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Procedia Engineering 29 (2012) 2376 – 2381
Procedia Engineering
www.elsevier.com/locate/procedia

2012 International Workshop on Information and Electronics Engineering (IWIEE)

Induction Motor Speed Control Based on Model Reference

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Abstract

This paper presents an optimizing algorithm for speed controlled of the induction motor under sensorless. According to the Lyapunov stability theory, applying the vector analyses method, through the stator current and the rotor flux are calculated to estimate rotor speed. Corresponding to sensorless control drawbacks, a variable structure control scheme for the induction motor is proposed combined with model reference method. Simulation results show that the control plan is effectively.

Keywords: Induction motor, sensorless speed control, vector control theory, model reference method, variable structure control

1. Introduction

In induction motor control, the speed sensor is used to detect motor output speed, since the provision of special motor-shaft extension and auxiliary devices, it leads to more expensive machines, it drops the system reliability also, especially in a hostile environment. 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 errors are largely. There are different influences to control the speed of the induction motor these. To improve control of the induction motor, there were beneficial research results to control the induction motor without the need for speed sensors [1]-[2].

But, the sensorless speed control for the induction motor, it has also drawbacks, such as calculate burden is greatly to implement sample control online, it may be unstable when the system loads are changed and the external disturbances are occurred， it makes parameter convergence speeds are slowly

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doi:10.1016/j.proeng.2012.01.318

in control. Corresponding to these problems, there were solving schemes, such as the optimal time control [3] and the PI controller [4], etc. This paper presents research plan that is a further attempt. In scheme, speed sensor is not used to detect the rotor speed firstly, while vector analysis methods are used based on Lyapunov stability theory, through a simplify algorithm is applied to estimate the stator voltage and the rotor flux, and then the correlative data is sampled to calculate rotor speed online. After the sensorless speed estimator is given, the variable construct control for the motor speed is proposed that is excellence compared with about schemes.

2. Estimation of the rotor speed of the induction motor

The stator voltage and the current equations of the induction motor in d-q reference frame are given below [1]

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

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

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 stator values respectively, referred to the stator, and the subscripts d and q denote the d-q axis components in the stationary reference frame. The relationship to the rotor flux and the motor speed, the stator currents are represented as:

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

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

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 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:

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

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

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

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

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

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

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

From Lyapunov stable theory[1], it can conclude that the error of the rotor speed tends to zero as the time t tends to infinity, therefore, the rotor speed w_r can be calculated through the speed estimator is proposed, which utilizes measurements of the voltages and the currents of the stator.

3. Variable structure control based on state feedback

In designing a sensorless speed controller for the motor driven, a proportion-integral (PI) control scheme has been proposed by [4]. However, with a fixed gain PI controller to implement commonly used, the maximum overshoot and the speed of system response conflict with each other, in other words, both small overshoot and fast output response cannot be achieved simultaneously.

This section presents variable structure control algorithm based on the model reference control technology, it is optimizing to control the speed of the induction motor, which speed tracing character is better. It is robust to the parameter changes of the system. The control algorithm is designed as bellow.

3.1. The model reference control method described

The motor dynamic model and the reference model are described as below，respectively.

$$\dot{x}(t) = A_p x(t) + B_p u(t) + D_p w(t) \tag{9}$$

$$\dot{\hat{x}}(t) = A_m \hat{x}(t) + B_m r(t) \tag{10}$$

Where, the $x(t)$ and the $\hat{x}(t) \in R^{n\times 1}$ are the state vector about the motor plant and the reference model respectively, $u(t) \in R^{m\times 1}$ is control vector, $r(t) \in R^{m\times 1}$ is reference input vector， $w(t) \in R^{m\times 1}$ is white noise signal (disturbance). $A_p, A_m \in R^{n\times n}$, $B_p, D_p, B_m \in R^{n\times m}$ (n>m), is bounded and is uncertain, (A_p, B_p) is controlled couple， A_m is stable. The convergence request for the model reference control is

$$\left\| A_p - A_m \right\| \le \eta \tag{11}$$

Where, η is upper bound of the uncertain matrix $\left\| A_p - A_m \right\|$. According to error criterion, η is choose as small enough, then equation (11) is established to each sample period. Therefore, it can structure a base of the variable structure control**.**

