International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 7, No. 3, September 2016, pp. 648~655
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v7.i3.pp648-655

Online Adaptation of Rotor Resistance based on Sliding Mode Observer with Backstepping Control of A Five-Phase Induction Motor Drives

H. Echeikh[1], R. Trabelsi[2], A. Iqbal[3], M.F. Mimouni[4] and R. Alammari[5]
[1,3]National Engineering School of Monastir, Tunisia
[2]High Institute of Applied Sciences and Technology of Sousse, Tunisia
[3,5]Qatar University, Department of Electrical Engineering, Qatar

Article Info

Article history:

Received Nov 12, 2015
Revised Mar 7, 2016
Accepted Apr 8, 2016

Keyword:

Backstepping control
Five-phase induction motor
Multiphase drive
Sliding mode observer

ABSTRACT

Multiphase electric drives have been developed due to numerous advantages offered by those machines when it compared with the conventional three-phase machines. Multiphase motor drives are considered for applications, where the reduction of power per phase for both motor and inverter and high reliability are required. High performance control techniques are developed for multi-phase drives. The performances of the high performance controller and flux observers may be degraded during the operation. Since the parameters of Induction Motor (IM) varies continuously due to temperature variation and heating.Thus it is significantly important that the value of rotor resistance is continuously observed online and adapted by the control algorithm in order to avoid detuning effects. The efficiency and performance of an induction motor drive system can be improved by online observation of the critical parameters, such as the rotor resistance and stator resistance. Among the parameters of IM, rotor resistance is a decisive one for flux estimation, and also the stator resistance becomescritical in the low-speed operation condition. This paper presents a new online estimation method for the rotor resistance of the IM for sliding mode observer. This method generally based on theoriesof variable structure and is useful in order to adjust online unknown parameters (load torque and rotor resistance). The presented non-linear compensator afford a voltage inputs on the articulation of stator current and rotor speed measurements, and engender an estimates for the unknown parameters simultaneously, the non-measurable state variables (rotor flux and derivatives of the stator current and voltage) that converge to the corresponding true values. Under the persistent excitation condition, the proposed method estimates the actual value of rotor resistance, which guarantees the exact estimation of the rotor flux. Non-linear Backstepping control and adaptive sliding mode observer of a five-phase induction motor drive is presented. The accuracy and validity of the method is verified by MATLAB simulation model.

Corresponding Author:

A. Iqbal,
Department of Electrical Engineering,
Qatar University, Qatar.
Email: atif.iqbal@qu.edu.qa

1. INTRODUCTION

Multiphase motor drive offer different advantages over three-phase motor drive. In [1-6] major of advantages of multiphase drive is discussed. Multiphase motor drives advantages are; density of the torque is higher, the pulsations of the torque are reduced, offer greater fault tolerance conditions, minimizes the per-phase current without increasing the per-phase voltage. In addition, the uses of multiphase machine permit to reduce the intended converter per-phase rating (per leg of inverter); therefore, more reliability of the power conditioning equipment and more suitable noise characteristics, elevated phase number afford smoother torque explained by the simultaneously increase of the frequency of the pulsation of the torque in the first side and the other side the clear reduction of the magnitude of the torque ripple.

The multiphase motor drive are restrained to use in critical domains, where high reliability and redundancy is needed such us, electric aircraft, electric traction, ship propulsion, other high power application and hybrid electric vehicles [1-6].

The popularity of multiphase drives is because ofthe fact that multiphase drives in high power application permit to reduce per inverter leg whichis considered as amajor advantage from converter point of view, indeed the switch ratings could be reduced per-phase. Concerning high power applications that required to process a large quantity of power, series or/and parallel combination of power electronics switches are recommended. Due to this series or parallel switches combinations some problems of dynamic and static current and voltage sharing appear. Nevertheless, due to reduce per leg inverter power, the series/parallel combination of switches can be avoided. In an electric aircraft which comes under the category of safety critical applications, the multiphase drives are used because they offers and enables great fault tolerance which is considered a predominance importance due to the impact of the behaviour of the drive for loss of one or more phases.In the end , the use of multiphase motor drive in the hybrid and electric vehicles areas authorize the reduction of the requisite rating current for the semiconductor switch, even those drives are not distinguish by high power.

