



Simple Speed Sensorless Control of Induction Motor Drive

Dejan D. Reljić¹, Darko B. Ostojić², Veran V. Vasić³

Abstract – Development trends in industrial electrical drives indicate that the next generation of electrical drives will include some type of sensorless control. Controlled induction motor drives without speed sensors have the attractions of low cost and high reliability due to the absence of the mechanical component and its sensor cable. Speed estimation schemes that allow high dynamic performances are based on vector control of induction machines. However, U/f electrical drives with slip compensation produce satisfactory precision in speed sensorless control down to 100 rpm and are adequate for low dynamics applications. This article presents simple, low cost U/f control of induction motor drive without mechanical speed sensor. Both simulation and experimental results are presented.

Keywords – Induction machine, sensorless speed control, U/f control.

I. INTRODUCTION

The need for tachless speed control of induction machines has become widely recognized because of the cost and fragility of a mechanical speed sensor, and because of the difficulty of installing the sensor in many applications. For these reasons, most industry experts agree that the next generation of commercial drives will include some sort of sensorless torque control [1].

Many attempts have been made in the past to extract the speed signal of an induction machine [2]. The very first attempts have been based on techniques that are only valid in the steady state. Various concepts for controlled high performance induction motor drives without speed sensor have been developed in the past few years [3]. Speed estimation schemes that allow high dynamic performances are based on vector control of induction machines.

¹Dejan D. Reljić is with the Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia and Montenegro, E-mail: reljic@uns.ns.ac.yu

²Darko B. Ostojić is with the Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia and Montenegro, E-mail: ostojic@uns.ns.ac.yu

³Veran V. Vasić is with the Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia and Montenegro, E-mail: veranv@uns.ns.ac.yu

U/f electrical drives with slip compensation produce satisfactory precision in speed sensorless control down to 100 rpm and are adequate for low dynamics applications [4]. U/f sensorless speed estimation schemes can be used in low cost drive applications, not requiring high dynamic performances, such as pumps, ventilators and the like.

This article presents simple, low cost U/f scalar control method of induction motor drive without mechanical speed sensor.

II. SCALAR (U/F) CONTROL

For pump and ventilator like applications the speed control range is only from 3 to 1 up to 10 to 1 [4]. Speed sensors are avoided in such electric drives. Usually scalar U/f open loop control has been used for such applications. The voltage U and its frequency f are related by:

$$U = U_0 + k(f) \cdot f \quad (1)$$

U_0 is called voltage boost and is required to run the motor properly at low speeds. The frequency is ramped as desired and an open loop PWM procedure, based on (1), is used to control the PWM inverter (Fig. 1). Ramping the frequency should be performed slowly enough to maintain stability because open loop scalar (U/f) control drives are prone to instability and they are vulnerable to fast ramp acceleration and large torque perturbations [4].

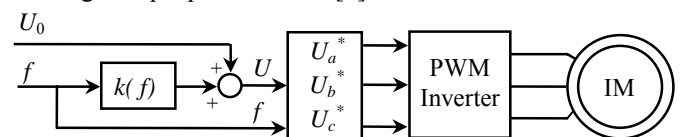


Fig. 1. Open loop scalar control

However, the scheme shown in Fig. 1 will result in speed errors caused by a load, since it has been assumed above that the stator frequency is equal to the reference speed, which is only correct if the slip is zero (there is no load). It follows that to ensure good steady state speed regulations, slip compensation must be employed [2]. The principle of slip frequency compensation method consists of increasing the reference frequency by the estimated slip frequency to make rotor speed independent of load.

III. TECHNIQUES FOR SLIP (SPEED) ESTIMATION OF U/F CONTROLLED INDUCTION MACHINE DRIVE

A. Slip Estimation Scheme Based on Steady State Equivalent Circuit

It is possible to construct a low cost slip sensing device which uses the stator voltages and currents of the induction motor. Such algorithm can be obtained by considering the steady state equivalent circuit of the induction motor and knowing that the steady state slip s can be derived from Kloss formula:

$$\frac{T_e}{T_{e\max}} = \frac{2}{\frac{s}{s_{\max}} + \frac{s_{\max}}{s}} \quad (2)$$

if the pull out slip (s_{\max}) and pull out torque ($T_{e\max}$) values are known. The electromagnetic torque T_e can be estimated from monitored stator voltages and currents by using the facts that the torque can be expressed as the cross vector product of the stator flux linkage and currents space vectors, and the stator flux linkage vector can be obtained by integrating the stator voltage space vector reduced by the stator voltage space vector of the omic drops [2]. Finally, the speed can be easily obtained. This technique is adequate only above 2 Hz but is acceptable in U/f electric drives [4].

