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Speed Control of Induction Motor fed by PWM inverter by Vector Control Method

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Abstract- *The speed control method for induction motor fed by PWM voltage source inverter is being introduced in this paper. LC filter is being used at inverter output terminal to reduce the voltage spikes. Observers are used to estimate the flux and torque to reduce the number of measurements and ultimately cost of setup. No additional voltage or current measurements are needed for vector control of the induction motor.*

Keywords—*PWM voltage source inverter, Induction Motor, LC filter, Observer*.

I.INTRODUCTION

The output voltage of PWM voltage source inverter contains voltage pulses with sharp spikes. If these pulses are altered suddenly then there will be bearing currents and high voltage stress in motor insulations. The Oscillations at switching frequency causes additional losses and acoustic noise. LC filter removes this phenomenon. There will be no need of EMI shielding of motor since voltage of inverter is nearly sinusoidal.

The high pass filtered stator voltage has been used to correct the voltage reference, and a multi-loop feedback controller has been proposed. Here we have to keep number of measurements low in order to obtain cost savings and reliability.

In this paper the speed control method for induction motor fed by PWM voltage source inverter is presented.

II.PRINCIPLE OF CONTROL SYSTEM

The principle of control system is explained by the block diagram as shown in figure1.The inverter output voltage $u_A$is filtered by LC filter and the induction motor is fed by filtered voltage u_S. The inverter current i_A, the angular speed ω_m of the rotor and the dc link voltage u_{dc} are the only measured quantities, whereas stator voltage and current of motor are estimated by an observer. The system is controlled by nested control loops in rotor flux reference frame.

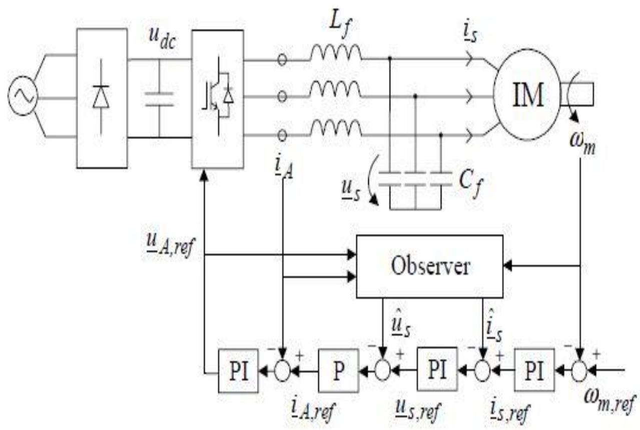

Fig.1. Principle of Control System

[1] *Filter and Motor Models*

In a reference frame rotating at angular speed ω_s, the equations of LC filter are

$$\frac{di_A}{dt} = -j\omega_s i_A - \frac{RL_f}{L_f} i + \frac{1}{L_f}(u_s - u_A) \qquad (1)$$

$$\frac{du_s}{dt} = -j\omega_s u_s + \frac{1}{C_f}(i_A - i_s) \qquad (2)$$

Where L_f is the inductance and R_{Lf} is the series resistance of the inductor, C_f is the capacitance of the filter.

The motor control is based on the model in synchronously rotating rotor flux frame. The stator and rotor voltage equations in this reference frame are

$$u_s = Ri + \frac{d\psi_s}{dt} + j\omega\psi_s \qquad (3)$$

$$0 = R_R i_R + \frac{d\psi_r}{dt} + j(\omega_s - \omega_m)\psi_r \qquad (4)$$

Respectively, where Ψ_s and Ψ_r are the stator and rotor flux linkages. R_s and R_R are the stator and rotor resistances, i_R is the rotor current and ω_m is the electrical angular speed.

[2] Cascade Control

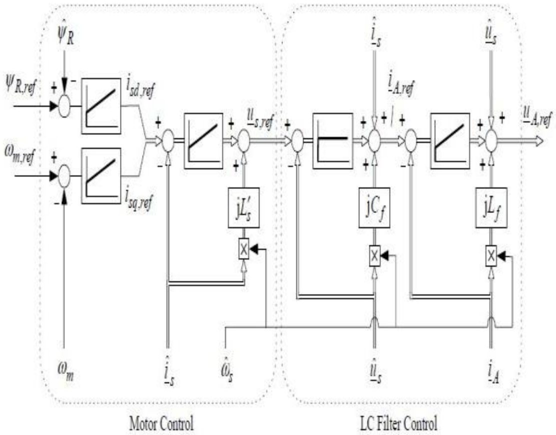

Fig. 2. Complex signal flow diagram of cascade control

In the LC filter control, the innermost control loop governs the inverter current $i_A$by means of a PI controller, and the stator voltage is governed by a P-type controller in the next control loop. In both control loops, decoupling terms are used to compensate the cross-couplings caused by the rotating reference frame. The motor control is based on vector control and forms two outermost loops of the cascade control. Thestator current is controlled by a PI-type controller with cross-coupling compensation, and the rotor speed is governed by a PI-controller. In addition, a PI-type rotor flux controller is used.

