International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 02, July - December 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

A Novel Adaptive Estimation of Stator and Rotor Resistance for Induction Motor Drives

Nagaraja Yadav Ponagani

Asst.Professsor, Department of Electrical & Electronics Engineering

Dhurva Institute of Engineering and Technology, JNTUH Hyderabad, (India)

ABSTRACT

In this paper presents a novel adaptive estimation of stator and rotor resistance for induction motor drives. Based on the adaptive variable structure identifier that provides finite time convergent estimate of the induction motor rotor resistance under feasible persistent of excitation condition. The rotor resistance scheme provides standard dynamic model of induction motor expressed in a fixed reference frame attached to the stator. The available variables are the rotor speed, stator currents and voltages. A simplified rotor resistance estimator is robust with respect to variation of the stator resistance, measurement noise, modeling errors, discretization effects and parameter uncertainties. This method has been tested in closed loop configuration by using a non-linear controller which is adaptive with respect to the rotor resistance. To design a rotor resistance estimation algorithm assuming that there exists control input which can stabilize the motor in a wide range of operating points. The proposed estimation scheme intended to improve performance and efficiency of currently available induction motor control algorithms. It is possible to estimate stator and rotor resistance for induction motor drives using MATLAB/ SIMULINK.

Index Terms: **Parameter estimation, non-linear observer, equivalent injection term, adaptive control, sliding mode control.**

I. INTRODUCTION

In power electronics and drives technology there is a nonlinear control theory stimulated recent efforts in the design of complex nonlinear control algorithms for induction motors (IMs). To obtain both high dynamic performance and efficiency compare to dc motors and permanent magnet synchronous motors are available in industry. The induction motors is widely used in the industry because of its good self- starting capability, simple and rugged structure, low cost and reliability. It is a multivariable, non-linear and highly coupled process with time varying parameters and state estimation. Under the hypothesis of linear magnetic circuit and balanced operating conditions, the classical fifth-order IM model is bilinear. The rotor resistance and stator resistance may vary up to 100% and 50% of their values respectively, during these operation rotor will be heating. Standard tests conduct for estimation of IM parameters includes the blocked rotor test, no-load test and standstill frequency response test. These tests cannot be used online normal operation of the machine. The tracking any desired reference signal usually required two control inputs (d-q stator voltages) and two output variables (rotor speed and flux modulus).The rotor flux cannot be directly measured, to estimate the rotor flux using various types of non-linear observers are required, based on the measurement of stator currents, stator voltages and

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 02, July - December 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

motor speed. In all electric drives, the load torque is typically unknown and flux observers used to estimate the rotor resistance. The field-oriented control (F.O.C.) it provides high-performance control of an IM. But F.O.C. methodology requires tracking of the rotor fluxes which are not usually measured.

IM parameter estimation is proposed using least square technique but filters are required when PWM inverter is used. Rotor resistance estimation for indirect field oriented control of IM based on reactive power reference model is presented under motoring and generating modes. Sensitivity of the algorithm to errors in other machines parameters is investigated but without variation of the rotor resistance. An adaptive sliding mode observer is used to estimate rotor flux components, rotor resistance and rotor speed for induction motor under the assumption that only stator currents and stator voltages are measurable. The variation of the stator and rotor resistance has been investigated but estimation parameters were achieved in Simulink implementation. The main drawback of this approach is that the rotor resistance estimator is based on a simplify model of IM which requires the rotor speed to vary slowly.

The rotor resistance is R_r estimated and its assumption of slowly variation of the rotor speed and its difficult to measure higher order harmonics.

The effect of the stator resistance R_s variation on the estimation of R_r is also investigated as follows.

In Section II, the IM mathematical model is recalled. The design procedure of the proposed rotor resistance identifier is described in Section III and the proof of the finite time convergent estimate to its nominal value is achieved under feasible persistent of excitation (P.E.).Reference speed and flux signals are in Section IV. Initialization machine parameters in Section V. Simulation model and results are reported in Section VI and conclusions are given in Section VII.

II. INDUCTION MOTOR MODEL

The classical a-b axes transformation with a fixed reference frame attached to the stator, assuming linear magnetic behavior and dynamic model of a balanced induction motor is given by the following fifth-order nonlinear system [1], [18]:

$$\frac{di_{sa}}{dt} = -\frac{R_s}{\sigma L_s} i_{sa} - \beta M \frac{R_r}{L_r} i_{sa} + \beta \frac{R_r}{L_r}\lambda_{ra} + n_p \beta \omega \lambda_{rb} + \frac{1}{\sigma L_s} v_{sa} \quad (1)$$

$$\frac{di_{sb}}{dt} = -\frac{R_s}{\sigma L_s} i_{sb} - \beta M \frac{R_r}{L_r} i_{sb} + \beta \frac{R_r}{L_r}\lambda_{rb} - n_p \beta \omega \lambda_{ra} + \frac{1}{\sigma L_s} v_{sb} \quad (2)$$

$$\frac{d\lambda_{ra}}{dt} = -\frac{R_r}{L_r}\lambda_{ra} - n_p \omega \lambda_{rb} + \frac{R_r}{L_r} M i_{sa} \quad (3)$$

$$\frac{d\lambda_{rb}}{dt} = -\frac{R_r}{L_r}\lambda_{rb} + n_p \omega \lambda_{ra} + \frac{R_r}{L_r} M i_{sb} \quad (4)$$

$$\frac{d\omega}{dt} = \frac{T_e}{m} - \frac{T_L}{m} \quad (5)$$

Where

ω: Rotor speed

$\lambda_{ra,}, \lambda_{rb}$: Rotor flux

i_{sa} , i_{sb} :Stator currents

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 02, July - December 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

v_{sa}, v_{sb}: Control inputs are stator voltages

ω, i_{sa} , i_{sb} :Measured variables

λ_{ra} ,λ_{rb} :Unknown variables

T_L : External load torque

m: Total motor and Load moment of inertia

R_r : Rotor winding resistance

R_s : Stator winding Resistance

L_r : Rotor inductance

L_s : Stator inductance

M : Mutual inductance

T_e : Electromagnetic Torque

n_P : Number of pole pairs

To simplify the notations, we use $\sigma = 1 - \frac{M^2}{L_S L_r}$ (leakage parameter) and the constant $\beta = \frac{M}{\sigma L_S L_r}$.

