\begin{aligned}e_{w_r} &= w_r - \hat{w}_r \\ &= c[(i_{ds} - \hat{i}_{ds})\psi_{qr} - (i_{qs} - \hat{i}_{ds})\psi_{dr}]\end{aligned} \qquad (8)$$

Where, $c = \frac{L_m}{T_r}\frac{1}{\psi_{dr}^2 + \psi_{qr}^2}$

From Lyapunov stable theory[4][5], it can conclude that the rotor speed error tends to zero as the time t tends to infinity, therefore, the rotor speed w_r can be calculated through the speed estimator proposed, which utilize measurements of the voltages and the currents of the stator.

III. SPEED CONTROL OF INDUCTION MOTOR [6-8]

A. Dynamic equation of the motor speed

In general, the mechanical speed equation of an induction motor can be written as:

$$J\dot{w}_m + Bw_m + T_L = T_e \qquad (9)$$

Where J and B are the inertia constant and the friction coefficient of the induction motor respectively; T_L is the external load; w_m is rotor mechanical speed in angular frequency, which is related to the rotor electrical speed by $w_m = 2w_r / p$ where p is the pole numbers, T_e is the generated torque of an induction motor; The relation between the stator current and the generated torque of the motor as:

$$T_e = K_T i_{qs}^e \qquad (10)$$

Where K_T is torque constant, substituting equation (10) into equation (9), it is obtained:

$$\dot{w}_m = -aw_m - f + bi_{qs}^e \qquad (11)$$

Where, $a = B/J, f = T_L/J, b = K_T/J$, because equation (11) with uncertainties, it is modified as:

$$\dot{w}_m = -(a + \Delta a)w_m - (f + \Delta f) + (b + \Delta b)i_{qs}^e \qquad (12)$$

Where， the terms $\Delta a, \Delta f$ and Δb representing uncertainties of the terms a, f and b respectively, they affect normal operation of the motor. It is necessary that effective control measure is taken in order to eliminate these uncertainties to ensure smooth run of the motor.

B. variable structure speed control algorithm

The tracking speed error of the motor is defined as follow:

$$e(t) = w_m(t) - w_m^*(t) \qquad (13)$$

Where $w_m^*(t)$ is the command rotor speed, to differentiate equation (13) and to relate with the previous derivative equations is yielded:

$$\begin{aligned}\dot{e}(t) &= \dot{w}_m(t) - \dot{w}_m^*(t) \\ &= -ae(t) + u(t) + d(t)\end{aligned} \qquad (14)$$

Where $u(t)$ is the speed control signal, $d(t)$ is sum of uncertainty terms of the system, the equation（14） can be written dynamic control signal that relates to track speed about the uncertainty system as：

$$u(t) = bi_{qs}^e(t) - aw_m^*(t) - f(t) - w_m^*(t) + d(t) \qquad (15)$$

The uncertainty terms have been collected in the signal $d(t)$

$$d(t) = -\Delta aw_m(t) - \Delta f(t) + \Delta bi_{qs}^e(t) \qquad (16)$$

It is necessary that designs an effective control $u(t)$ for speed error $e(t)$ tends to zero as the time t tends to infinity that is mechanical speed to track command speed when the motor is running, it is the basic task of the motor control, for the purpose, it needs to overcome the negative influence to track speed in the system uncertainty, then the system should have adaptive gain that can eliminate the uncertainty, the switching control action on the sliding surface, it can solve the above problems. Sliding surface design is given as follow.

C. design of sliding mode surface

Choose of sliding surface to share adaptive function, it can provide a switch control to restrain error between the measured speed and the command speed, so that running speed can trace command speed in induction motor. In order to eliminate about the harmful effects that are the external disturbance and the load change when motor is running, it requires sliding motion to have enough gain on the sliding surface also. Considering the velocity error and add error increment, the sliding surface is selected as follow:

$$S(t) = e(t) + \int_0^t (a + k)e(\tau)d\tau \qquad (17)$$

Where, $S(t)$ is sliding variable, k is constant, for eliminating error, the sliding control needs to adapt to error changes, changing rate of sliding surface as speed error changed is:

$$\dot{S}(t) = \dot{e}(t) + (a + k)e(t) \qquad (18)$$

The equation (14) is substituted into equation (18) then result is obtained as:

$$u(t) = -ke(t) + \dot{S}(t) - d(t) \qquad (19)$$

When time tends to infinity, the control function makes that speed error $e(t)$ tends to zero, while sliding control should eliminate $d(t)$ as sum of uncertainty, therefore it needs to add a term of control that can eliminate all of uncertainty, equation (19) is presented as:

$$u(t) = -ke(t) + u_{vc}(t) \qquad (20)$$

Where， $u_{vc}(t)$ is a term of control that relates switch function on the sliding surface. To eliminate action of uncertainty in the system, the sliding surface should have sliding gain ρ , where ρ is finite and ρ is set as $\rho > d_{\max}$, where $d_{\max}$ is finite also, then sliding control law is denoted as:

$$u_{vc}(t) = \dot{S}(t) - d(t) = -\rho\,\mathrm{sgn}(S) \qquad (21)$$

In which $\mathrm{sgn}(S)$ is a sign function, sliding gain ρ is adapted changed as sliding hitting, from the sliding control action of equation（21）, it achieves as follow some results:

$$\hat{\rho} = |S|，\ \hat{\rho}(0) = 0 \qquad (22)$$

D. design of the variable structure control low

On base of the sliding surface designed, it is necessary that effective control is designed to ensure parameters convergence also, so that the system has robust to restrain external disturbance, it can guarantee the system globally stability, wherefore, a variable structure control low is proposed as bellow:

A Lyapunov function candidate is chosen as:

$$V = \frac{1}{2}S^2(t) \qquad (23)$$

Differentiating (23) with respect to time and using (21) leads to:

$$\begin{aligned}\dot{V} &= S(t)\dot{S}(t) = S(t)[d(t) - \rho\,\mathrm{sgn}(S(t))] \\ &= S(t)d(t) - |S(t)|\rho \le |S(t)||d| - |S(t)|\rho \qquad (24) \\ &= -|S(t)|(\rho - |d|) \le 0\end{aligned}$$

According to Lyapunov stable principle, when time t is enough large then it leads to $\rho - |d| \to 0$, it shows that sliding gain can despite uncertainty of the system. Differentiating (23) with respect to time is obtained as:

$$\ddot{V}(t) = d(t)\dot{S}(t) - \rho\frac{d}{dt}|S(t)| \qquad (25)$$

In equation (25), as $\ddot{V}$ is bounded with $\dot{S}(t)$ is bounded, while $\dot{V}$ is continuous function, according to

Barbala's lemma [9], it leads to $\dot{V} \to 0$ when as $S(t) \to 0$ with $t \to \infty$, the error and the error change rate are also tends to zero in equation (18), therefore, from equation (20), it constructs variable structure control low as:

$$u(t) = -ke(t) - \rho\,\mathrm{sgn}(S) \qquad (26)$$

It can ensure the stable condition and the convergence condition.

In summary, the variable structure control presented, it can eliminate the velocity error to ensure convergence characteristics for the controlled system, stability of the motor run is guaranteed also. At the same time, applying sliding gain, it eliminate system uncertainties with the parameter variation and the external load disturbance on the sliding surface, it makes the system to work in good condition.

Because the controller presented is applying current estimated to calculate control speed, therefore, the generating current to drive electromagnetic torque is used to control motor speed, by substituting (20) (21) into (15) is got:

$$i_{qs}^{e*}(t) = \frac{1}{b}[ke - \rho\,\mathrm{sgn}(S) + aw_m^* + w_m^* + f] \qquad (27)$$

Equation (27) shows also that calculation current of the motor to relate with variable structure control law directly.

IV. SIMULATION ANALYSIS

From above the controller, simulation model is structured as is shown in figure 1