[3] Observability

The observability of the system can be investigated using

$$M_o = [C \; CA \; CA^2 \; CA^3]^T \qquad (5)$$

The system is observable if the rank of the observability matrix is equal to the number of states [4]. [3]Full Order Observer

The most essential part of the control is a full-order observer, which is implemented in the estimated rotor flux reference frame, i.e., in a reference frame where $\widehat{\Psi_R} = \widehat{\Psi_R} + j0$. the observer is defined as

$$\hat{x} = A\hat{x} + Bu_A + K(i_A - \widehat{i_A})$$

Where estimated states are marked by the symbol '^' and $\mathbf{K} = [k_1 k_2 k_3 k_4]^T$ is the observer gain vector. The digital implementation of the full-order observer based on the conventional forward Euler discretization causes instability at higher speeds. Other alternatives, such as the backward

Euler method or the bilinear transformation, hold the stability but are more complicated to implement. A simple symmetric Euler method has been found to be an effective and Reliable discretization method in electromechanical simulations [5] and full-order flux observers [6]. The observer gain vector **K** can be selected in many ways. The selection can be based on the pole placement method, or a simple constant gain can be used, as will be presented in the following.

1). Pole Placement

In the pole placement method, the poles of the estimation error dynamics are placed to desired locations. Because the system model is time variant, the pole placement should be carried out at every calculation step. However, this would increase the computing time of the processor dramatically. Apractical solution is to use gain scheduling: the observer

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gain vector is calculated in advance as a function of the angular speed of the rotor, and interpolation between tabulated valuesis used during the operation. The poles also depend on the angular slip frequency $\omega_r = \omega_s - \omega_m$ as the estimated rotor flux reference frame is used. If the gains obtained for no-load operation are used, the slip frequency affects only the imaginary parts of the observer poles. Therefore, the assumption of $\omega_r = 0$ in the pole placement method does not cause stability problems.

2). Simple Constant Gain

The observer becomes relatively simple when the real-valued gain $K = [k_1 \quad 0 \quad 0 \quad 0]^T$ is selected.

III. SIMULATION RESULTS

The behavior of the system was investigated by means of computer simulations with MATLAB/Simulink software. The data of a 2.2-kW four-pole induction motor (400 V, 50 Hz), given in Table I, were used for the simulations. The sampling frequency of 5 kHz was equal to the switching frequency. The LC filter was designed to have a cutoff frequency of 566 Hz in order to meet a rule of thumb that the cutoff frequency should be about one decade below the switching frequency and one decade above the nominal fundamental frequency [7]. The fundamental-frequency voltage drop in the filter inductance was chosen to be less than 5 % of the nominal voltage in the nominal operating point [8]. The filter parameters are also given in Table I. The bandwidths of the controllers were 500 Hz for the inverter current, 250 Hz for the stator voltage, 150 Hz for the stator current, 15 Hz for the rotor speed, and 3 Hz for the rotor flux as shown in Table 1.

TABLE1.PARAMETERS OF THE MOTOR AND THE LC FILTER

MOTOR PARAMETERS	VALUES
Stator Resistance, R_S	3.67 Ω
Rotor Resistance, R_R	1.65 Ω
Stator Transient Inductance, L_S'	0.0209 H
Magnetizing Inductance, L_M	0.264 H
Total Moment of inertia, J	0.0155 kg m^2
Rated Speed, n_N	1430 r/min
Rated Current, I_N	5 A
Rated Torque, T_N	14.6 Nm

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LC FILTER PARAMETERS	VALUES
Inductance, L_f	8.0mH
Capacitance, C_f	9.9µF
Series Resistance, R_{Lf}	0.1Ω

The behaviour of motor speed and torque variation with time is shown in fig. 3 and fig. 4.

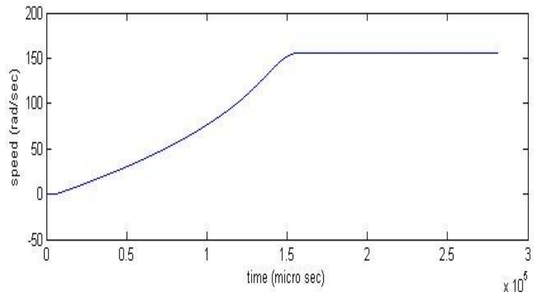

Fig. 3: Variation of motor speed

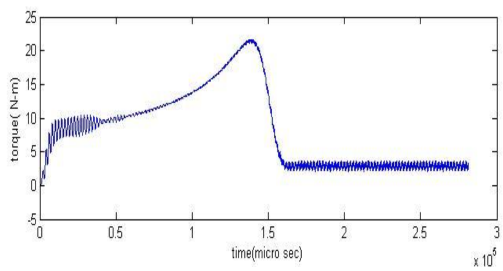

Fig. 4: Variation of torque with time

IV.CONCLUSION

When the inverter output voltage is filtered by an LC-filter, the vector control of an induction motor can be based on nested control loops. Simulation results show that the proposed control method operates correctly. The observer gain can be selected by means of pole placement, or a constant gain can be used.

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