The following assumptions will be considered until further notice.

i) Stator currents and voltages are bounded signals;

ii) Rotor resistance $R_r \varepsilon \Omega_{Rr}$, where Ω_{Rr} is a compact set of $\mathbb{R}$.

To design a rotor resistance estimation algorithm assuming that there exists a control input which can stabilize the motor in a wide range of operating points.

III. ROTOR RESISTANCE ALGORITHM

To derive an estimation of the rotor resistance, let us consider the following observer (K > 0 is a constant designed parameter):

$$\frac{d\hat{i}_{sa}}{dt} = -\frac{R_s}{\sigma L_s} i_{sa} - \beta M \frac{\hat{R}_r}{L_r} i_{sa} + \beta \frac{\hat{R}_r}{L_r} \hat{\lambda}_{ra} + n_p \beta \omega \hat{\lambda}_{rb} + \frac{1}{\sigma L_s} v_{sa} + K\text{sign}(i_{sa} - \hat{i}_{sa}) \quad (6)$$

$$\frac{d\hat{i}_{sb}}{dt} = -\frac{R_s}{\sigma L_s} i_{sb} - \beta M \frac{\hat{R}_r}{L_r} i_{sb} + \beta \frac{\hat{R}_r}{L_r} \hat{\lambda}_{rb} - n_p \beta \omega \hat{\lambda}_{ra} + \frac{1}{\sigma L_s} v_{sb} + K\text{sign}(i_{sb} - \hat{i}_{sb}) \quad (7)$$

$$\frac{d\hat{\lambda}_{ra}}{dt} = -\frac{\hat{R}_r}{L_r} \hat{\lambda}_{ra} - n_p \omega \hat{\lambda}_{rb} + \frac{\hat{R}_r}{L_r} M i_{sa} + u_a \quad (8)$$

$$\frac{d\hat{\lambda}_{rb}}{dt} = -\frac{\hat{R}_r}{L_r} \hat{\lambda}_{rb} + n_p \omega \hat{\lambda}_{ra} + \frac{\hat{R}_r}{L_r} M i_{sb} + u_b \quad (9)$$

Where u_a and u_b are additional signals yet to be designed and "sign" is the well known "sign" function.

The estimated quantities are shown as $\hat{x}$ and the error quantities are shown as $\tilde{x} = x - \hat{x}$. (e.g., $\tilde{\iota}_s = i_s - \hat{\iota}_s, \tilde{\lambda}_r = \lambda_r - \hat{\lambda}_r, \tilde{R}_r = R_r - \hat{R}_r$). The dynamics of the observer error can be computed using (1) - (4) and (6) - (9) as follows.

$$\frac{d\tilde{\imath}_{sa}}{dt} = -K\text{sign}(\tilde{\imath}_{sa}) + \frac{\beta}{L_r}\left(R_r \lambda_{ra} - \hat{R}_r \hat{\lambda}_{ra}\right) + \beta n_p \omega \tilde{\lambda}_{rb} - \frac{\beta}{L_r} M i_{sa} \tilde{R}_r \quad (10)$$

$$\frac{d\tilde{\imath}_{sb}}{dt} = -K\,\text{sign}(\tilde{\imath}_{sb}) + \frac{\beta}{L_r}\left(R_r \lambda_{rb} - \hat{R}_r \hat{\lambda}_{ra}\right)$$

$$-\beta n_p \omega \tilde{\lambda}_{ra} - \frac{\beta}{L_r} M i_{sb} \tilde{R}_r \quad (11)$$

$$\frac{d\tilde{\lambda}_{ra}}{dt} = -\frac{1}{L_r}\left(R_r \lambda_{ra} - \hat{R}_r \hat{\lambda}_{ra}\right) - n_p \omega \tilde{\lambda}_{rb}$$

$$+\frac{M}{L_r} i_{sa} \tilde{R}_r - u_a \quad (12)$$

$$\frac{d\tilde{\lambda}_{rb}}{dt} = -\frac{1}{L_r}\left(R_r \lambda_{rb} - \hat{R}_r \hat{\lambda}_{rb}\right) + n_p \omega \tilde{\lambda}_{ra}$$

$$+\frac{M}{L_r} i_{sb} \tilde{R}_r - u_b \quad (13)$$

The above associated error dynamics can be rewritten as

$$\frac{d\tilde{\imath}_{sa}}{dt} = -K\,\mathrm{sign}(\tilde{\imath}_{sa}) + \beta n_p \omega \tilde{\lambda}_{rb} + R_r \frac{\beta}{L_r} \tilde{\lambda}_{ra} + \tilde{R}_r \frac{\beta}{L_r}(\hat{\lambda}_{ra} - M i_{sa}) \quad (14)$$

$$\frac{d\tilde{\imath}_{sb}}{dt} = -K\,\mathrm{sign}(\tilde{\imath}_{sb}) - \beta n_p \omega \tilde{\lambda}_{ra} + R_r \frac{\beta}{L_r} \tilde{\lambda}_{rb}$$

$$+\tilde{R}_r \frac{\beta}{L_r}(\hat{\lambda}_{rb} - M i_{sb}) \quad (15)$$

$$\frac{d\tilde{\lambda}_{ra}}{dt} = -u_a - \frac{R_r}{L_r}\hat{\lambda}_{ra} - n_p \omega \tilde{\lambda}_{rb}$$

$$-\frac{\tilde{R}_r}{L_r}(\hat{\lambda}_{ra} - M i_{sa}) \quad (16)$$

$$\frac{d\tilde{\lambda}_{rb}}{dt} = -u_b - \frac{R_r}{L_r}\tilde{\lambda}_{rb} + n_p \omega \tilde{\lambda}_{ra}$$

$$-\frac{\tilde{R}_r}{L_r}(\hat{\lambda}_{rb} - M i_{sb}) \quad (17)$$

To achieve design of the rotor resistance identifier the following additive assumption is required.

