A New Induction Motor Adaptive Robust Vector Control based on Backstepping

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ABSTRACT

In this paper, a novel approach to nonlinear control of induction machine, recursive on-line estimation of rotor time constant and load torque are developed. The proposed strategy combines Integrated Backstepping and Indirect Field Oriented Controls. The proposed approach is used to design controllers for the rotor flux and speed, estimate the values of rotor time constant and load torque and track their changes on-line. An open loop estimator is used to estimate the rotor flux. Simulation results are presented which demonstrate the effectiveness of the control technique and on-line estimation.

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1. INTRODUCTION

Induction machine constitutes the workhorse of the industry and is used in a lot of industrial applications. Induction machine is robust, necessitates very little maintenance and is generally less expensive than synchronous or permanent magnet motors. Induction machine is a class of highly coupled nonlinear multivariable system with two crucial control inputs (stator voltages) and two output variables (mechanical speed, rotor flux) required to track given reference signals. Parameters of induction machine are time varying with temperature, magnetic saturation and frequency. Therefore, machine control performance deteriorates as the parameters vary and the controller loses its tuning.

It is therefore desirable to track on-line changes in the system parameters and to continually update the controller parameters to ensure optimal tuning all time. The speed and rotor flux control is difficult because of the complexity of the model of the induction machine.

Many control strategies to solve the above problem have been proposed. One of these techniques is the vector control. This technique allows an induction machine to achieve torque control performance similar to that of a dc machine in many high performance drives.

Vector control can be realized in a direct or indirect fashion. The principal drawback of indirect vector control is its sensitivity to parameters variations especially the rotor time constant [1]. The latter varies with time, thus using a robust controller with fixed parameters will not guarantee the performance required in all possible operating conditions. Many algorithms have been proposed to estimate the rotor time constant [1-4].

Practically, load torque is measured using either contact or non contact type torque sensor where the latter is not economic. Load torque estimation of induction machine is essential in trajectory tracking control of rotor speed, so the observed load torque is fed forward to increase the robustness of the induction motor speed drive. Methods for estimating load torque are interesting many researches and many solutions were proposed [5-7].

Vector control enables an asymptotic decoupling between torque and rotor flux of the machine as opposed to the nonlinear control that offers global decoupling [8].The implementation of a new nonlinear control law with parametric adaptation by combining the Backstepping technique and indirect vector control is necessary to improve tracking of trajectories, guarantee stability, robustness to changes in parameters and rejection of disturbances. The nonlinear controller and the adaptive law are designed for the mechanical speed and rotor flux using a fourth order model of induction machine.

This paper is organized as follows: Section 2 describes modeling of the system, Section 3 introduces the theoretical aspects of vector control, control law and the adaptation laws, Section 4 presents simulation results and section 5 introduces the perspectives of practical implementation.

2. MODELING OF THE SYSTEM

2.1. Modeling of Induction Machine

The dynamic equations of induction machine in the synchronously rotating reference frame are expressed as:

$$\begin{cases} v_{sd} = R_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega_s \psi_{sq} \\ v_{sq} = R_s i_{sq} + \frac{d\psi_{sq}}{dt} + \omega_s \psi_{sd} \\ 0 = R_r i_{rd} + \frac{d\psi_{rd}}{dt} - (\omega_s - \omega_r)\psi_{rq} \\ 0 = R_r i_{rq} + \frac{d\psi_{rq}}{dt} + (\omega_s - \omega_r)\psi_{rd} \end{cases} \tag{1}$$

Where $\mathbf{i_{sd}}$, $\mathbf{i_{sq}}$, $\mathbf{v_{sd}}$, $\mathbf{v_{sq}}$, $\boldsymbol{\psi_{rd}}$, $\boldsymbol{\psi_{rq}}$, $\mathbf{i_{rd}}$, $\mathbf{i_{rq}}$, $\boldsymbol{\omega_r}$, $\boldsymbol{\omega_s}$, $\boldsymbol{\psi_{sd}}$, $\boldsymbol{\psi_{sq}}$, $\mathbf{R_s}$ and $\mathbf{R_r}$ are dq axis stator current, dq axis stator voltage, dq axis rotor flux, dq axis rotor current, rotor electric angular pulsation, stator electric angular pulsation, dq axis stator flux, stator resistance and rotor resistance respectively.