3.2. Variable structure control law design

Based on the equation (9) and (10), dynamic error between the motor plant and reference model is proposed as:

$$\begin{aligned} \dot{e}(t) &= \dot{x} - \dot{\hat{x}} \\ &= A_m e(t) + (A_p - A_m)x(t) + B_p u(t) + D_p w(t) - B_m r(t) \end{aligned} \tag{12}$$

Because the error is uncertain as the A_p is uncertain, it affects system stability, therefore a variable structure control is used to restrain the dynamic error, which has robustness to treat the system uncertain, at the same time, it can accelerate error convergence through a switch control is utilized, where, the switch function S(t) is selected as below[5]:

$$S(t) = Ce(t) - \int_0^t (CA_m + CB_p G)e(\tau)d\tau \qquad (13)$$

Where, the $C, G \in R^{m\times 1}$, they need to solve in scheme implemented, C is chosen to meet the $CB_p \neq 0$ and the $CD_p = 0$, the G is feedback gain matrix, the literature [6][7] deduces when expression $(A_m + B_p G)$ is stable then steady state error is convergent, to solve G, it needs to meet Lyapunov equation by below:

$$(A_m + B_p G)\xi + \xi(A_m + B_p G)^T + D_p w D_p^T = 0 \qquad (14)$$

Where, ξ is coefficient matrix to guarantee the steady state error convergence and that is set $\xi = \xi^T > 0$, feedback gain matrix G is chosen to satisfy equation (14). According to the inference mentality in the literature [6] , through to solve Lyapunov equation, as below result is achieved:

$$G = -1/2B_p^{-1}(A_m\xi + \xi A_m^T + D_p w D_p^T)\xi^{-1} + (B_p^{-1}HB_p)\xi^{-1} + (I - B_p^{-1})Z \qquad (15)$$

Where, the $H \in R^{n\times n}$ is arbitrary Hermitian matrix, $Z \in R^{m\times n}$ is arbitrary matrix to meet the steady state error convergence. Through feedback gain G is chosen that the variable structure control $u(t)$ is designed to ensure state error convergence in sliding surface, it makes the system stability also. According to the stable condition [6], when the equation $CD_p = 0$ is met, the control law is deduced [8] as:

$$u(t) = Ge(t) - (CB_p)[k\|C\|\cdot\|x(t)\| + \|C\|\cdot\|B_m\|\cdot\|r(t)\| + \alpha]\mathrm{sgn}(S(t)) \qquad (16)$$

3.3. Motor speed governing course

Aforementioned variable control, it employs variance principle to control the error between the reference model and the motor pant, the control course is indicated as below. The dynamic equation of the induction motor is presented as:

$$J\ddot{\theta} + B\dot{\theta} = k_T i + T_L \qquad (17)$$

Where, J and B are the inertia constant and the friction coefficient for 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. Transformed the motor dynamic equation into the state equation as:

$$\dot{x} = \begin{bmatrix} 0 & 1 \\ 1 & -B/J \end{bmatrix} x + \begin{bmatrix} 0.5 \\ k_T/J \end{bmatrix} u + \begin{bmatrix} 0 \\ -1/J \end{bmatrix} w \qquad (18)$$

$$y = [1 \quad 0]x \qquad (19)$$

Where, $x = [\theta \quad \dot{\theta}]^T$, $u = i$, $w = T_L$.

Corresponding to equation (18), state coefficient matrix A_p, B_p, D_p are obtained as:

$$A_p = \begin{bmatrix} 0 & 1 \\ 1 & -B/J \end{bmatrix}, \quad B_p = \begin{bmatrix} 0.5 \\ k_T/J \end{bmatrix}, \quad D_p = \begin{bmatrix} 0 \\ -1/J \end{bmatrix} \tag{20}$$

Coefficient matrix the A_m and the B_m on the reference model are set as, respectively:

$$A_m = \begin{bmatrix} 0 & 1 \\ 2\delta & \delta \end{bmatrix}, \quad B_m = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \tag{21}$$

Where, δ is simulation modulation coefficient that needs to set in the simulation so that equation (14) can establish. In actual control, a fuzzy adaptive algorithm may be used to calculate A_p, B_p, cf [9]. Matrix C= [2 0] is Chosen to meet CD_p=0, the variable structure control (19) is achieved lastly.