Assumption (iii): It is assumed that the following rotor resistance identifies ability condition holds:

$\|\lambda_r(t) - M i_s(t)\| = \|p(t)\| \geq \delta > 0 \forall t \geq 0.$ (18)

Remark 1

The identify ability condition (18) can be replaced by the following persistency of excitation (P.E.) condition. There exists $\alpha > 0$, $T > 0$, $t_0 > 0$ such that $\forall\, t \geq 0$.

$$\int_t^{t+T} P(s)P(s)^T ds \geq \alpha I > 0 \quad (19)$$

Remark 2

The persistency of excitation condition (19) is often satisfied when the IM is fed by PWM power inverter. This is the case of the control system considered in this work.

By considering the following Lyapunov candidate function

$$V_1 = \frac{1}{2}\tilde{\imath}_{sa}^{\,2} + \frac{1}{2}\tilde{\imath}_{sb}^{\,2} \quad (20)$$

And computing its time-derivative along the trajectories of (14) and (15), we obtain

$$\dot{V}_1 = -K|\tilde{\imath}_{sa}| + R_r \frac{\beta}{L_r}\tilde{\imath}_{sa}\tilde{\lambda}_{ra} + \beta\omega n_p \tilde{\imath}_{sa}\tilde{\lambda}_{rb}$$

$$+\tilde{R}_r \frac{\beta}{L_r}\tilde{\imath}_{sa}(\tilde{\lambda}_{ra} - M i_{sa}) - K|\tilde{\imath}_{sb}| + R_r \frac{\beta}{L_r}\tilde{\imath}_{sb}\tilde{\lambda}_{rb}$$

$$-\beta\omega n_p \tilde{\imath}_{sb}\tilde{\lambda}_{ra} + \tilde{R}_r \frac{\beta}{L_r}\tilde{\imath}_{sb}(\tilde{\lambda}_{rb} - M i_{sb}). \quad (21)$$

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 02, July - December 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

From (21), by taking into account assumptions (i) and (ii), the following inequalities hold:

$$\dot{V}_1 \le -|\tilde{\imath}_{sa}|\left\{K-\beta\left|\frac{R_r}{L_r}\tilde{\lambda}_{ra}+\omega n_p\tilde{\lambda}_{rb}+\frac{\tilde{R}_r}{L_r}(\hat{\lambda}_{ra}-Mi_{sa})\right|\right\}$$

$$-|\tilde{\imath}_{sb}|\left\{K-\beta\left|\frac{R_r}{L_r}\tilde{\lambda}_{rb}-\omega n_p\tilde{\lambda}_{ra}+\frac{\tilde{R}_r}{L_r}(\hat{\lambda}_{rb}-Mi_{sb})\right|\right\}$$

$$\le -|\tilde{\imath}_{sa}|\left\{K-\beta\left[\frac{R_r}{L_r}|\tilde{\lambda}_{ra}|+\omega n_p|\tilde{\lambda}_{rb}|+\frac{|\tilde{R}_r|}{L_r}(|\hat{\lambda}_{ra}|-M|i_{sa}|)\right]\right\}$$

$$-|\tilde{\imath}_{sb}|\left\{K-\beta\left[\frac{R_r}{L_r}|\tilde{\lambda}_{rb}|+\omega n_p|\tilde{\lambda}_{ra}|+\frac{|\tilde{R}_r|}{L_r}(|\hat{\lambda}_{rb}|-M|i_{sb}|)\right]\right\} \quad (22)$$

Assuming that the estimated $\hat{R}_r$ and $\hat{\lambda}_r$ are bounded, let positive constants ξ_a and ξ_b be available such that

$$\frac{\xi_a}{\beta}=\frac{R_r}{L_r}|\tilde{\lambda}_{ra}|_m+\omega n_p|\tilde{\lambda}_{rb}|_m$$

$$+\frac{|\tilde{R}_r|_m}{L_r}\left(|\tilde{\lambda}_{ra}|_m+M|i_{sa}|_m\right)$$

$$\frac{\xi_b}{\beta}=\frac{R_r}{L_r}|\tilde{\lambda}_{rb}|_m+\omega n_p|\tilde{\lambda}_{ra}|_m$$

$$+\frac{|\tilde{R}_r|_m}{L_r}\left(|\tilde{\lambda}_{rb}|_m+M|i_{sb}|_m\right) \quad (23)$$

Where $|.|_m$ denotes the maximum value of $|\cdot|$.

Remark 3

The values of the constants ξ_a and ξ_b can be evaluated for any given operating condition on the IM by using the nominal values of the rotor resistance and inductance to compute the value of (R_r/L_r) and the maximum admissible values of the rotor resistance and rotor flux estimation errors in transient period.

To evaluate the nominal value of the rotor time constant without using the nominal values of R_r and L_r in the case of Squirrel Cage IM.

By choosing

$$K > \sup(\xi_a, \xi_b) \quad (24)$$

The derivative of V_1 will be negative definite $\forall\tilde{\imath}_{sa} \neq 0$ and $\forall\tilde{\imath}_{sb} \neq 0$. Therefore the observer errors $\tilde{\imath}_{sa}$ & $\tilde{\imath}_{sb}$ converge to 0 in finite time if K is chosen such that condition (24) is satisfied.