The stator and the rotor flux are defined as

$$\begin{aligned} [\psi_{sd} \quad \psi_{sq}]^T &= L_s[i_{sd} \quad i_{sq}]^T + M[i_{rd} \quad i_{rq}]^T \\ [\psi_{rd} \quad \psi_{rq}]^T &= M[i_{sd} \quad i_{sq}]^T + L_r[i_{rd} \quad i_{rq}]^T \end{aligned} \tag{2}$$

Where L_s, L_r and M are stator inductance, rotor inductance and mutual inductance respectively.
The load torque acts as a disturbance via the mechanical rotation

$$J\frac{d\omega_r}{dt} = pp(\frac{3}{2}\frac{ppM}{L_r}(\psi_{rd} i_{sq} - \psi_{rq} i_{sd}) - T_L - \frac{K_f \omega_r}{pp}) \tag{3}$$

Where T_L, J, K_f and pp are load torque, moment of inertia, viscous friction coefficient and number of pole pairs respectively.

The model of an induction machine can be expressed in a state space representation. By considering the stator currents, the rotor flux and the rotor electric angular pulsation as state variables and two control inputs.

2.2. Modeling of the Inverter

The various switches are assumed perfect.We can replace the arm of the inverter with one or two switches positions modeled by a logic function. The latter is defined as follows:

$$F_i = \begin{cases} 0 \text{ if Ki1 is opend and Ki2 is closed} \\ 1 \text{ if Ki1 is closed and Ki2 is opend} \end{cases} \tag{4}$$

Let F_{ij}, with $i \in \{1, 2, 3\}$ and $j \in \{1, 2\}$ the switching function of the switch K_{ij} associated with the arm i of this inverter. The relationships between these different functions are expressed by:

$$F_{i1} = 1 - F_{i2} \tag{5}$$

The potentials of the nodes A, B and C of the inverter relative to the point M are given by:

$$[\mathrm{V_{AM}} \quad \mathrm{V_{BM}} \quad \mathrm{V_{CM}}]^T = [\mathrm{F_{11}} \quad \mathrm{F_{21}} \quad \mathrm{F_{31}}]^T E \tag{6}$$

We can also express phase voltages from line voltages as follows:

$$\begin{aligned} V_{AN} &= \frac{V_{AB}-V_{CA}}{3} \\ V_{BN} &= \frac{V_{BC}-V_{AB}}{3} \\ V_{CN} &= \frac{V_{CA}-V_{BC}}{3} \end{aligned} \tag{7}$$

Using (7), the expression of phase voltages are formulated by

$$\begin{bmatrix} \mathrm{V_{AN}} \\ \mathrm{V_{BN}} \\ \mathrm{V_{CN}} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} \mathrm{F_{11}} \\ \mathrm{F_{21}} \\ \mathrm{F_{31}} \end{bmatrix} \mathrm{E} \tag{8}$$

We choose $\mathrm{F_{11}} = \mathrm{S_1}$ $\quad \mathrm{F_{21}} = \mathrm{S_2}$ $\quad \mathrm{F_{31}} = \mathrm{S_3}$

Let $\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix}; \begin{bmatrix} K_{sd} \\ K_{sq} \end{bmatrix} = T(\theta)\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix}; \begin{bmatrix} \mathrm{v_{sd}} \\ \mathrm{v_{sq}} \end{bmatrix} = T(\theta)\begin{bmatrix} \mathrm{V_{AN}} \\ \mathrm{V_{BN}} \\ \mathrm{V_{CN}} \end{bmatrix}$

With $T(\theta) = \frac{2}{3}\begin{bmatrix} \cos(\theta) \cos\left(\theta - \frac{2\pi}{3}\right) \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) - \sin\left(\theta - \frac{2\pi}{3}\right) - \sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix}$ is d-q transformation.