Voltage source inverter based drives are mostly employed in electric drive industry. The assigned outputs are commonly shaft position, phase currents, rotor flux and also electromagnetic torque. However, there is some grandeur are designated as not measured such as the stator and rotor fluxes due to non-accessibility of measurement due to non-existent sensors. It is well illustrious that the IM drive is conventionally fed by variables measured like the stator currents. The progressive techniques of motor drive generally equipped in order to adjust the torque, speed and flux with state observers and also parameters estimators.

Recently the research work of the control field of electrical motor drives have been motivated due to the fact that the IM is well known as a non-linear and strongly coupled system with parameters variations. The field oriented control (FOC) technique is the most popular option method in the different drive applications to obtain high performance control of an Induction motor. Moreover, this strategy of control needs the knowledge of rotor flux position and rotor resistance [7]. However, the parameters values manifested in the controller strategy need to be authentic in order to obtain in both dynamic and static state, high performances for the IM drive. Nevertheless, in the presence of improper values of the parameters in the control algorithm causes a loss of the control of the oriented field [8]. Many research in the literature talked about the percent of parameters variations precisely the rotor and stator resistances due to the temperature variation of the IM in fact of the heating, indeed this variations could achieve or rise to 50% and 100% of the rated values [7-24]. Most of the control system for motor drive application need precise values of motor parameters. Therefore, using sensors such hall of sensing coils the flux of the IM motor can be instantaneously measured but there are problems still remain.Those problems familiarized in different types like the increment of the volume, increase of the cost due to the sensors and abasement in mechanical robustness. Nevertheless, using the measured values of stator currents, voltages and rotor speed one can estimate or observe the flux due to the current model if it is rotor flux and voltage model if it stator flux [9]. A short review of the rotor and stator resistances estimator and stator and rotor flux observes used in sensorless control algorithms is reviewed and presented in the subsequent sub section.

Rotor and stator resistance observers: the on-line observation of respectively rotor and stator resistance parameters presented in and discussed in [10-15], it should be noted that all those parameters estimators are depend of the measurement of some quantities like stator currents and stator voltages.

In the literature many researches discusses the on-line parameters identification and estimation in Induction motor drives. However, Kan Akatsu el al develops an online rotor observation using speed sensorless control [10]. ZHOU Dehong et al and Amuliu Bogdan Proca el succeeded to develop in predictive torque control a sliding mode flux observer taking into account the online rotor and stator resistance estimations [11-12]. T. Abbasian et al presents an estimation of core loss rotor resistance by using an improved feedback linearization control [13]. In order to enhance the performance of online rotor resistance estimation S. M. Nayeem Hasan et al develop a Luenberger sliding mode observer [8]. N. Jaalam et al construct a new structure scheme of online estimation, a neuro fuzzy for stator resistance estimation and Baburaj Karanayil et al develop another observation scheme based on using an artificial neutral networks both rotor and stator resistances estimation [14-15]. A new algorithm of speed and flux adaption control was developed by using unknown time varying load torque and rotor resistance [16]. S. Legrioui et al investigate a reaching law sensorless controller with MRAS observer based on online parameters identification [17]. Suman Maiti et al detailed a model of reference adaptive controller and use reactive power for online estimation of rotor resistance [18]. In other way F. L. Mapelli et al proposed a nonlinear correction of rotor resistance of induction motor drive forelectrical vehicle based on reactive stator power [19]. Riccardo Marino el al designed a ninth order estimation approach to provide on-line exponentialconvergence for both rotor and stator resistances of IM [20]. Other estimation methods were developed in the literature such as Pegah Rokhforoz et al developed a robust extended Kalman filter in order to estimate the speed and rotor resistance [21]. K. Lakshmi Varaha Iyer el al and Elham Mohammadalipour Tofighi et al presents a new observer scheme of online estimation of rotor and stator resistance of IM using particle swarm optimization intelligence (PSO) [22] [23]. Fazard R Salmasi et al developed an Adaptive flux methodology of both rotor resistance and DC-voltage estimation [24].