The following quadratic function of the rotor flux observer error and rotor resistance estimation error:

$$V_2=\frac{1}{2}\tilde{\lambda}_{ra}^{\ 2}+\frac{1}{2}\tilde{\lambda}_{rb}^{\ 2}+\frac{1}{2}\tilde{R}_r^{\ 2} \quad (25)$$

Its time-derivative along the trajectories of (16) and (17) yields

$$\dot{V}_2=-\frac{R_r}{L_r}\tilde{\lambda}_{ra}^{\dot{}\,2}-u_a\tilde{\lambda}_{ra}+\frac{\tilde{R}_r}{L_r}\tilde{\lambda}_{ra}(Mi_{sa}-\hat{\lambda}_{ra})\ -\frac{R_r}{L_r}\tilde{\lambda}_{rb}^2-\tilde{\lambda}_{rb}u_b+\frac{\tilde{R}_r}{L_r}\tilde{\lambda}_{rb}(Mi_{sb}-\hat{\lambda}_{rb})+\tilde{R}_r\dot{\tilde{R}}_r \quad (26)$$

If we choose u_a, u_b and $\dot{\tilde{R}}_r$ as follows ($k_{R_r}>0$ is designed parameter).

$$u_a=\frac{\tilde{R}_r}{L_r}(Mi_{sa}-\hat{\lambda}_{ra})$$

$$u_b=\frac{\tilde{R}_r}{L_r}(Mi_{sb}-\hat{\lambda}_{rb})$$

$$\dot{\tilde{R}}_r = -k_{R_r}\,\mathrm{sign}(\tilde{R}_r) \quad (27)$$

$\dot{V}_2$ Becomes

$$\dot{V}_2 = -\frac{R_r}{L_r}\left(\tilde{\lambda}_{ra}{}^2 + \tilde{\lambda}_{rb}{}^2\right) - k_{R_r}|\tilde{R}_r|. \quad (28)$$

Consequently, under P.E. (19) and if they are auxiliaries variables u_a, u_b and $\dot{\widetilde{R_r}}$ are chosen as in (27), $\dot{V}_2$ will be negative definite $\tilde{\lambda}_{ra} \forall \neq 0, \tilde{\lambda}_{rb} \neq 0$ and $\forall\, \tilde{R}_r \neq 0$. Thus $\hat{\lambda}_r$ and $\hat{R}_r$ converge in finite time to their nominal values λ_r and R_r with the convergence rate $\frac{1}{T_r} = \frac{R_r}{L_r}$ and k_{R_r} respectively.

Remark 4

If $k_{R_r} > \frac{1}{T_r}$, the rotor resistance convergence will be faster than that of the rotor flux. In contrary, if $k_{R_r} < \frac{1}{T_r}$, the rotors flux convergence will be faster than that of rotor resistance. The case $k_{R_r} = \frac{1}{T_r}$ is difficult to implement in practice since T_r is assumed to be unknown and is time varying but verified in normal operation of the Induction motor $T_{rmin} \leq T_r \leq T_{rmax}$.

To achieve the design of the rotor resistance estimator, implementable expression for $\tilde{R}_r$ is required. Under condition (24), a sliding-mode occurs in finite time on the 2-D manifold

$$\tilde{\imath}_{sa} = i_{sa} - \hat{\imath}_{sa} = 0;$$

$$\tilde{\imath}_{sb} = i_{sb} - \hat{\imath}_{sb} = 0 \quad (29)$$

The equivalent injection terms [19] can be computed by solving the equation.

$$\dot{\tilde{\imath}}_{sa} = 0\,;\ \dot{\tilde{\imath}}_{sb} = 0. \quad (30)$$

Consequently equations (14) and (15) can be rewritten as

$$-W_{aeq} + \beta n_p \omega \tilde{\lambda}_{rb} + R_r \frac{\beta}{L_r}\tilde{\lambda}_{ra}$$

$$+\tilde{R}_r \frac{\beta}{L_r}\left(\hat{\lambda}_{ra} - M i_{sa}\right) = 0 \quad (31)$$

$$-W_{beq} - \beta n_p \omega \tilde{\lambda}_{ra} + R_r \frac{\beta}{L_r}\tilde{\lambda}_{rb}$$

$$+\tilde{R}_r \frac{\beta}{L_r}\left(\hat{\lambda}_{ra} - M i_{sb}\right) = 0 \quad (32)$$

Where, $W_{aeq} = [K\mathrm{sign}(\tilde{\imath}_{sa})]_{eq}$ and

$W_{beq} = [K\mathrm{sign}(\tilde{\imath}_{sb})]_{eq}$

The expressions of the equivalent injection terms W_{aeq} and W_{beq} can be deduced from (31) and (32) but these expressions cannot be implemented in practice since $\widetilde{R_r}$ and $\widetilde{\lambda_r}$ are not available.

To overcome this problem, we approximated the equivalent injection terms W_{aeq} and W_{beq} by using the first order low-pass filters as in (19).

If the design parameter K_{R_r} is chosen such that

$$0 < k_{R_r} < \frac{1}{T_{rn}}, \text{ with } T_{rn} = \frac{L_{r_n}}{R_{r_n}} \quad (33)$$

Where L_{rn} and R_{rn} are the nominal values of the rotor inductance and rotor resistance and T_{rn} is the nominal rotor time constant, the rotor flux convergence will be faster than that of the rotor resistance.

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 02, July - December 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

Under this assumptions and P.E condition (19), the implementable expression of the rotor resistance estimation error $\dot{\widetilde{R}}_r$ can be derived from (31) and (32) by neglecting the terms containing the rotor flux estimation error. We then obtain

From (31)

$$\widetilde{R}_r = \frac{L_r}{\beta}\frac{\left(\hat{\lambda}_r - Mi_s\right)^T W_{eq}}{\left\|\hat{\lambda}_r - Mi_s\right\|^2}$$

With $W^T{}_{eq} = (W_{aeq}, W_{beq})$ (34)

Remark 5

The denominator of (34) can become zero in transient periods since the identify ability condition (18) or P.E condition (19) is based on the real value of the flux and not on the estimated value. However, this singularity cannot affect significantly the estimate value of the rotor resistance since the adaptation law (27) uses the "sign" function. A singularity detector can also be used and such algorithm can provide as output the nominal value of the rotor resistance when the singularity is detected.