The inverter model in the d-q reference frame is given by

$$[\mathrm{v_{sd}} \quad \mathrm{v_{sq}}]^{\mathrm{T}} = \mathrm{E}[\mathrm{K_{sd}} \quad \mathrm{K_{sq}}]^{\mathrm{T}} \tag{9}$$

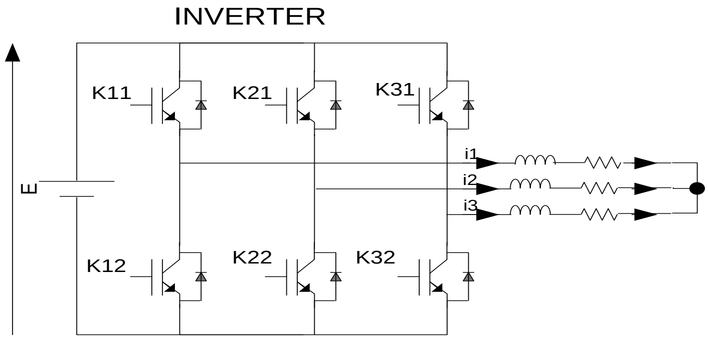

Figure 1. Structure of a three phase inverter

2.3. Modeling of the System

The model of an induction machine can be formulated in a state space representation. By considering the stator currents, the rotor flux and the rotor electric angular pulsation as state variables and the switching functions $(\mathrm{K_{sd}}, \mathrm{K_{sq}})$ yielding the following fifth –order model.

$$\dot{\mathrm{x}} = \mathrm{f(x)} + \mathrm{gu} \tag{10}$$

With: $\mathrm{x} = \left[\omega_{\mathrm{r}} \ \mathrm{i_{sd}} \ \mathrm{i_{sq}} \ \psi_{\mathrm{rd}} \psi_{\mathrm{rq}}\right]^{\mathrm{T}}$ is the state vector, $\mathrm{u} = \left[\mathrm{K_{sd}} \ \mathrm{K_{sq}}\right]^{\mathrm{T}}$ is the control vector

$$f(x)=\begin{bmatrix} a_1\left(\psi_{rd}i_{sq}-\psi_{rq}i_{sd}\right)-a_2-a_3\omega_r \\ a_4i_{sd}+\omega_s i_{sq}+a_5\psi_{rd}+a_6\omega_r\psi_{sq} \\ a_4i_{sq}-\omega_s i_{sd}+a_5\psi_{rq}-a_6\omega_r\psi_{sd} \\ a_7i_{sd}+a_8\psi_{rd}+(\omega_s-\omega_r)\,\psi_{rq} \\ a_7i_{sq}+a_8\psi_{rq}-(\omega_s-\omega_r)\,\psi_{rd} \end{bmatrix};\ g=\begin{bmatrix} 0 & b*E & 0 & 0 & 0 \\ 0 & 0 & b*E & 0 & 0 \end{bmatrix}^T$$

$$a_1=\frac{3}{2}pp^2M/(JL_r);\ a_2=ppT_r/J;\ a_3=K_f/J\ ;a_4=-{}^1\!/_{\sigma\tau_s}+(1-\sigma)/(\sigma\tau_r)\ ;a_5=M/(\sigma L_sL_r\tau_r)$$

$$a_6=M/(\sigma L_sL_r)\ ;\ a_7=M/\tau_r\ ;\ a_8=-1/\tau_r\ ;b=1/(\sigma L_s)\ ;\ \tau_r={}^{L_r}\!/_{R_r};\ \tau_s={}^{L_s}\!/_{R_s}.$$

From the state space representation, we can see that the dynamic model of induction machine and the inverter is strongly coupled nonlinear multivariable system. The aim objectives is to choose K_{sd} , K_{sq} in such a way as to force the speed and the rotor flux to track given reference values denoted by ω_{ref} and ψ_{ref}, respectively, to design an adaptation laws $\frac{d\hat{p}}{dt}$ and $\frac{d\hat{a}_2}{dt}$ to on-line estimate the value of rotor time constant, estimate the value of load torque and track their variations.