Flux observers: conventionally the voltage model is used to carefully estimate the stator fluxes, therefore, this method based on the integration of the equation of the stator voltages. However, this method is sensitive to the stator resistance, especially at very low speeds.In order to mitigate this problem, generally rotor model flux observes are employed during the estimation of rotor fluxes, moreover, this method is basically depend on the measurement of phase currents. In these circumstances, there are corresponding flux observers with addition of the estimation of the motor parameters. An extensive works in the literature is reported on this topic [7-24]. Until now (as far as the authors know) no Backstepping (BSC) control has been presented in the literature concerning multi-phase motor drive precisely for a five-phase induction motor drive. This paper proposes online rotor resistance estimation for BSC controlled five-phase induction motor drive. The paper is structured as follow, in section II closed-loop adaptive sliding mode observer with backstepping control of five-phase IM, section III summarized, simulation results and discussion of the obtained results, the conclusion is given in section IV.

2. CLOSED-LOOP ADAPTIVE SLIDING MODE OBSERVER WITH BACKSTEPPING CONTROL OF FIVE-PHASE INDUCTION MOTOR

Five-phase motor is considered one of the most frequently used multiphase motors. In the literature, five-phase motor can be found in two different constructions depending on the shape of MMF. Two types of induction motors are used namely distributed winding and concentrated winding. In distributed winding configuration, a five-phase motor requires only sinusoidal stator voltages since distribution windings generate a near sinusoidal air-gap MMF. So the low order harmonic are disagreeable in the motor input's voltage. In concentrated type construction, the goal is to enhance the torque production of five-phase motor using low order air-gap MMF harmonics injection. Several assumptions are used to simplify and model of five-phase motor cited in [25]. Mathematical model of a distributed type of five-phase induction motor is:

$$\begin{cases} \dot{x} = Ax + BV_s \\ y = Cx \end{cases} \tag{1}$$

$$x = [i_s \quad \lambda_r]^T \tag{2}$$

$$A = \begin{bmatrix} A_{11}I & 0 & (A_{15}I - A_{16}J) \\ 0 & -I/\tau_{ls} & 0 \\ MI/\tau_r & 0 & (-I/\tau_r - \omega_r J) \end{bmatrix} \tag{3}$$

$$B = \begin{bmatrix} I/\sigma L_s & 0 \\ 0 & I/L_{ls} \\ 0 & 0 \end{bmatrix} \tag{4}$$

$$C = \begin{bmatrix} I & 0 & 0 \\ 0 & I & 0 \end{bmatrix} \tag{5}$$

$$i_s = [i_{s\alpha} \quad i_{s\beta} \quad i_{sx} \quad i_{sy}]^T \tag{6}$$

$$\lambda_r = [\lambda_{r\alpha} \quad \lambda_{r\beta}]^T \tag{7}$$

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{8}$$

where $\sigma = 1 - M^2/L_s L_r$,$\tau_r = L_r/R_r$and ,$\tau_s = L_s/R_s$.

L_r,L_s, M, R_r and R_s are rotor inductance, stator inductance, mutual inductance, rotor resistance and stator resistance. V_s, λ_r and i_s are respectively, Stator voltage, rotor flux and stator current. $A_{11} = -(1/(\sigma\tau_s) + (1-\sigma)/(\sigma\tau_r))$, $A_{15} = (1-\sigma)/(\sigma M \tau_r)$ $A_{16} = \omega_r(1-\sigma)/(\sigma M)$. The sliding mode observer of five-phase Induction motor which estimates simultaneously the rotor flux and stator current given by:

$$\dot{\hat{x}} = \hat{A}\hat{x} + BV_s + K\text{sign}(\tilde{\iota_s}) \quad (9)$$

$$\hat{\iota_s} = C\hat{x} \quad (10)$$

where ^ denotes observed quantities, $\text{Ksign}(\tilde{i_s})$ in the proposed observer represents the sliding mode component and K is the gain matrice. The sign term occur the robustness of the proposed observer. Figure 1 shows the diagram block of the observation method. Motor data as shown in Table 1 and sliding mode parameter as shown in Table 2.