Finally, a novel adaptive estimation of stator and rotor resistance for induction motor drives can be summarized as follows:

$$\frac{d\hat{i}_{sa}}{dt} = -\frac{R_s}{\sigma L_s} i_{sa} - \beta M \frac{\hat{R}_r}{L_r} i_{sa} + \beta \frac{\hat{R}_r}{L_r}\hat{\lambda}_{ra} + n_p \beta\omega\hat{\lambda}_{rb} + \frac{1}{\sigma L_s} v_{sa} + K\mathrm{sign}(i_{sa} - \hat{i}_{sa})$$

$$\frac{d\hat{i}_{sb}}{dt} = -\frac{R_s}{\sigma L_s} i_{sb} - \beta M \frac{\hat{R}_r}{L_r} i_{sb} + \beta \frac{\hat{R}_r}{L_r}\hat{\lambda}_{rb} - n_p \beta\omega\hat{\lambda}_{ra} + \frac{1}{\sigma L_s} v_{sb} + K\mathrm{sign}(i_{sb} - \hat{i}_{sb})$$

$$\frac{d\hat{\lambda}_{ra}}{dt} = -\frac{\hat{R}_r}{L_r}\hat{\lambda}_{ra} - n_p\omega\hat{\lambda}_{rb} + \frac{\hat{R}_r}{L_r} Mi_{sa} + u_a$$

$$\frac{d\hat{\lambda}_{ra}}{dt} = -\frac{\hat{R}_r}{L_r}\hat{\lambda}_{ra} - n_p\omega\hat{\lambda}_{rb} + \frac{\hat{R}_r}{L_r} Mi_{sb} + u_b$$

$$u_a = \frac{\hat{R}_r}{L_r}(Mi_{sa} - \hat{\lambda}_{ra}),$$

$$u_b = \frac{\hat{R}_r}{L_r}(Mi_{sb} - \hat{\lambda}_{rb})$$

$$\dot{\hat{R}}_r = -k_{R_r}\mathrm{sign}(\widetilde{R}_r)$$

$$= -k_{R_r}\mathrm{sign}\left(\frac{L_r}{\beta}\frac{\left(\hat{\lambda}_r - Mi_s\right)^T W_{eq}}{\left\|\hat{\lambda}_r - Mi_s\right\|^2}\right) \qquad (35)$$

IV. INITIALIZATION PARAMETERS

rr=0.52; %rotor resistance

rs=0.22; %stator resistance

lls=0.052; %stator inductance

llr=0.0516; %rotor inductance

lm=0.0495; %mutual inductance

```
fb=50;              %base frequency
p=4;                %number of poles
np=2;               %number of poles per pair
j=1.5;              %moment of inertia
sigma=0.096;
B=lm/(sigma*lls*llr);
M=lm;
lr=llr+lm;
tr=lr/rr;
% impedance and angular speed calculations
wb=2*pi*fb;         %base speed
xls=wb*lls;         %stator impedance
xlr=wb*llr;         %rotor impedance
xm=wb*lm;           %magnetizing impedance
xmlstar=1/(1/xls+1/xlm+1/xlr);
vd=300;
```

V. SPEED AND FLUX REFERENCE SIGNALS

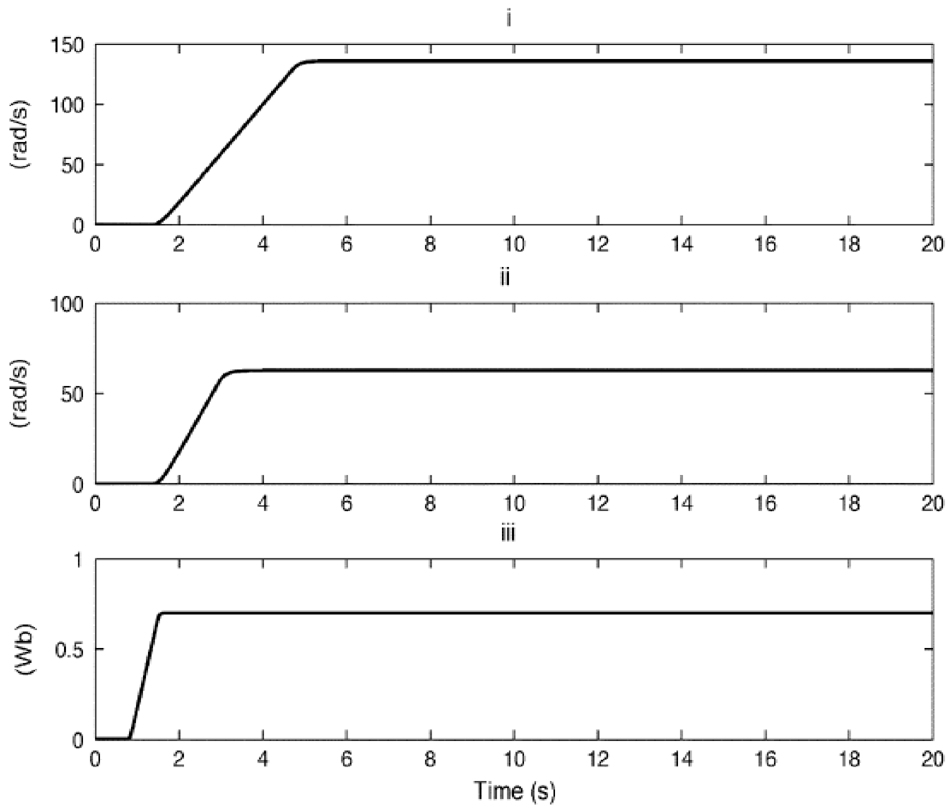


Fig.1 Speed and flux reference signals. (i) Speed reference in rotor resistance, (ii) Speed reference in stator resistance, (iii) Rotor flux.