2.4. Indirect Field Oriented Control

This control strategy is based on the orientation of the flux vector along d-axis, which can be expressed by considering

$$\frac{d\psi_{rq}}{dt}=0\ ,\quad \psi_{rq}=0\ \text{ and }\ \psi_{rd}=\psi_r \tag{11}$$

Using (11), we eliminate all the terms with quadrature component of rotor flux and reduce the five equation in (10) to this expression of the synchronous angular speed.

$$\omega_s=\omega_r+\frac{Mi_{sq}}{\tau_r\psi_{rd}} \tag{12}$$

If the above condition is satisfied, the decoupling of the rotor voltage equations is realized. To what extent this decoupling is actually achieved will depend on the accuracy of motor parameters used. On-line parameter adaptive technique is employed to tune the value of these parameters used in the controller which combines Backstepping and the indirect field oriented (IFO) control techniques.

To design the nonlinear control and the adaptation law based on the technique of Backstepping, we use a simplified model of induction machine in order to develop a simple algorithm that can be implemented easily. The simplified model of induction machine is obtained by setting $\frac{d\psi_{rq}}{dt}$ and ψ_{rq} to zero in (10).

$$\dot{x}=f(x)+gu \tag{13}$$

With: $x=\left[\omega_r\ \ i_{sd}\ \ i_{sq}\ \psi_{rd}\right]^T$ is the state vector, $u=\left[K_{sd}\ K_{sq}\right]^T$ is the control vector

$$\text{And } f(x)=\begin{bmatrix} f_1(x) \\ f_2(x) \\ f_3(x) \\ f_4(x) \end{bmatrix}=\begin{bmatrix} a_1\psi_{rd}i_{sq}-a_2-a_3\omega_r \\ a_4i_{sd}+\omega_s i_{sq}+a_5\psi_{rd} \\ a_4i_{sq}-\omega_s i_{sd}-a_6\omega_r\psi_{rd} \\ a_7i_{sd}+a_8\psi_{rd} \end{bmatrix}$$

Which is a fourth order model.

3. ADAPTIVE BACKSTEPPING CONTROL

Backstepping is a recursive Lyapunov-based scheme for the class of strict feedback systems. The main idea of Backstepping is to design a recursive control by choosing some variables a virtual control and designing for them intermediate control laws. This approach guarantees global or regional regulation and tracking proprieties. An important advantage of the design of Backstepping design stabilizing controllers is

following a step-by-step algorithm. This technique has also the flexibility to avoid cancellations and achieve stabilization and tracking. Many researches were proposed using the adaptive robust control [9-12].
The principal objective: Choose the control vector in such a way that:

$$\begin{array}{ccc} \omega_r & \longrightarrow & \omega_{ref} \\ \psi_{rd} & \longrightarrow & \psi_{ref} \\ p & \longrightarrow & \hat{p} \\ a_2 & \longrightarrow & \hat{a}_2 \end{array} \quad \text{as } t \longrightarrow \infty \tag{14}$$

The output to be controlled is:

$$y = h(x) = [\omega_r \quad \psi_{rd}]^T \tag{15}$$

3.1. Control Law

Step1: We define the variable representing the error between ω_r and ω_{ref}.

$$z_1 = \omega_r - \omega_{ref} \tag{16}$$

With ω_{ref} is the desired value of rotor electric angular pulsationand $\dot{\omega}_{ref} = 0$.

Let $\tilde{a}_2 = a_2 - \hat{a}_2$

Consider a Lyapunov function

$$V_1 = \frac{1}{2} z_1^2 \tag{17}$$

Taking the time derivative of V_1, we have

$$\dot{V}_1 = z_1\left(a_1 \psi_{rd} i_{sq} - \hat{a}_2 - a_3 \omega_r\right) - \tilde{a}_2 z_1 \tag{18}$$

In this step, our objective is to design a virtual control law α_1 which makes z_1 converge to 0.

