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# Application of Backstepping Strategy for Induction Motor Control

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***ABSTRACT:*** *In this paper, a novel field-oriented induction motor using backstepping control is presented. Backstepping control is proposed for replacing the existing PI controller to obtain high performance motion control systems, for the speed, flux and currents control loops. Stability analysis based on Lyapunov theory is also performed to guarantee the convergence of the speed tracking error from all possible initials conditions. Computer simulations confirm that the proposed backstepping control scheme offers improved performance in terms of the trajectory tracking ability to time-varying reference input.*

***Keywords:*** *Induction Motor, Backstepping Control, Lyapunov, Nonlinear Control, Indirect Vector Control.*

## 1. Introduction

Induction motor is the most used in industrial applications compared to other electric machines, due to its excellent reliability, great robustness and reduced maintenance [1]. the induction motor is complex because its dynamic model is nonlinear. In industrial application, the design of control law is essentially based on classical regulator for their simple structures; however this type of controllers ignores the nonlinearity of the system. Several types of nonlinear control have been introduced in the last two decades and have been applied to the induction motor as the backstepping method [2]. This type of control is a systematic and recursive design of controlling nonlinear system.

The backstepping technique is applied to the induction motor to design a speed controller. The present paper is organized as follows; in In the second part, the model of induction motor as defined. In the third part is devoted to developing the control law by the backstepping technique. Improving performance and robustness of the proposed control is established in section [3].

## 2. Induction Motor Modeling

The model of the induction motor on the axis "*d* " can be described in a reference connected to the rotating field by the following equation:

$$\begin{cases} \dfrac{di_{ds}}{dt} = \alpha_1 + \delta V_{ds} \\ \dfrac{di_{qs}}{dt} = \alpha_2 + \delta V_{qs} \end{cases} \tag{1}$$

And:

$$\begin{cases} \frac{d\phi_{dr}}{dt} = M.\beta_r i_{ds} - \beta_r \phi_{ds} \\ \frac{d\omega}{dt} = \frac{n_p^2}{jL_r}\phi_{dr} i_{qs} - \frac{n_p}{j}T_1 - \frac{f}{j}\omega \end{cases} \tag{2}$$

With $i_s$, $\phi_r$, are stator currents, rotor flux, the index s and r representing stator and rotor, $\omega$ is the rotor speed and $\sigma$ is the mutual and leakage inductance [6].

$$\begin{cases} \alpha_1 = -\gamma i_{ds} + \omega i_{qs} + k.\beta_r \phi_{dr} i_{ds} + M\beta_r \frac{i_{qs}^2}{\phi_{dr}} \\ \alpha_2 = -\omega_r i_{dr} - M\beta_r \frac{i_{qs} i_{ds}}{\phi_{dr}} - \gamma i_{qs} - k\,\omega_r.\phi_{dr} \\ \beta_r = \frac{1}{T_r}; \gamma = \delta R_{sr}; \delta = \frac{1}{\sigma L_r} \\ \sigma = 1 - \frac{M^2}{L_s L_r}, T_s = \frac{R_s}{L_s}, T_r = \frac{R_r}{L_r} \end{cases}$$

## 3. Backstepping Control:

the backstepping control law can be obtained in several steps. Each step will provide a reference for the next step. Stability and performance of our system will be studied using Lyapunov theory [4-6].In the first step, we consider the trajectories of speed and flux as a reference, and we define the tracking errors as follows:

$$\begin{cases} e_\omega = \omega_{ref} - \omega \\ e_\varphi = \varphi_{ref} - \varphi_{dr} \end{cases} \tag{3}$$

By deriving equation (3) we obtain:

$$\begin{cases} \dot{e}_\omega = \dot{\omega}_{ref} - \dot{\omega} \\ \dot{e}_\varphi = \dot{\varphi}_{ref} - \dot{\varphi}_{dr} \end{cases} \tag{4}$$

When replacing $\dot{\omega}\ et\ \dot{\psi}_{dr}$ with these expressions from the system of equations (1) (2), equations (4) become:

$$\begin{cases} \dot{e}_\omega = \omega_{ref} - \frac{n_p^2 M}{jL_r}\dot{\psi}_{ref} i_{qs} + \frac{f}{j}\omega + \frac{n_p}{j}T_1 \\ \dot{e}_\omega = \dot{\psi}_{ref} - M.\beta_r i_{ds} + \beta_r \psi_{ref} \end{cases} \tag{5}$$