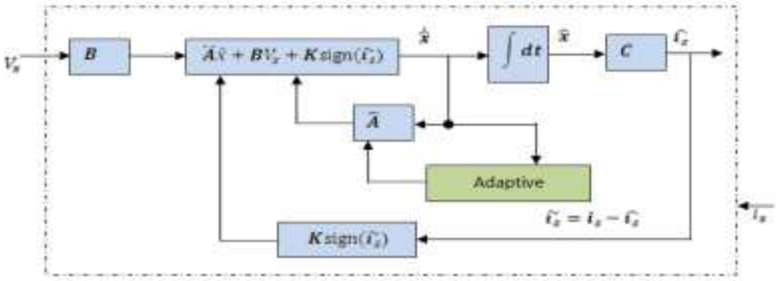

Figure 1. Adaptive parameter sliding mode observer

Table 1. Motor data

Symbols	Quantity	Value
R_r	Rotor resistance	6.3Ω
R_s	Stator resistance	10Ω
L_r	Rotor inductance	0.46 H
L_s	Stator inductance	0.46 H
L_{ls}	Stator leakage inductance	0.04H
L_{lr}	Rotor leakage inductance	0.04H
M	Mutual inductance	0.42H
P	Pair of Pole	2
N	Rated speed	1500 rpm
Tn	Rated torque	8.33N.m
J	Inertia moment	0.01
Pn	Rated Power	1.5kW

Table 2. Sliding mode parameter

Symbols	Value
k1	10
k2	10
k3	5
k4	5
m	1000

The structure scheme present a novel sliding mode observer follows with adaptive identification approach for parameter estimation. It is a closed-loop observer however; the estimated variables are fed back for correction. The observer is sixth order and requires less computation when compared to the other observers exist in theliterature [8-25], in addition it is easy to set and fix the sliding mode gain. The sliding mode observer assists quick parameters tracking, the part of SMO take care of the mismatches in the parameters, relatively in measurements and the system internal noise.

Problem Statement: for the structure based observer scheme, the problem can be stated in the design of K gain matrice such that the errors $i_s - \hat{i_s} \rightarrow 0$ and $x - \hat{x} \rightarrow 0$ when the limit of time $t \rightarrow \infty$.subtracting equation (1) from equation (10), the output of the dynamics error can be found as follows:

$$\dot{\psi} = C\frac{d(x - \hat{x})}{dt} \tag{11}$$

$$\dot{\psi} = CAC^T\psi - C\Delta A\hat{x} - CK\text{sign}(\psi) \tag{12}$$

where $\Delta A = \hat{A} - A$

To obtain a sufficient condition that the nonlinear system is asymptotically stable, the Lyapunov's stability used to determinate the error dynamics, however, an adequate Lyapunov function is familiarize to drive the expression of the rotor resistance estimation

$$V = \psi^T\psi + \frac{(\hat{R}_r - R_r)^2}{m} \tag{13}$$

where m is a constant which chosen positive. The derivation of V is written in equation (14). Where $\psi_{s\alpha} = i_{s\alpha} - \hat{\imath}_{s\alpha}$ and$\psi_{s\beta} = i_{s\beta} - \hat{\imath}_{s\beta}$, V needs to be decreased to have a sufficient asymptotic stability when the error is not zero. Thus the derivation of Lyapunov's function gives in equation (15) is negative definite. This condition is satisfied where the follows terms are zero since the first term in equation (15) is always negative. One obtains two equations gives by equation (16) and equation (17). Therefore, the rotor resistance estimation equation is obtained as:

$$\dot{\hat{R}}_r = k_r\psi_{s\alpha}(\hat{\lambda}_{r\alpha} - M\hat{\boldsymbol{\imath}}_{s\alpha}) + \psi_{s\beta}(\hat{\lambda}_{r\beta} - M\hat{\boldsymbol{\imath}}_{s\beta}) \tag{14}$$

where $k_r = M/L_r(L_rL_s - M^2)m$. The structure scheme of Backstepping Control was developed in detail in [25]. Figure 2 presents the closed Loop control of Non-Linear backstepping with Adaptive Sliding mode observer.

$$\begin{aligned}\dot{V} &= [\psi^T\{(CAC^T)^T + (CAC^T)\}\psi - K^TC^T\psi\text{sign}(\psi) - \psi^TCK\text{sign}(\psi)] \\ &+2\frac{(\hat{R}_r - R_r)}{m}\dot{\hat{R}}_r + 2\frac{M(\hat{R}_r - R_r)}{L_r(L_rL_s - M^2)}\{\psi_{s\alpha}(\hat{\lambda}_{r\alpha} - M\hat{\boldsymbol{\imath}}_{s\alpha}) + \psi_{s\beta}(\hat{\lambda}_{r\beta} - M\hat{\boldsymbol{\imath}}_{s\beta})\}\end{aligned} \tag{15}$$

$$[\psi^T\{(CAC^T)^T + (CAC^T)\}\psi - K^TC^T\psi\text{sign}(\psi) - \psi^TCK\text{sign}(\psi)] < 0 \tag{16}$$

$$\frac{(\hat{R}_r - R_r)}{m}\dot{\hat{R}}_r + \frac{M(\hat{R}_r - R_r)}{L_r(L_rL_s - M^2)}\{\psi_{s\alpha}(\hat{\lambda}_{r\alpha} - M\hat{\boldsymbol{\imath}}_{s\alpha}) + \psi_{s\beta}(\hat{\lambda}_{r\beta} - M\hat{\boldsymbol{\imath}}_{s\beta})\} = 0 \tag{17}$$

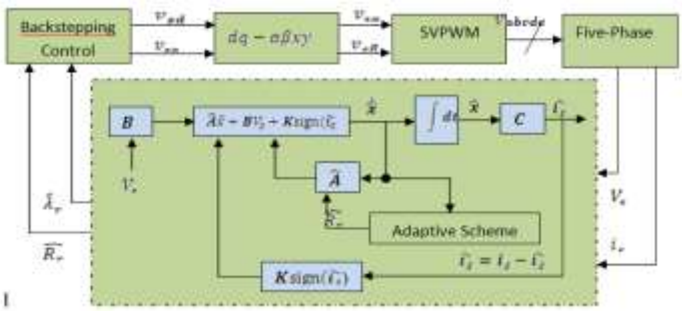

Figure 2. Closed Loop Backstepping controller (the backstepping control with feedback considering the estimation of the rotor resistance and rotor flux)

3. SIMULATION RESULTS

In order to examine the rotor resistance observation, simulation tests of the closed loop based on non-linear backstepping controller systems was done. The tests were done using a five-phase Induction motor 1.5kW as rated power and rated torque 8.33N.m. The initial value of the rotor resistance determinates using the classic test from short-circuit test where the resistance $R_r = 6.3\Omega$. The simulation algorithm written in Matlab Simulink, however, the simulation results used to characterize the characteristics of the drive system with both rotor resistance and rotor flux estimation. Figure 3 presented the simulations results of the closed loop (non-linear backstepping control).