Define a virtual control $\alpha_1$and let $\alpha_1 = (\psi_{rd} i_{sq})_{ss}$ with $(\psi_{rd} i_{sq})_{ss}$ means the expression of $\psi_{rd} i_{sq}$ in the steady state.We can now select an appropriate virtual control α_1 by choosing $\dot{V}_1 \leq 0$.

$$\begin{aligned} \alpha_1 &= (-c_1 z_1 + \hat{a}_2 + a_3 \omega_r)/a_1 \\ \dot{\alpha}_1 &= (-c_1 \dot{z}_1 + \frac{d\hat{a}_2}{dt} + a_3 \dot{\omega}_r)/a_1 \end{aligned} \tag{19}$$

Where c_1 is a positive constant.
Let z_2 be the variable representing the error between the actual $\psi_{rd} i_{sq}$and virtual control α_1

$$z_2 = \psi_{rd} i_{sq} - \alpha_1 \tag{20}$$

Then the time derivative of V_1 becomes

$$\dot{V}_1 = -c_1 z_1^2 + a_1 z_1 z_2 - \tilde{a}_2 z_1 \tag{21}$$

Step2: We define

$$\tilde{p} = p - \hat{p}\ ;\ \hat{a}_4 = -\left(\frac{1}{\sigma\tau_s}\right) - \left(\frac{1-\sigma}{\sigma}\right)\hat{p}\ ;\ \hat{a}_5 = -\left(\frac{M}{\sigma L_s L_r}\right)\hat{p}\ ; \hat{a}_7 = -M\hat{p}\ ;\ \hat{\omega}_s = \omega_r - \frac{M i_{sq}}{\psi_{rd}}\hat{p}\ ;\ \hat{a}_8 = \hat{p}\ .$$

With p is the unknown parameter.
Consider a Lyapunov function

$$V_2 = V_1 + \frac{1}{2} z_2^2 \tag{22}$$

The time derivative of Lyapunov function candidate can be computed as following

$$\dot{V}_2 = -c_1 z_1^2 + z_2(\frac{d\hat{z}_2}{dt} + \psi_{rd} i_{sq}\tilde{p}/\sigma) - \tilde{a}_2(z_1 + (c_1 - a_3)z_2/a1) \tag{23}$$

Where

$$\frac{d\hat{z}_2}{dt} = a_1 z_1 + \hat{f}_4(x) i_{sq} + \hat{f}_3(x)\psi_{rd} - ((c_1 - a_3)\hat{f}_1(x) + \frac{d\hat{a}_2}{dt})/a_1 + b\psi_{rd} E K_{sq}$$

The control input K_{sq} is given by

$$K_{sq} = (-c_2 z_2 - a_1 z_1 + ((c_1 - a_3)\hat{f}_1(x) + \frac{d\hat{a}_2}{dt})/a_1 - \hat{f}_4(x) i_{sq} - \hat{f}_3(x)\psi_{rd})/(b\psi_{rd} E) \tag{24}$$

Using (24), $\dot{V}_2$ becomes

$$\dot{V}_2 = -c_1 z_1^2 - c_2 z_2^2 + \psi_{rd} i_{sq} z_2 \tilde{p}/\sigma - \tilde{a}_2(z_1 + (c_1 - a_3)z_2/a1) \tag{25}$$

Step3: We define the variable representing the error between ψ_{rd} and ψ_{ref}

$$z_3 = \psi_{rd} - \psi_{ref} \tag{26}$$

With ψ_{ref} is the desired value of rotor flux and $\frac{d\psi_{ref}}{dt} = 0$
Consider a Lyapunov function candidate

$$V_3 = \frac{1}{2} z_3^2 \tag{27}$$

Its derivative with respect to time is

$$\dot{V}_3 = z_3 \frac{d\psi_{rd}}{dt} \tag{28}$$

In this step, our objective is to design a virtual control law α_2 which makes z_2 converge to 0.

Define a virtual control α_2 let $\alpha_2 = (i_{sd})_{ss}$ with $(i_{sd})_{ss}$ means variable state i_{sd} in the steady state.We can now select an appropriate virtual control α_2 by choosing $\dot{V}_3 \leq 0$.

$$\alpha_2 = (-c_3 z_3 - \hat{a}_8 \psi_{rd})/\hat{a}_7 \tag{29}$$

$$\frac{d\hat{\alpha}_2}{dt} = -((c_3 + \hat{a}_8)\hat{f}_4(x) + \frac{d\hat{a}_8}{dt}(\psi_{rd} - M\alpha_2))/\hat{a}_7 \tag{30}$$

$$\frac{d\tilde{\alpha}_2}{dt} = -\frac{(c_3 + \hat{a}_8)}{\hat{a}_7}\left(-M i_{sd} + \psi_{rd}\right)\tilde{p} \tag{31}$$