International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 02, July - December 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

VI. SIMULIATION MODELS

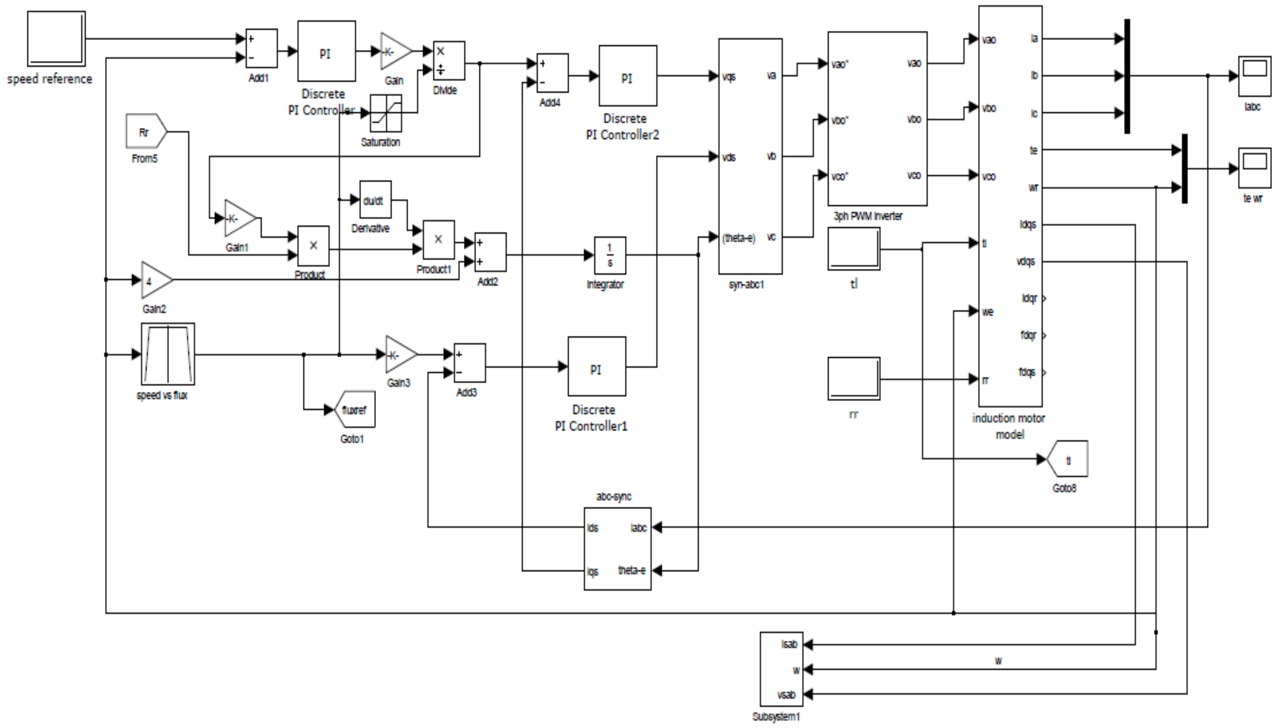
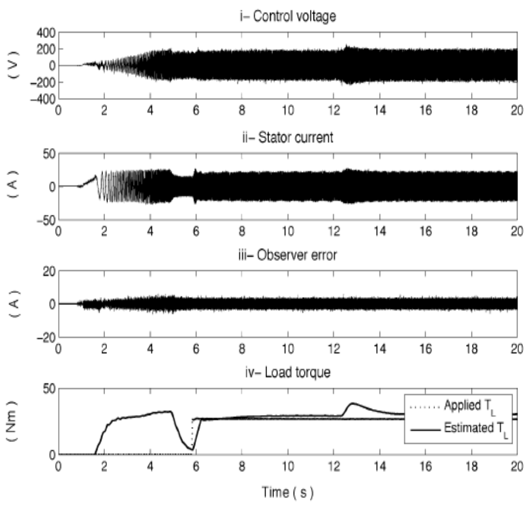


Fig .2 Tracking performance of the proposed method with respect to variation of the rotor resistance



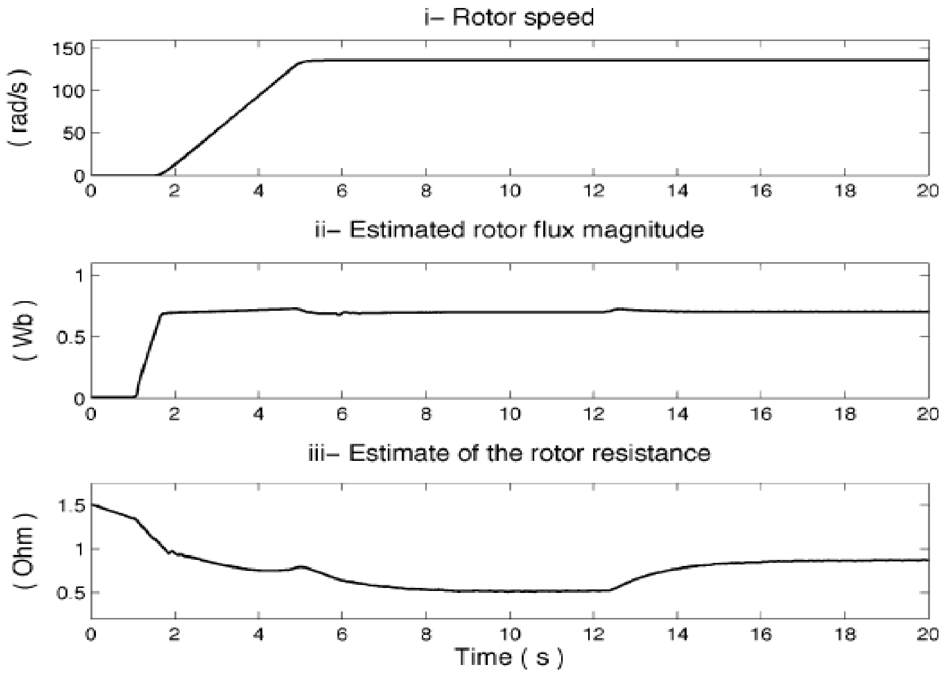
(a)

Fig.2.1 (a) (i) Control voltage (ii) Stator current (iii) Observer error (iv) Load torque.