The Lyapunov function associated with the error and flux velocity, to achieve the objective of pursuit is chosen as follows:

$$f1 = \frac{1}{2}\left(e_\omega^2 + e_\psi{}^2\right) \tag{6}$$

The derivate of equations (6) is written as follows:

$$\dot{f}1 = -k_\omega e_\omega^2 - k_\omega e_\psi{}^2 \tag{7}$$

With $k_\omega$ and $k_\psi$ are positive constant, chosen so as to guarantee the exponential convergence errors of flux and speed To satisfy equation (7), we must choose the dynamic errors as the following form:

$$\begin{cases} e_{iq} = (i_{qs})_{ref} - i_{qs} \\ e_{id} = (i_{ds})_{ref} - i_{ds} \end{cases} \tag{8}$$

Considering that $i_{qs}$ and $i_{ds}$ as virtual control inputs, then equations (4) and (8) can generate the stabilizing functions based on the stability condition of Lyapunov theory to achieve the objective of pursuit, which can be written as follows:

$$\begin{cases} \left(i_{qs}\right)_{ref} = \frac{jL_r}{n_p^2 M\phi_{dr}}\left(\dot{\omega}_{ref} + \frac{f}{j}\omega + \frac{n_p}{j}T_1 + k_\omega e_\omega\right) \\ \left(i_{ds}\right)_{ref} = \frac{1}{M\beta_r}\left(\dot{\phi}_{ref} + \beta_r \phi_{dr} + k_\phi e_{d\phi}\right) \end{cases} \tag{9}$$

The system of equations (5) highlights the desired behavior of flux and the stator currents to ensure the pursuit of speed and rotor flux.

To achieve these desired behaviors, we will define in the second step the error between stator currents, direct flux and their references as follows:

$$\begin{cases} e_{iq} = \left(i_{qs}\right)_{ref} - i_{qs} \\ e_{id} = \left(i_{ds}\right)_{ref} - i_{ds} \end{cases} \tag{10}$$

By replacing equation (9) into equation (10) we obtain:

$$\begin{cases} e_{iq} = \dfrac{jL_r}{n_p^2 M\,\phi_{dr}}\left(\dot{\omega}_{ref} + \dfrac{f}{j}\omega + \dfrac{n_p}{j}T_1\,k_\omega e_\omega\right) - i_{qs} \\ e_{id} = \dfrac{1}{M\,\beta_r}\left(\dot{\phi}_{ref} + \beta_r\phi_{dr} + k_\phi e_\phi\right) - i_{ds} \end{cases} \tag{11}$$

Then we can write equation (4) as follows:

$$\begin{cases} \dot{e}_\omega = -k_\omega e_\omega + \dfrac{n_p^2 M\,\phi_{dr}}{jL_r} e_{iq} \\ \dot{e}_\omega = -k_\phi e_\phi + M\,.\beta_r i_d \end{cases} \tag{12}$$

To have an exponential decrease error of $e_{iq}$ and $e_{id}$ we must impose that:

$$\begin{cases} \dot{e}_{iq} = \dfrac{jL_r}{n_p^2 M\,\phi_{dr}}\left(\ddot{\omega}_{ref} + \dfrac{f}{j}\omega + k_\omega^2 e_\omega\right) + k_\omega^2 e_\omega + \left(\alpha_1 + \delta V_{sq}\right) \\ \dot{e}_{id} = \dfrac{1}{M\,\beta_r}\left(\ddot{\phi}_{ref} - M\,\beta_r^2\phi_{dr} + \beta_r\phi_{dr} - k_\phi e_\phi^2\right) - k_\phi e_{id} - \left(\alpha_1 + \delta V_{dq}\right) \end{cases}$$

(14)

To have an exponential decrease error of $e_{iq}$ and $e_{id}$ we must impose that:

$$\begin{cases} \dot{e}_{iq} = -k_{iq}\,e_{iq} \\ \dot{e}_{id} = -k_{id}\,e_{id} \end{cases} \tag{15}$$

Where $k_{iq}$ and $k_{id}$ are positives parameters

Final step in the design of the control law is to determine the expressions of the stator voltages $V_{ds}$ and $V_{qs}$ from a suitable choice of the new Lyapunov function associated with flux errors, speed and errors of currents which is given by the following expression:

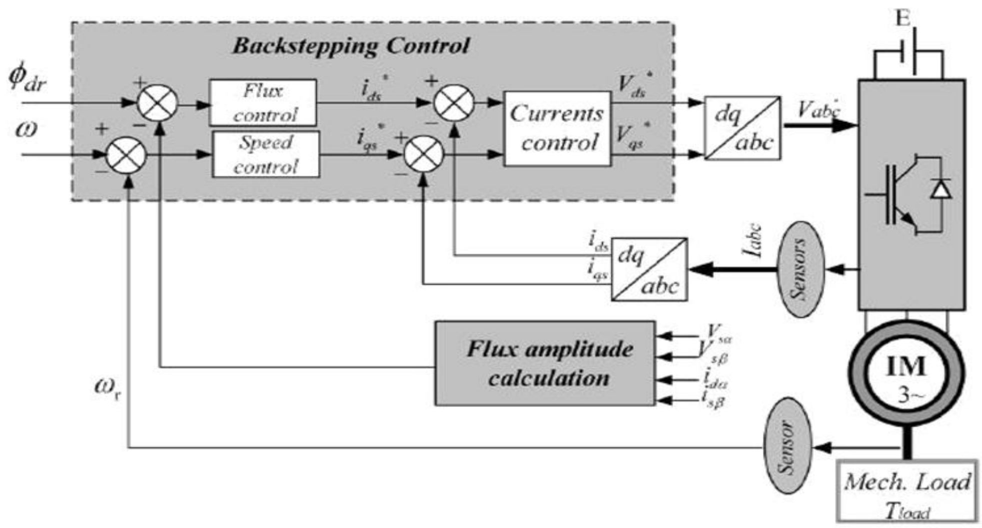


***Figure 1. Block diagram of Backstepping control***

## 4. Simulation Results

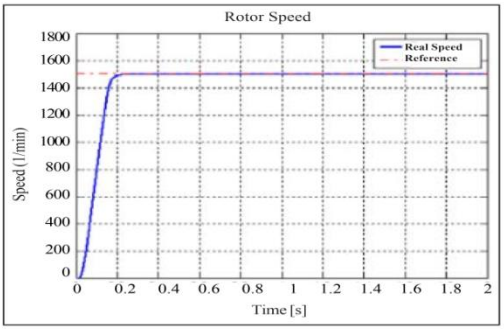


***Figure 2. Simulated results to a step speed 1500tr/mn***

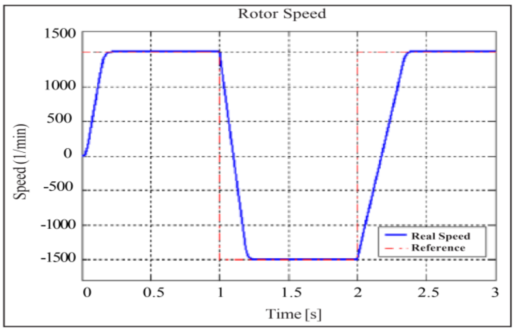


***Figure 3. Simulated results for tracking speed***

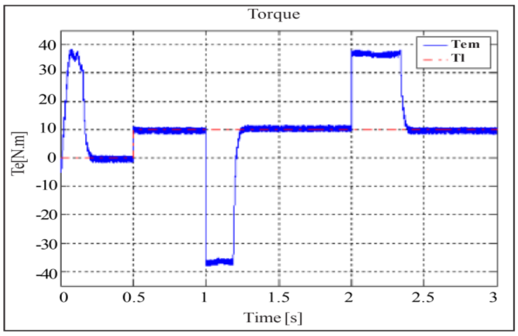


***Figure 4. Torque response (second test)***

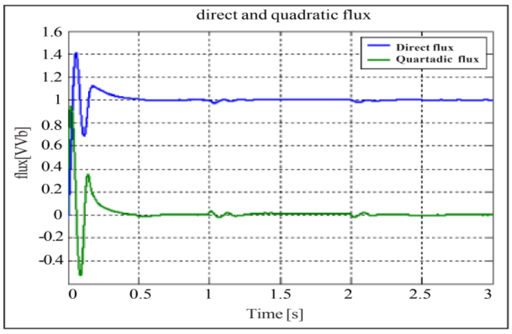


***Figure 5. Direct and quadratic flux response***

To verify the proposed solution of the nonlinear control using backstepping control of induction motor, a discrete model in Matlab-Simulink is built with a 10ms sample time.

Figure 1 shows the architecture of the vector control algorithm incorporating backstepping technique to design the control law. Figure 2 shows the first test of the machine to a step speed 1500r/mn under a load torque of 10Nm. In 0.21s the motor reach the steady state. Figure 3 shows the second test concerning the tracking speed. The electromagnetic torque developed by the motor in the second test is showing in figure 4. Figure 5 shows the dynamic responses of the rotor flux for the tracking speed.

## 5. Conclusion

In this paper, we have proposed a backstepping control for the induction motor with fifth order nonlinear dynamic model which is controlled by primary voltage source. Field-oriented control and backstepping design are combined to design nonlinear model for induction motor. Step by step control designs are given. Simulation results have demonstrated the effectiveness of the proposed design scheme and have shown that backstepping control can achieve superior performance in comparison to the conventional PI controller.

## 6. References

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