Where c_3 is a positive constant.
Let z_4 be the variable representing the error between the actual i_{sd} and virtual control α_2

$$z_4 = i_{sd} - \alpha_2 \tag{32}$$

Then the time derivative of V_3 becomes

$$\dot{V}_3 = -c_3 z_3^2 + \hat{a}_7 z_3 z_4 + (\left(-M i_{sd} + \psi_{rd}\right)) z_3 \tilde{p} \tag{33}$$

Step 4: We define

$$z_4 = i_{sd} - \alpha_2 \tag{34}$$

Consider a Lyapunov function

$$V_4 = V_3 + \frac{1}{2} z_4^2 \tag{35}$$

Its derivative with respect to time can be found us

$$\dot{V}_4 = -c_3 z_3^2 + (\hat{a}_7 z_3 + \hat{f}_2(x) - \frac{d\hat{\alpha}_2}{dt} + bEK_{sq}) z_4 + \tilde{z}_{34}\tilde{p} \tag{36}$$

Where

$$\tilde{z}_{34} = \left(z_3 + \frac{c_3 + \hat{a}_8}{\hat{a}_7} z_4\right)\left(-Mi_{sd} + \psi_{rd}\right) - \left(\frac{1-\sigma}{\sigma} i_{sd} + \left(\frac{M}{\sigma L_s L_r}\right)\psi_{rd} + \frac{Mi_{sq} i_{sq}}{\psi_{rd}}\right) z_4$$

The control input K_{sd} is formulated by

$$K_{sd} = (-c_4 z_4 - \hat{a}_7 z_3 + \frac{d\hat{\alpha}_2}{dt} - \hat{f}_2(x))/(bE) \tag{37}$$

Uing (37), $\dot{V}_4$ becomes

$$\dot{V}_4 = -c_3 z_3^2 - c_4 z_4^2 + +\tilde{z}_{34}\tilde{p} \tag{38}$$

3.2. Adaptation Laws

Step 5: Consider a Lyapunov function

$$V_5 = V_2 + V_4 + \frac{1}{2\gamma_1}\tilde{p}^2 + \frac{1}{2\gamma_2}\tilde{a}_2{}^2 \tag{39}$$

Its derivative with respect to time can be found us

$$\dot{V}_5 = \dot{V}_2 + \dot{V}_4 - \frac{1}{\gamma_1}\tilde{p}\frac{d\hat{p}}{dt} - \frac{1}{\gamma_2}\tilde{a}_2\frac{d\hat{a}_2}{dt} \tag{40}$$

Using (25) and (38) the adaptation laws are expressed by

$$\frac{d\hat{p}}{dt} = \gamma_1 (z_2 \psi_{rd} i_{sq}/\sigma + \left(z_3 - \frac{c_3 + \hat{p}}{M\hat{p}} z_4\right)\left(-Mi_{sd} + \psi_{rd}\right) - \left(\frac{1-\sigma}{\sigma} i_{sd} + \left(\frac{M}{\sigma L_s L_r}\right)\psi_{rd}\right) z_4)$$
$$-Mi_{sq} i_{sq} z_4/\psi_{rd} \tag{41}$$

$$\frac{d\hat{a}_2}{dt} = -\gamma_2 (z_1 + (c_1 - a_3) z_2/a1) \tag{42}$$

4. RESULTS AND ANALYSIS

The algorithm proposed above, is applied to the nonlinear control of an induction machine, and has been implemented in the MATLAB/SIMILINK environment to validate its performance. The parameters of the induction machine simulated are as shown in Table 1:

Table 1. Parameters of Induction Machine

Parameter	Value
V/U	220/380V
pp	2
R_s	2,25 Ω
R_r	0.7 Ω
L_s	0,1232H
L_r	0,1122H
M	0.1118H
J	0,038Kgm^2
K_f	0,0124Kgm^2

The controller gains have been chosen as follows $c_1 = 9{,}5e3$ $c_2 = 5e4$ $c_3 = 9{,}5e4$ $c_4 = 8e3$. The adaptation gains are chosen as $\gamma_1 = 1e-6$ $\gamma_2 = 7$. The choice of controller gains and adaptation gains is not arbitrary. Therfore, if this choice is correct, we obtain the high performances of the controller. If $c_2 > c_3$the error between the rotor flux and its reference is increasing. So we lose the information which enables the adaptation law to track changes of rotor time constant. To obtain good performance of the controller, we must respect this order of controller gains $c_3 > c_2 > c_1 > c_4$, $\gamma_1 = 1e-6$ and $\gamma_2 = 7$.