International Journal of Electrical and Electronics Engineers

Vol. No. 9, Issue No. 02, July - December 2017

ISSN (O) 2321-2055
ISSN (P) 2321-2045



(b)

Fig.2.2 (b) (i) Rotor speed (ii) Estimated rotor flux magnitude (iii) Estimate of the rotor resistance.

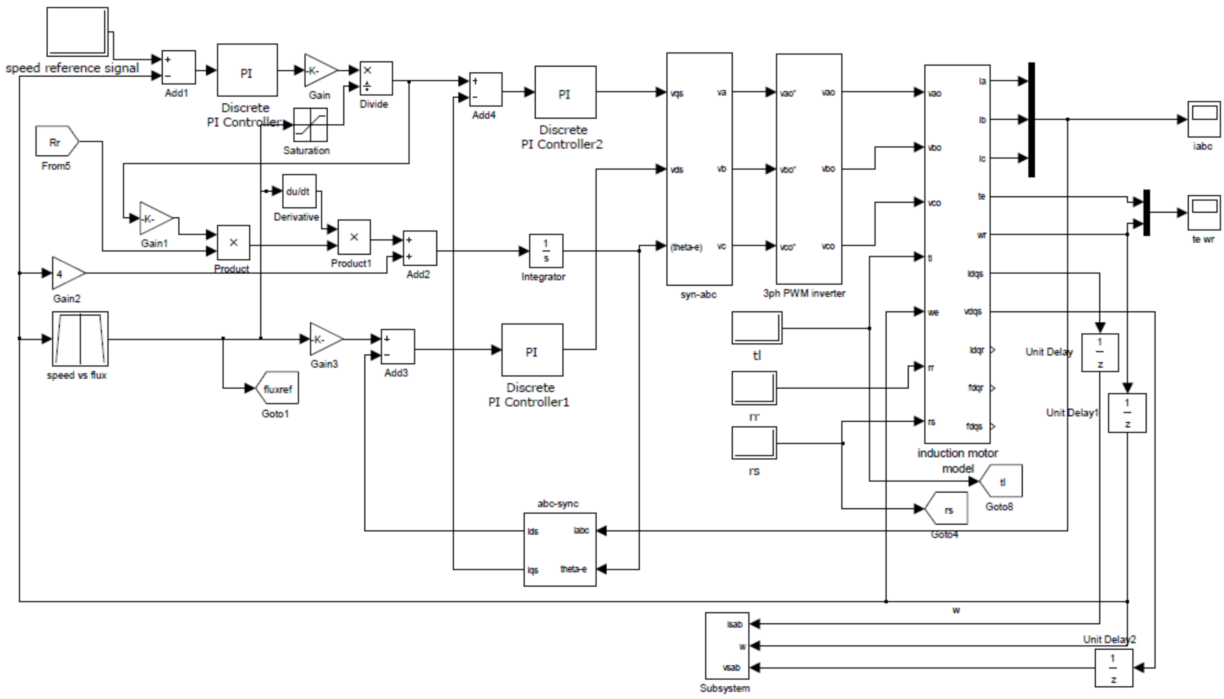
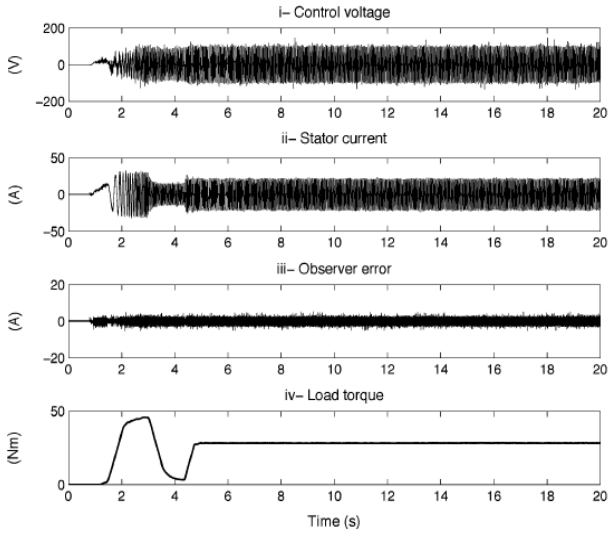
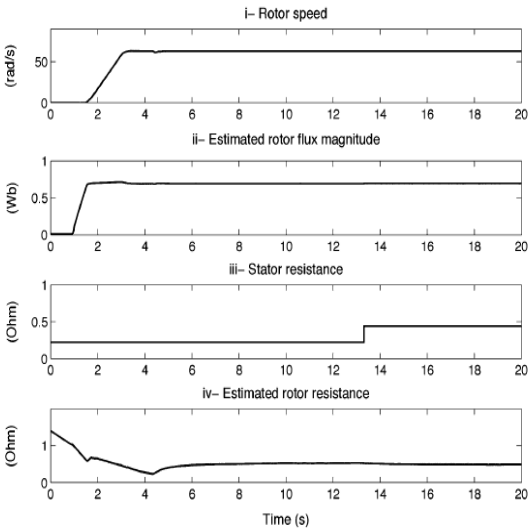


Fig.3 Proposed method at relatively low speed (63 rad/s) with 100% variation of the stator resistance R_s



(a)

Fig.3.1 (a) (i) Control voltage, (ii) Stator current, (iii) Observer error, (iv) Load torque.