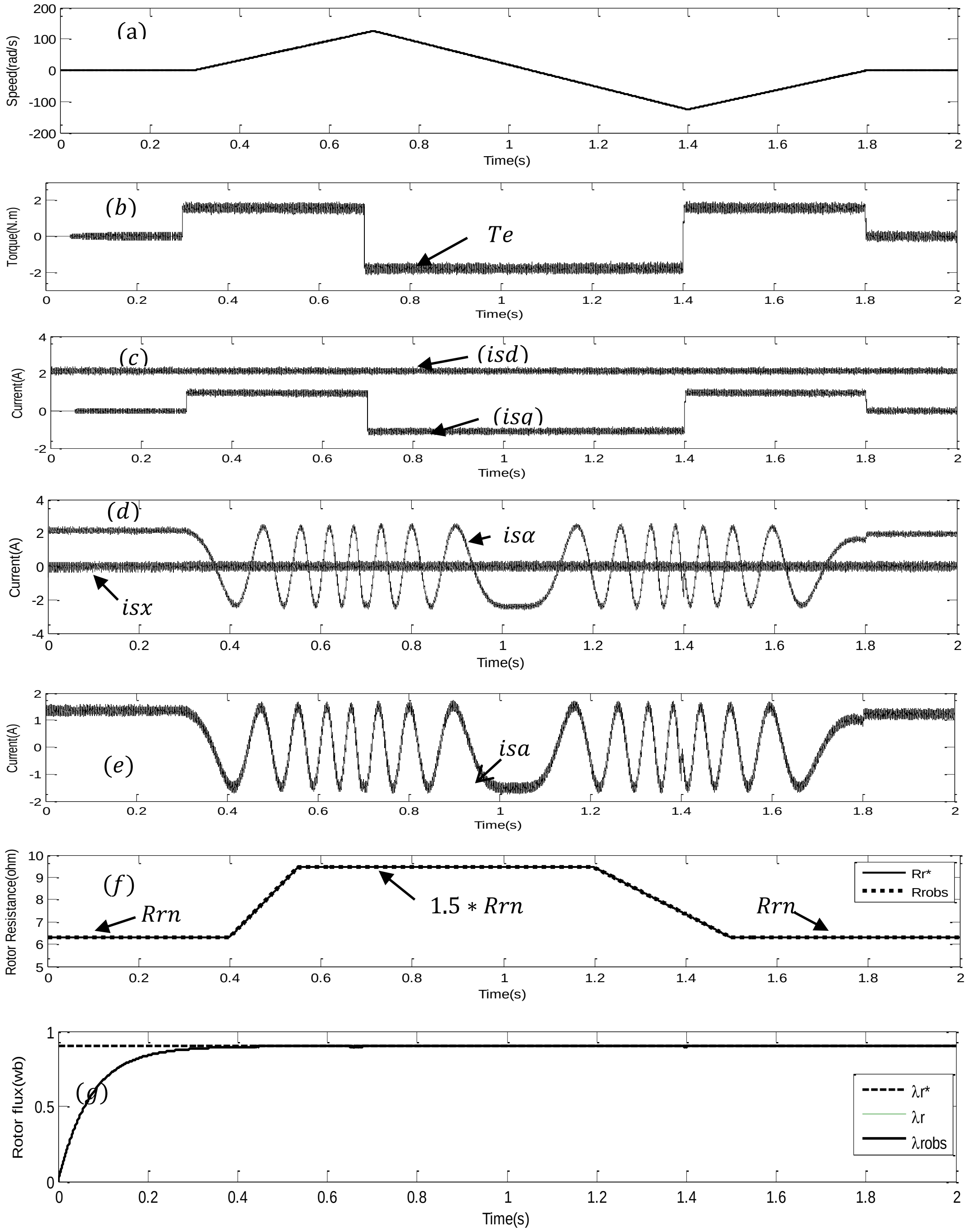

Figure 3. Simulation Results

The motor is drive with speed shows in Figure 3(a) equal 100 rad/s applied at t=0.3s and revers at t=0.7s. The system starts with the rated rotor resistance value $R_r = 6.3\Omega$. It is well known that the rotor resistance of the motor model is not constant, nevertheless is change with the time and the temperature. The rotor resistance presents in Figure 3 (f) increases by 50% at t=0.55s and return back to $R_r = 6.3\Omega$ at t=1.5s. The real R_r follows perfectly the reference value and eliminate the effect of perturbation in the rotor flux module shows in Figure 3 (g). Figure 3(c) shows the measurement of d-and q-axis currents, where q-axis currents demonstrate a fast tracking response without any extend overshoot. In other hand the d-axis current undisturbed in the time of the q-axis current transients. The currents isa, sx, isα and torque shown respectively, in Figure 3 (e), (d) (b) present an acceptable ripple. The flux and current observer with online estimation of rotor resistance using sliding mode observer using Lyapunov theory which show the high performance and effectiveness of the proposed method.Those parameters are arbitrary determinates until on have the best convergence of the observer flux and rotor flux to the desired value.

4. CONCLUSION

In this paper closed-loop nonlinear backstepping control is proposed for a five-phase induction motor. Taking into account the rotor resistance estimation using sliding mode observer. The overall control scheme involves the nonlinear bacckstepping in order to converge the system asymptotically and the error equal to zero. The adaptive observer provides estimating and imposing the reference value of the modulus of rotor flux. The simulation results confirm the feasibility and effectiveness of the presented approach.

REFERENCES

[1] Zhang, X., Zhnag, C., Qiao, M., and Yu, F. (2008) *Analysis and experiment of multi-phase induction motor drives for electrical propulsion*. Proc. Int. Conf. Elect. Mach., ICEM, pp. 1251–1254.

