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A robust sliding mode flux and speed observer for speed sensorless control of an indirect field oriented induction motor drives

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Abstract

In this paper a new sliding mode flux and speed observer is proposed for indirect field oriented induction motor drive system. The error between the actual and observed currents converges to zero, which guarantees the accuracy of the flux observer. The rotor speed and the rotor time constant are estimated based on the estimated stator currents and rotor flux. The estimated rotor time constant is used in slip calculation and observer structures and the estimated speed is used as feedback to the speed regulation. Computer simulation and experimental results of the speed control verify the validity of the proposed speed estimation algorithm. The experimental results show the robustness and performance of the proposed observer structure. Experimental results have been realized without load, with load and with external disturbances.

Keywords: Sensorless control; Induction machine; Sliding mode observer; Indirect field oriented control

1. Introduction

Control of an induction motor without mechanical sensor has been widely used because of some advantages of the sensorless control such as reliability and low level of maintenance. Various methods to implement the sensorless control can be summarized as; using voltage and current signals available from the drive system, through the carrier frequency signal injection or creating saliency by changing the machine rotor structure. Last two methods mentioned above suffer from the disadvantage that they need either extra hardware or special rotor manufacturing and therefore, cannot be used for an off-the-shelf induction machine. The much-preferred choice for sensorless control for an off-the-shelf machine is through flux and speed estimation using terminal quantities. Therefore, the focus of this paper is flux and speed estimation using the voltage and current signals only.

Slip frequency control [1] and field orientation control [2] are the two major techniques for high performance sensorless control of induction machine. The slip frequency control has been documented to be more sensitive to the rotor resistance variation [3–5]. Many on-line identification schemes of the rotor time constant have been designed [6–8]. These methods have provided some improvement, but are quite complex because they either require more parameters or have hardware complications. Some fuzzy logic based techniques [9–11] have been proposed to overcome the detuning. However, these solutions are also very complex with respect to the software and require extensive calculation that put extra load on the processor.

The proposed observer in this paper estimates the machine speed as well as the rotor time constant and therefore, overcomes the problems, caused by rotor resistance variations, inherited by the slip frequency control. The sliding mode flux observers for induction machine have been investigated [12–17]. However, most of the studied observer structures depend heavily on the machine parameters. In this paper a new sliding mode flux observer structure is proposed such that the convergence of the observed flux is guaranteed by the convergence of the observed currents. Once the convergence of the observed flux is guaranteed, then the rotor speed and the rotor time constant are found through the equivalent control. To avoid using sensors on the machine, terminal quantities of the machine are used to estimate the fluxes and speed of the machine. In this case, the success in achieving the field orientation depends heavily on how well the rotor flux position is estimated. To solve this

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problem, different algorithms are proposed. These proposed algorithms are categorized in two basic groups [18]. First one is 'the closed-loop observers' where the feedback correction is used along with the machine model itself to improve the estimation accuracy [19,20]. Second one is 'the open-loop observers' in a sense an on-line model of the machine, which do not use the feedback correction [21,22]. One of the main problems for both of those observer structures is the integration process inherited from the induction machine dynamics, and some work is based on cancellation strategies to avoid the integration effect. The other important problem is insufficient information about the machine parameters, which yield the estimation of some machine parameters along with the sensorless structure. In this study, a closed-loop sliding mode observer has been used and a low pass filter (LPF) has been used to solve the integration effect. When the motor frequency is lower than the cut-off frequency of the LPF, an estimation error will be produced. To estimate exactly stator flux in a wide speed range, the LPF should have a very low cutting frequency [22]. It is observed that when the filter cut-off frequency is higher than 15 Hz, the closed loop system performance degrades considerably, especially at low speed the closed loop system suffers from excessive noise and oscillations. From our experience, the cut-off frequency of the LPF has been chosen as 5 Hz in the implementation.

2. Indirect field oriented (IFO) sensorless control structure

The slip frequency proposed sensorless control scheme is shown in Fig. 1. In this drive system, the inner feedback loop performs the synchronous current regulation. The current command i_{qs}^{e*} is produced by the outer speed control loop based on the command speed (ω_r^*) and the observed speed ($\hat{\omega}_r$). This speed regulation is conventionally done by using a PI controller [23].