B. Slip Estimation Scheme Based on Mathematical Model of Induction Machine

Another technique for slip estimation that will be presented in this paper is based on mathematical model of induction machine drive. Such a model can be obtained by the utilization of space phasor theory. Space vectors are intermediary in transforming $a-b-c$ phase winding quantities into dq winding quantities that will be used for dynamic analysis. It is possible to assume any arbitrary value for the dq winding speed ω_d . However, the choice of $\omega_d = \omega_s$ results in dq windings rotating at the same speed as the field distribution in the air gap. The starting point is the system of differential equations:

$$u_{sd} = R_s \cdot i_{sd} + \frac{d\Psi_{sd}}{dt} - \omega_s \cdot \Psi_{sq} \quad (3)$$

$$u_{sq} = R_s \cdot i_{sq} + \frac{d\Psi_{sq}}{dt} + \omega_s \cdot \Psi_{sd} \quad (4)$$

$$0 = R_r \cdot i_{rd} + \frac{d\Psi_{rd}}{dt} - (\omega_s - \omega) \cdot \Psi_{rq} \quad (5)$$

$$0 = R_r \cdot i_{rq} + \frac{d\Psi_{rq}}{dt} + (\omega_s - \omega) \cdot \Psi_{rd} \quad (6)$$

$$\Psi_{sd} = L_s \cdot i_{sd} + L_m \cdot i_{rd} \quad (7)$$

$$\Psi_{sq} = L_s \cdot i_{sq} + L_m \cdot i_{rq} \quad (8)$$

$$\Psi_{rd} = L_m \cdot i_{sd} + L_r \cdot i_{rd} \quad (9)$$

$$\Psi_{rq} = L_m \cdot i_{sq} + L_r \cdot i_{rq} \quad (10)$$

The absolute slip can be derived from previous equations (with a few approximations):

$$\omega_s - \omega = - \frac{R_r \cdot (\Psi_{sq} - L_s \cdot i_{sd}) + L_r \cdot \frac{d\Psi_{sq}}{dt}}{L_r \cdot (\Psi_{sd} - L_s \cdot i_{sd}) + L_m^2 \cdot i_{sd}} \quad (11)$$

The stator flux estimator can be obtained by integrating the stator voltage space vector reduced by the stator voltage of the omic drops and transforming into dq synchronous quantities.

Based on mathematical model, *MATLAB/Simulink* mathematical model has been created in order to verify the results of previous analysis. A test induction motor has the following specifications: 1.5 kW, 380 V, 3.8 A, 50 Hz.

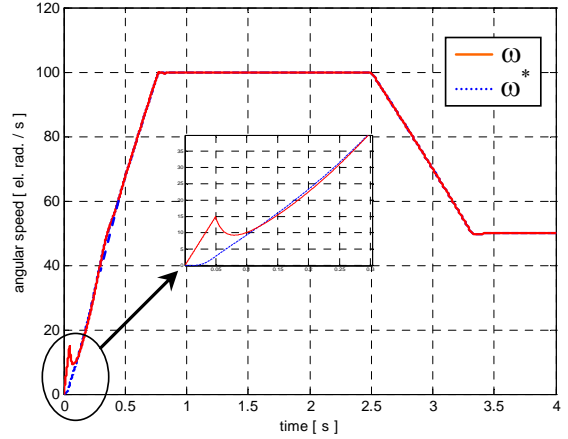


Fig. 2. Simulation result

In Fig. 2 are shown results of simulation. Motor is loaded. Speed reference is 100 rad/s and after acceleration the speed reference is changed to 50 rad/s. Good tracking specifications are achieved, except for low speeds where some previously done simplifications are expressed as bad set point tracking.

IV. EXPERIMENTAL RESULTS

The effectiveness of this method (slip estimation scheme based on mathematical model of induction machine) will be verified by a laboratory prototype of U/f sensorless controlled induction machine drive. The drive consists of induction machine ZK 90 L4, laboratory prototype of inverter and dSpace 1104 Development Kit.

REFERENCES

- [1] K. Hurst, T. Hableter, G. Griva, and F. Profumo: "Zero-Speed Tachless IM Torque Control: Simply a Matter of Stator Voltage Integration", *IEEE Trans. on Ind. Appl.*, Vol. 34, No.4, July/Aug. 1998, pp. 790-795.
- [2] P. Vas, "Sensorless Vector and Direct Torque Control", Oxford University Press, 1998.
- [3] K. Rajashekara, A. Kawamura, K. Matsuse, "Sensorless Control of AC Motor Drives", Piscataway, NJ: IEEE Press, 1996.
- [4] I. Boldea, S. A. Nasar, "Electric Drives", Taylor & Francis Group, 2005.