(b)

Fig.3.2 (b) (i) Rotor speed, (ii) Estimated rotor flux magnitude, (iii) Stator resistance, (iv) Estimated rotor resistance.

The effectiveness of the proposed algorithm combined with a nonlinear controller which stabilizes the rotor flux magnitude and the rotor speed to references values with adaptation of the rotor resistance and load torque.

Remark 6

The combination of both estimation algorithms (rotor resistance and load torque estimators) still converges since it has been proved in [7] that the proposed nonlinear controller can stabilize the IM to reference trajectories when the estimated values of and are bounded in the operational domain and the (P.E.) condition satisfied.

In all cases, Simulation models have been performed during motor startup and after the motor are operated under load torque T_L. After the motor startup and in all Simulink implementation, the applied external unknown load torque is estimated by using the method described in [7]. In all cases the parameters of the rotor resistance identifier (35) were chosen as follows.

K=30000, K_{Rr}=0.6.The equivalent injection terms W_{aeq} and W_{beq} has been approximated using first order low-pass filter with time- constant of 5ms.Note that the value of K_{Rr} verifies condition (33) since $1/T_{rn}$=10.08s^{-1}.Using expression (23), the value of the constant ξ_a or ξ_b is approximately 5500.Therefore, the value of K also verifies condition (24).Both speed and flux reference signals used in all Simulation model are given in Fig.1.

In the first Simulation model, the performance of the algorithm to track the variation of the rotor resistance has been investigated. In this case, the variation of rotor resistance has been carried out using rotor resistance estimation algorithm. The results demonstrated that the proposed algorithm has a powerful approach to track the variation of the rotor resistance are reported in Fig.2.

In the second Simulation model, the proposed method with respect to the variation of the stator resistance when the motor operates relatively low speed (63 rad/s). The results show that there is no significant effects on the rotor resistance estimate for a wide range of variation of the stator resistance are reported in Fig.3.

In all cases, the estimate of the rotor resistance is very accurate and exhibits a short convergence transient. The steady-state error between the estimated rotor resistance and its nominal value is due to the measurement noise, mismatching between the motor and the model parameters.

VII. CONCULSION

In this paper a simple structure has been designed to estimate the stator and rotor resistance for induction motor drives. It has been tested in closed-loop configuration by using a non-linear controller adaptive with respect to the rotor resistance. The finite time convergence of the rotor resistance estimate to its nominal value has been achieved under mild Persistency excitation operating conditions of the induction motor.

An adaptive control algorithm achieved very good tracking performance, for a wide range operation of induction motor with a variation of the rotor resistance (up to 87%) is beneficial for motor efficiency.

This method also presented high decoupling performance and very interesting robustness properties. When the motor operates relatively low speed, these results shows that there is no significant effect on the rotor resistance estimate with respect to variation of the stator resistance (up to 100%).

A simplified rotor resistance estimator has robustness properties with respect to variation of the stator resistance, modeling errors, discretization effects and parameter uncertainties.

The extension of the proposed technique in speed sensorless adaptive control of induction motor drives.

APPENDIX A INDUCTION MOTOR DATA

Rated power	5KW
Rated torque	32NM
Rated frequency	50HZ
Rated current	22.9A
Stator resistance R_{sN}	0.22Ω
Rotor resistance R_{rN}	0.52 Ω

Stator inductance L_{sN}	0.052H
Rotor inductance L_{rN}	0.0516H
Mutual inductance M_N	0.0495H
Number of poles n_p	2
Motor-load inertia m	0.12kg.m^2

REFERENCES

[1] K. Akatsu and A. Kawamura, "On-line rotor resistance estimation using the transient state under the speed sensorless control of induction motor," *IEEE Trans. Power Electron.*, vol. 15, no. 3, pp. 553–560, May 2000.

[2] R. Marino, S. Peresada, and P. Tomei, "On-line stator and rotor resistance estimation for induction motors," *IEEE Trans. Control Syst. Technol.*, vol. 8, no. 3, pp. 570–579, May 2000.

[3] K.Wang, J. Chiasson, M. Bodson, and L. M. Tolbert, "An online rotor time constant estimator for the induction machine,"

[4] *IEEE Trans. Control Syst. Technol.*, vol. 15, no. 5, pp. 339–348, Sep. 2007.

[5] P. Roncero-Sánchez, A. García-Cerraba, and V. Feliu-Batlle, "Rotor resistance estimation for induction machines with indirect field orientation," *Control Eng. Practice*, vol. 15, pp. 1119 -1133, 2007.

[6] Y. Koubaa, "Application of least-squares techniques for induction motor parameters estimation," *Math. Comput. Model. Dyn. Syst.*, vol. 12, pp. 363–375, 2006.

[7] G. Bartolini, A. Pisano, and P. Pisu, "Simplified exponentially convergent rotor resistance estimation for induction motors," *IEEE Trans. Autom. Control*, vol. 48, no. 2, pp. 325–330, Feb. 2003.

[8] 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 Trans.Energy Conv.*, vol. 24, no. 2, pp. 375–387, Jun. 2009.

A. Mezouar, M. K. Fellah, S. Hadjeri, and Y. Sahali, "Adaptive speed sensor less vector control of induction motor using singularly perturbed sliding mode observer," in Proc. 32nd Ann. Conf. IECON, 2006, pp. 932–939.

[9] P. Castaldi, W. Geri, M. Montanari, and A. Tilli, "A new adaptive approach for on-line parameter and state estimation of induction motors," *Control Eng. Practice*, vol. 13, pp. 81–94, 2005.

[10] T. Ahmed-Ali, F. Lamnabhi-Lagarrigue, and R. Ortega, "A globally stable adaptive indirect field-oriented controller for current-fed induction motors," *Int. J. Control*, vol. 72, pp. 996–1005, 1999.