The initial value of the rotor resistance is chosen as the nominal value 0,7 Ω and it increases rapidly to 0,84 Ω. The initial value of the load torque is chosen as 0 Nm. In this study, the motor is running unloaded, at t >5s it set at 14Nm. The rotor flux is required to track a constant reference value of 1Wb, the rotor speed is required to track constants references values of 50 rad/s for 0s< t<7,5s and 65 rad/s 7.5s< t<9s. The Simulink model of the drive is given in Figure 2. The time histories of the actual and desired value of the flux, speed, rotor time constant and load torque are reported on Figures 3, Figure 4, Figure 5 and Figure 6. The bloc induction machine “IM’’ is based on the fifth order model. The bloc ‘‘FLUX ESTIMATOR’’ is the estimator of the rotor flux and its frequency. The block ‘‘Adaptive Law’’ is the adaptation law of rotor constant time and load torque. The bloc ‘‘CONTROL LAW’’ is the bloc which produces the control vector. The block ‘‘dq-abc-PWM-Inverter’’ is the block of the inverter controlled by a PWM circuit based on sinusoidal modulation technique.

It is observed that the mechanical speed, the rotor flux, the load torque and the rotor time constant track the reference values accurately. With or without load torque the robustness of the proposed approach is guaranteed.

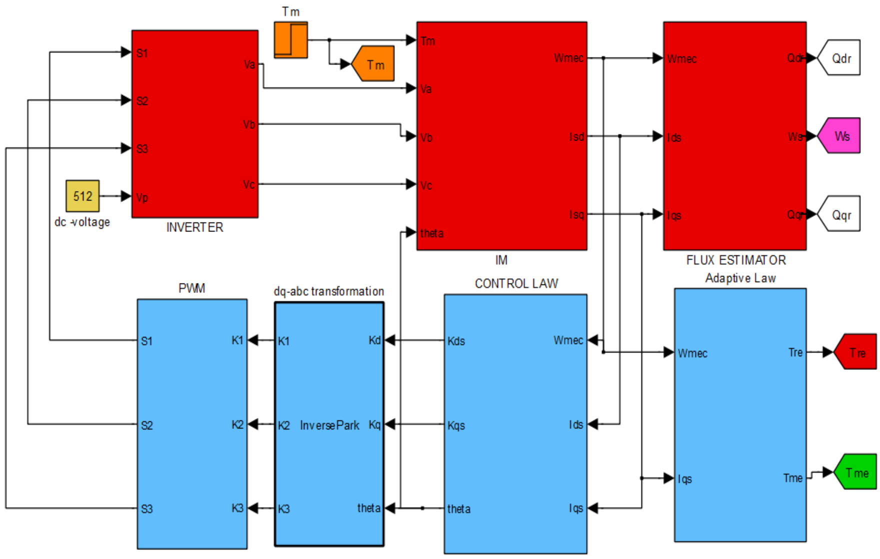

Figure 2. Simulation scheme of adaptive robust vector control based on Backstepping

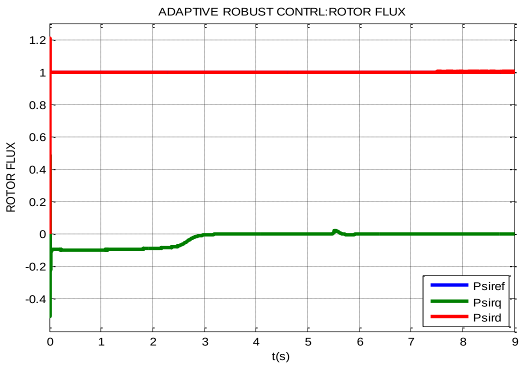

Figure 3. Rotor flux (Wb)