[2] Sadehgi, S. and Parsa, L. (2010) Design and dynamic simulation of five-phase IPM machine for series hybrid electric vehicles. Proc. Green Tech. Conf., pp. 1–6.

[3] Chan, C.C., Jiang, J.Z., Chen, G.H., Wang, X.Y., and Chau, K.T. (1994) A novel polyphaser multipole square wave PM motor drive for electric vehicles. IEEE Trans. Ind. Appl., 30(5).

[4] Jayasundara, J. and Munindradasa, D. (2006) *Design of multi-phase in-wheel axial flux PMmotor for electric vehicles*. Proc. Int. Conf. Ind. Info. Syst., pp. 510–512.

[5] Abolhassani, M.T. (2005) *A novel multiphase fault tolarent high torque density PM motor drive for traction application*. Proc. IEEE Int. Conf. Elect. Mach., pp. 728–734.

[6] Scuiller, F., Charpentier, J., Semail, E., and Clenet, S. (2007) Comparision of two 5-phase PM machine winding configurations, Application on naval propulsion specification. Proc. Elect. Mach. Drives Conf. IEMDC, pp. 34–39.

[7] G. Kenne, R. Simo, F. Lamnabhi-Lagarrigue, A. Arzandé and J. Vannier, "An Online Simplified Rotor Resistance Estimator for Induction Motors," *IEEE Transactions on Control Systems Technology* , vol. 18, no. 5, pp. 1188 - 1194, 2009.

[8] S. Hasan and I. Husain, "A Luenberger–Sliding Mode Observer for Online Parameter Estimation and Adaptation in High-Performance Induction Motor Drives," *IEEE Transactions on Industry Applications* , vol. 45, no. 2, pp. 772 - 781, 2009.

[9] S.H. Jeon, K.K. Oh and J.Y. Choi, "Flux Observer With Online Tuning of Stator and Rotor Resistances for Induction Motors," *IEEE Transactions on Industrial Electronics,* vol. 43, no. 3, pp. 653 - 664, 2002.

[10] K. Akatsu and A. Kawamura, "Online rotor resistance estimation using the transient state under the speed sensorless control of induction motor," *IEEE Transactions on Power Electronics,* vol. 15, no. 3, pp. 553 - 560, 2000.

[11] Z. Dehong and Z. Jin, "A Sliding Mode Flux Observer for Online Rotor and Stator Resistance," in *34th Chinese Control Conference (CCC)*, Hangzhou, 2015.

[12] A. Proca and A. Keyhani, "Sliding-Mode Flux Observer With Online Rotor," *IEEE Transactions on Industrial Electronics* , vol. 54, no. 2, pp. 716 - 723, 2007.