4. Simulation analysis

From previous the control algorithm, simulation course are given as:

1) For equation (21), the reference model vector is given, equation (18) is used to calculate state vector of the motor model.

2) From 3 section given algorithm, setting up $r(t)=1$, $w=1$, the convergence matrix ξ with the state error is given simultaneously.

3) The matrix C is chosen so that equation the (14) and the (16) are established, it makes sliding state finish also.

4) Chosen the H and the Z, equation (18) is used to calculate feedback gain matrix G.

5) Substituting G to equation (15), then S(t) is solved.

6) In equation (16), setting up $\alpha = 1$, through the simulating course to select k, the control law to regulate motor speed that is indicated as:

$$u(t) = [3.25 \quad 1.743]e(t) - (6.25\|x\| + |r(t)| + 1)\,\mathrm{sgn}(S(t)) \tag{22}$$

For the section 3 and the section 4, equation (22) is implemented to control the speed error, the running speed $\hat{w}$ of induction motor traces command speed w_r finer, response character of the motor speed is showed as Fig 1, which the k is sample interval. From simulation results, the control effect is ideal.

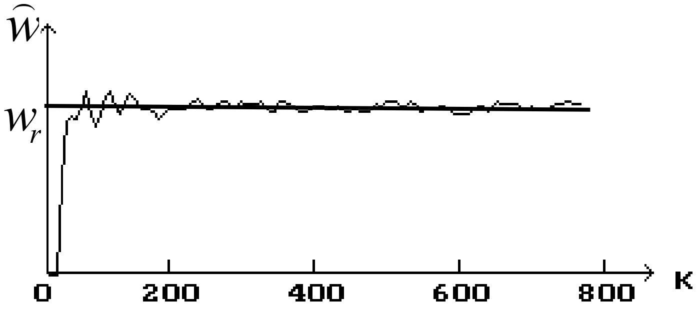

Fig 1 response character of the motor speed

5. Conclusion

The paper presents the sensorless speed control scheme for the induction motor, it applies the model reference control to restrain the convergence errors and applies the variable structure control to guarantee the parameter fast convergence. Compared with some of the schemes, it is optimizing to improve speed controlled and to revise about insufficient schemes in the induction motor control. The simulation results show that the control algorithm proposed is effectively and the control effect is satisfactorily. It also shows that the controller proposed is suitable for a class of dynamic tracking control for the speed process of the induction motor.

References

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

[2] Wai R.J, Lin C.M, Hsu C.F. Hybrid control for induction servomotor drive. IEE Proc-Control Theory Appl 2002; 149: 555-563.

[3] Yusheng Lu. Smooth speed control of asymptotic disturbance compensation. Control Engineering Practice 2008; 16: 597-608.

[4] Moallem M, Mirzaeian B, Mohammed O.A, Lucas C. Multi-objective genetic-fuzzy optimal design of PI controller in the indirect field oriented control of an induction motor. IEEE Transactions on Magnetics 2008: 37: 3608-3612.

[5] Shyu K, Shieh H.J. A switching surface sliding-mode speed control for induction motor drives. IEEE Trans, Power Electron 1996; 11: 660-667.

[6] Chan H.Q.W. New scheme of sliding-mode control for high performance induction motor drives. proc, IEE-Elect, Power Applicat 1996; 143: 177-185.

[7] Kang H, Kim N.J, Yoo Y, Park G.T, Yu S.Y. Variable structure approach for induction motor control-practice implementation of DSP. in Proc, IEEE INCON. 1994; 94 :50-55.

[8] Chang Yuh. Varible structure-based covariance assingnment for stochastic multivariable model reference systems. Automatic 2000; 36: 141-146.

[9] Wang Tanaka H.O, kriffin M.F. An approach to fuzzy control of nonlinear system：stability and design issues. IEEE Trans. Fuzzy Systems 1996; 4:14-23.