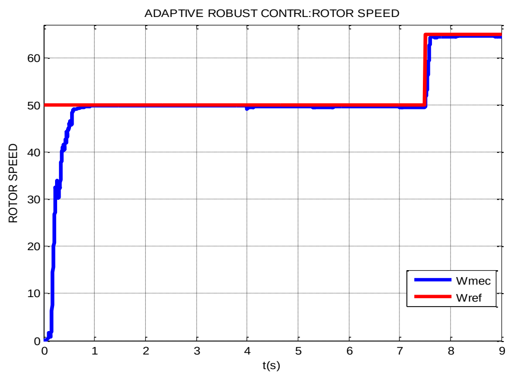

Figure 4. Rotor speed (rad/s)

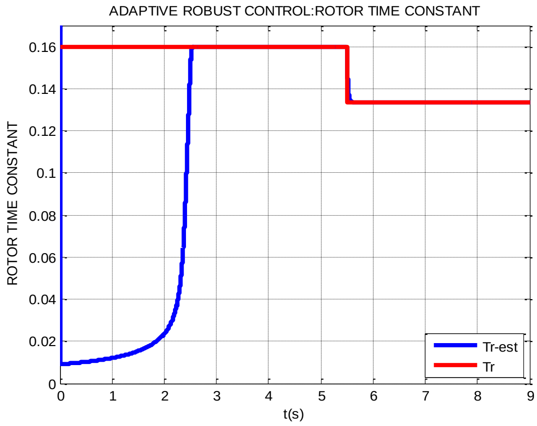

Figure 5. Rotor time constant

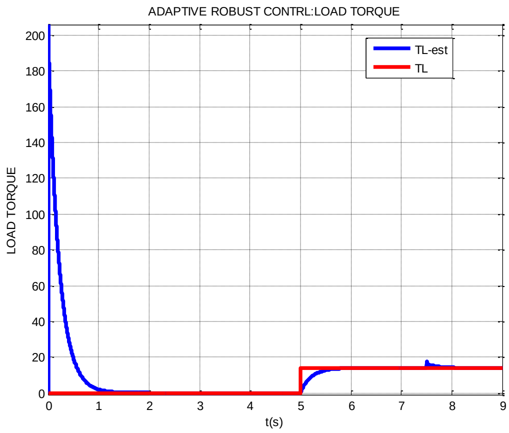

Figure 6. Load torque (Nm)

5. PERSPECTIVE of PRACTICAL IMPLEMENTATION

The IFO control based on classical PI is widely used due to the simplicity of its implementation and the linearity of its steady state torque-slip characteristics [13], [14], [15]. The novel approach proposed in this paper was tested in MATLAB/SIMLINK environment, and the obtained results proved its feasibility. This technique has a good dynamic performance but is difficult to implement compared to the first one. This is due to the complexity of choosing appropriate controllers gains. To validate experimentally these results the next study will be consecrated to develop a Rapid Control Prototyping bench. The latter includes:

a. An induction machine that will be controlled by the developed approach;
b. A DC motor that will be used to provide load torque;
c. A three phase IGBT inverter controlled by sinusoidal PWM operating at 10 kHz;
d. A TMS320C40 digital signal processor connected to PC bus;
e. A set of A/D and D/A converters boards;
f. A PC used to develop, debug and download control programs;
g. Stator currents and rotor speed are measured by using Hall effect sensors and shaft encoder respectively.

The flux can not be measured and must be estimated from accessible measured variables. The frequency of rotor flux is deduced from the fifth equation of the dynamic model. The control law, adaptation laws and rotor flux estimation algorithms, will be written in C code and downloaded to the DSP in order to implement the new vector control approach, and to estimate the actual values of rotor time constant, load torque, rotor flux and its spatial position.

6. CONCLUSION

Simulation work, carried out in this work, demonstrates that the controller performance is satisfactory. Moreover, using the adaptive Backstepping, the robustness of the proposed control scheme is guaranteed. Combining Backstepping and indirect field oriented control techniques constitutes a new approach for high performance control drives of induction machine. The recursive on-line estimation predicts and tracks quickly and accurately the desired value of rotor time constant and load torque.

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