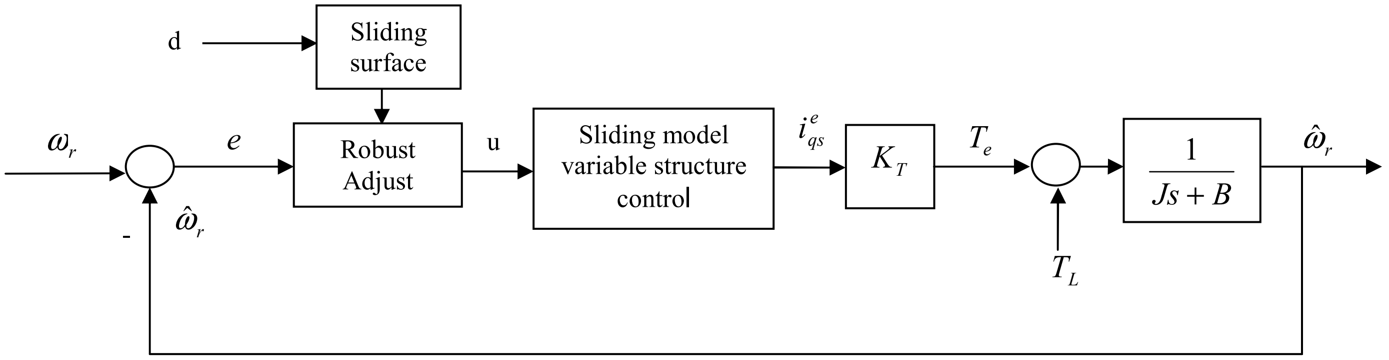

Figure 1 simulation structure figure of sliding model variable structure control system

Simulating parameters are selected as follows:

$K_T = 0.4456$； $J = 6.225$； $B = 5.55$； $\rho = 6.55$； $T_L = 0.85$

In figure 1, d is random white noise signal, corresponding to the command rotor speed, treating the actual speed are real-time sampled online in every sampling period, then the computer control system is applied to implement the variable structure adaptive control according to control scheme as Figure 1, it gets simulation results as figure 2. Figure 2 shows that the motor speed measured and the motor speed given keep good tracking characteristics.

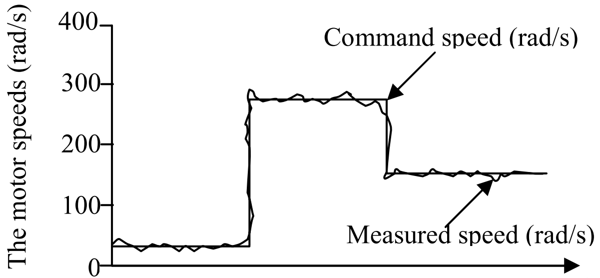

Figure 2 speed control simulation curve of the induction motor

V. CONCLUSION

The induction motor run at the low speed and the extremely low speed, when output feedback is used to the speed control, using speed sensor that is restricted that sensing errors are larger or errors are difficult detected, it makes that tracking motor speed at command value is difficult also. This paper presents the scheme that improves traditional control method by speed sensor to detect speed. Through the stator current and the rotor flux are calculated then rotor speed is calculated. In the controller design, according to the Lyapunov stability control theory, a sliding surface under the robust properties is designed, it can restrain uncertainty of the system. Using adaptive gain on the sliding surface, the variable structure control law to track speed is designed, it guarantees system stability. Summary, control algorithm designed is reasonable to implement motor speed control. The simulation results show that the control algorithm given is effectively, it is feasible for speed control of the same classes of induction motor.

REFERENCES:

[1] R Ortega, C Canudal, IS Seleme. Nonlinear control of induction motors: torque tracking with unknown load disturbances. IEEE Transactions on Automatic Control. Vol. 38, 1993, pp.1675-1680.

[2] R Marino, S Peresada, P Tomei. Adaptive output feedback control of current-fed induction motors with uncertain rotor resistance and torque. Automatica. Vol. 34, 1998, pp.617-624.

[3] H Quadi, F Giri, A Elfadili, L Dugard. Induction machine speed control with flux optimization. ontrol Engineering Practice. Vol. 18, 2002, pp. 55-66.

[4] R.J Wai, C.M lin and C.F Hsu. Hybrid control for induction servomotor drive. IEE Proc-Control Theory Appl.Vol. 149, 2002. pp. 555-563.

[5] Li Shiyong, the fuzzy control and neural control and intelligent control theory. Harbin industrial university press, Harbin, 1996.

[6] M Menaa, O Touhami, R Ibtiouen, M Fadel. Sensorless direct vector control of an induction motor. Control Engineering Practice. Vol. 16, 2008, pp. 67-77.

[7] TL Chern, J Chang, KL Tsai. Integral variable structure control based adaptive speed estimator and resistance identifier for an induction motor. International Journal of Control. Vol. 69, 1998 pp.31-47

[8] O Barambones, A.J Garrido. Adaptive sensorless robust control of AC drives based on sliding mode control theory. INTERNATIONAL JOURNAL OF ROBUST AND NONLINEAR CONTROL. Vol. 17, 2007, pp. 862-879.

[9] J.J.E Slotine, Li W.P. Applied nonlinear control. Prentice Hall, Engliwood Cliffs, NJ, 1999.