[13] T. Abbasian, F. Salmasi and M. Yazdanpanah, *"Improved Adaptive Feedback Linearization Control of Induction Motors Based on Online Estimation of Core Loss and Rotor Resistance,"* in International Symposium on Power Electronics, Electrical Drives, Automation and Motion SPEEDAM , Taormina, 2006.

[14] N. Jaalam, A. Haidar, N. Ramli, N. Ismail and A. Sulaiman, *"A Neuro-fuzzy Approach for Stator Resistance,"* in International Conference on Electrical, Control and Computer Engineering (INECCE, Pahang, 2011.

[15] B. Karanayil, M. Rahman and C. Grantham, "Online Stator and Rotor Resistance Estimation Scheme Using Artificial Neural Networks for Vector Controlled Speed Sensorless Induction Motor Drive," *IEEE Transactions on Industrial Electronics,* vol. 54, no. 1, pp. 167 - 176, 2007.

[16] G. Kenne, T. Ahmed-Ali, F. Lamnabhi-Lagarrigue and A. Arzandé, " Real-Time Speed and Flux Adaptive Control of Induction Motors Using Unknown Time-Varying Rotor Resistance and Load Torque," *IEEE Transactions on Energy Conversion* , vol. 24, no. 2, pp. 375 - 387, 2009.

[17] S. Legrioui, S. Rezgui and H. Benalla, *"Robust IM exponential reaching law sensorless control with MRAS-based online parameters identification,"* in IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC), Rome, 2015.

[18] S. Maiti, C. Chakraborty, Y. Hori and M. Ta, "Model Reference Adaptive Controller-Based Rotor Resistance and Speed Estimation Techniques for Vector Controlled Induction Motor Drive Utilizing Reactive Power," *IEEE Transactions on Industrial Electronics* , vol. 55, no. 2, pp. 594 - 601, 2008.

[19] F. Mapelli, D. Tarsitano and F. Cheli, *"A Rotor Resistance MRAS Estimator for EV Induction Motor Traction Drive based on Torque and Reactive Stator Power: simulation and experimental results,"* in International Conference on Electrical Machines (ICEM) , Berlin, 2014.

[20] R. Marino, S. Peresada and P. Tomei, "On-Line Stator and Rotor Resistance Estimation for Induction Motors," *IEEE Transactions on Control Systems Technology,* vol. 8, no. 3, pp. 570 - 579, 2000.

[21] P. Rokhforoz and J. Poshtan, "Rotor Speed and Resistance Estimation Using Robust Extended Kalman Filter for Sensorless Vector Control of Induction Motor Drives," in *6th Conference on Power Electronics, Drives Systems & Technologies (PEDSTC)*, Tehran, 2015.

[22] E. Tofighi, A. Mahdizadeh and M. Feyzi, *"Online estimation of induction motor parameters using a modified particle swarm optimization technique,"* in 39th Annual Conference of the IEEE Industrial Electronics Society, 39th Annual Conference of the IEEE, Vienna , 2013.

[23] K. Iyer, X. Lu, K. Mukherjee and N. Kar, *"Online Stator and Rotor Resistance Estimation Scheme Using Swarm Intelligence for Induction Motor Drive in EV/HEV,"* in 1st International Electric Drives Production Conference (EDPC), Nuremberg, 2011.

[24] F. Salmasi, T. Najafabadi and P. Jabehdar-Maralani, "An Adaptive Flux Observer With Online Estimation of DC-Link Voltage and Rotor Resistance For VSI-Based Induction Motors," *IEEE Transactions on Power Electronics,* vol. 25, no. 5, pp. 1310 - 1319, 2010.

[25] H. Echeikh, R. Trabelsi, M. Mimouni, A. Iqbal and R. Alammari, *"High performance backstepping control of a five phase induction motor drive,"* in Industrial Electronics (ISIE) IEEE 23rd International Symposium on, Istanbul, 2014.