The induction machine model is defined by the stator currents and rotor fluxes as state variables in rotor flux oriented stationary reference frame by the following equations:

$$\frac{\partial i_{ds}^s}{\partial t} = \beta \frac{1}{T_r} \lambda_{dr}^s + \beta \omega_r \lambda_{qr}^s - k_1 i_{ds}^s + k_2 V_{ds}^s \quad (1)$$

$$\frac{\partial i_{qs}^s}{\partial t} = \beta \frac{1}{T_r} \lambda_{qr}^s - \beta \omega_r \lambda_{dr}^s - k_1 i_{qs}^s + k_2 V_{qs}^s \quad (2)$$

$$\frac{\partial \lambda_{dr}^s}{\partial t} = -\frac{1}{T_r} \lambda_{dr}^s - \omega_r \lambda_{qr}^s + \frac{L_m}{T_r} i_{ds}^s \quad (3)$$

$$\frac{\partial \lambda_{qr}^s}{\partial t} = -\frac{1}{T_r} \lambda_{qr}^s + \omega_r \lambda_{dr}^s + \frac{L_m}{T_r} i_{qs}^s \quad (4)$$

where $\sigma = 1 - (L_m^2/L_s L_r)$, $T_r = L_r/R_r$, $k_2 = 1/\sigma L_s$, $\beta = k_2 L_m/L_r$, $k_1 = k_2(R_s + (L_m^2/L_r T_r))$, T_r the rotor time constant, ω_r the electrical rotor speed, subscripts d and q are used for d-axis and q-axis components and superscript s represents stationary reference frame.

3. Design of the sliding mode current and flux observers

The proposed speed and rotor time constant estimation structure is based on sliding mode current and flux observers. Ensuring the convergence of the current observer, the equivalent control is produced. Then, it is used in the flux observation to produce fluxes along the d and q axes. Once the flux values are found, then the rotor speed and rotor time constant are estimated by using observed fluxes. For clarity (1)–(4) can be written as

$$\begin{bmatrix} \frac{\partial i_{ds}^s}{\partial t} \\ \frac{\partial i_{qs}^s}{\partial t} \end{bmatrix} = \beta \begin{bmatrix} \frac{1}{T_r} & \omega_r \\ -\omega_r & \frac{1}{T_r} \end{bmatrix} \begin{bmatrix} \lambda_{dr}^s \\ \lambda_{qr}^s \end{bmatrix} - k_1 \begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix} + k_2 \begin{bmatrix} V_{ds}^s \\ V_{qs}^s \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} \frac{\partial \lambda_{dr}^s}{\partial t} \\ \frac{\partial \lambda_{qr}^s}{\partial t} \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_r} & -\omega_r \\ \omega_r & -\frac{1}{T_r} \end{bmatrix} \begin{bmatrix} \lambda_{dr}^s \\ \lambda_{qr}^s \end{bmatrix} + \frac{L_m}{T_r} \begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix}$$

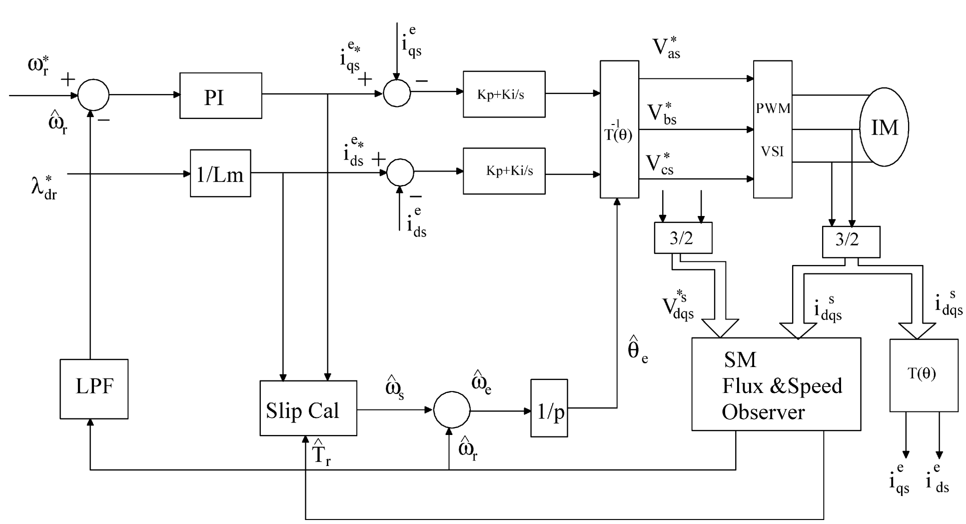

Fig. 1. Block diagram of the IFO closed-loop speed control with sliding mode observer structure.