The Use of Power Measurement and Fuzzy Logic to Sensorless Vector Control of Induction Motors

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Abstract: – **In the proposed paper, the use of power measurement to realize sensorless control of the induction machine will be presented. The control system is very useful to the traction application. The proposed method is applied to the field oriented control, however, may be used in any type of induction motor control system. The method of rotor speed calculation is based on power measurement. PI and fuzzy logic controller will be used to generate the motor speed. The system control could be applied in traction drives. In presented paper, simulation results will be presented.**

1. Introduction

Since the introducing of the idea of vector control of induction motors [5], this type of machine almost replaced the separately excited dc motors in adjustable electrical drives. To deal with induction motor as separately excited dc motor it is important to find two input orthogonal values. These values could be the direct and quadrature components of stator current. The decoupling between the input and the output in this coupled and complicated machine obtained as a result of using the idea of vector representation and transformation from one frame to other. If our coordinate system rotates with of rotor flux then the electromagnetic torque could be controlled by only one component while the second one is kept constant [7, 8].

The application of vector representation and the advancement in power electronics, microprocessors and digital electronics cause a revolution in the use of a complicated squirrel cage induction motors.

The main problem during realization of vector control systems was the identification of not available, for direct measurement, state variables. The presented by authors systems control of induction motor give the possibility to solve several problems, which faced the using of vector control of induction motor. In the paper steady state relationships between active and reactive powers and other variables are used instead of the full state observer.

Speed sensor has many defects and presents many problems like spoiling of the raggedness and simplicity of ac motors. Also this factor is expensive. Authors proposed many papers with sensorless control of induction motors [1, 2, 4].

It has been proposed in the paper sensorless version of the system control. The rotor speed is calculated from the differential equations in steady state and using power measurement. The calculated speed is used in the feedback to make it possible to linearize a dynamic of the control system.

The used model of induction motor is fed by the voltage source inverter with PI current controllers. Simulation results in real time have been curried out

2. Induction motor description

The squirrel cage type of induction motor as differential equations for the stator current and rotor flux vector components presented in coordinate system XY rotating with arbitrary angular speed is:

$$\frac{di_{sx}}{d\tau} = -\frac{R_s L_r^2 + R_r L_m^2}{L_r w} i_{sx} + \frac{R_r L_m}{L_r w}\psi_{rx} + \omega_s i_{sy} + \omega_r \frac{L_m}{w}\psi_{ry} + \frac{L_r}{w}u_{sx} \tag{1}$$

$$\frac{di_{sy}}{d\tau} = -\frac{R_s L_r^2 + R_r L_m^2}{L_r w} i_{sy} + \frac{R_r L_m}{L_r w}\psi_{ry} - \omega_s i_{sx} - \omega_r \frac{L_m}{w}\psi_{rx} + \frac{L_r}{w}u_{sy} \tag{2}$$

$$\frac{d\psi_{rx}}{d\tau} = -\frac{R_r}{L_r}\psi_{rx} + (\omega_s - \omega_r)\psi_{ry} + R_r \frac{L_m}{L_r} i_{sx} \tag{3}$$

$$\frac{d\psi_{ry}}{d\tau} = -\frac{R_r}{L_r}\psi_{ry} - (\omega_s - \omega_r)\psi_{rx} + R_r \frac{L_m}{L_r} i_{sy} \tag{4}$$

$$\frac{d\omega_r}{d\tau} = \frac{L_m}{L_r J}(\psi_{rx} i_{sy} - \psi_{ry} i_{sx}) - \frac{1}{J} mo \tag{5}$$

where: $w = \delta L_r L_s$, $\delta = 1 - L_m^2 / L_r L_s$, $\psi_{rx}, \psi_{ry}, i_{sx}, i_{sy}$ are the rotor flux and stator current vectors in coordinate system XY rotating with arbitrary speed, ωr is the angular speed of the rotor shaft, R_r, R_s, L_r, L_s are rotor and stator resistance and inductances respectively, L_m is a mutual inductance, J is the inertia, m_o is the load torque, and:

3. Vector control system

The idea of vector control of AC machines depends on vector representation and transformation from one coordinate system (stationary) to the rotating one (Fig. 1. . The prduced torque Te in the machine has the next form:

$$T_e = \frac{L_m}{L_r J}(\psi_{rd} i_{sq} - \psi_{rq} i_{sd}) \tag{6}$$

where dq are the variables in rotating frame. If our coordinate system rotates with of rotor flux ψ_r then the electromagnetic torque could be controlled by only one component while the second one is kept constant. This happens because the imaginary comp[onent of rotor flux ($\psi_{rq}=0$) which gives the next form:

$$T_e = \frac{L_m}{L_r J}(\psi_{rd} i_{sq}) \tag{7}$$

If we keep constant i_{sd} then the rotor flux will keep constant. By this way the produced torque will linearly depends on the imaginary component of stator current (i_{sq}). The vector control system is shown at Fig. 1.

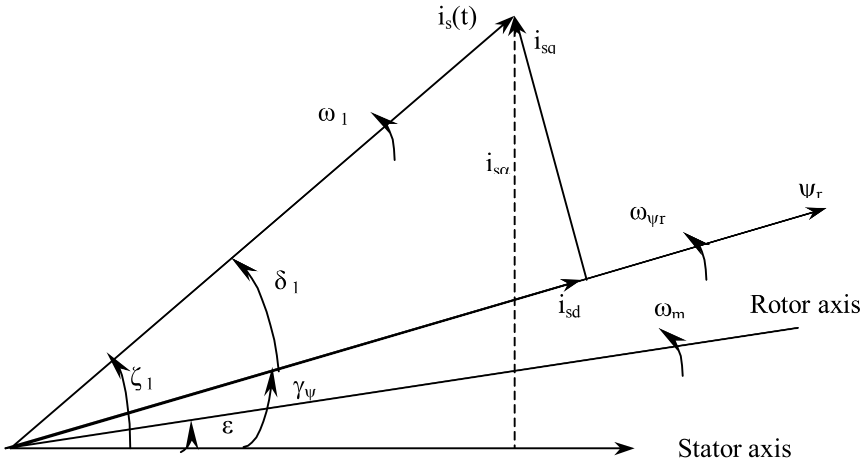

Fig. 1: Angular relations of current vectors

4. State variables calculation using stator flux measurement

The stator flux vector is presented as next:

$$\psi_s = (u_s - R_s i_s) dt \tag{8}$$

Where u_s, i_s, R_s are stator voltage, current and resistance respectively.

The expressions of stator flux and rotor flux vectors are will known:

$$\psi_s = L_s i_s + L_m i_r \tag{9}$$

$$\psi_r = L_r i_r + L_m i_s \tag{10}$$

Taking into account the above equations get the expression of rotor flux vector components in stationary coordinate system:

$$\psi_{r\alpha} = \frac{L_r}{L_m}(\psi_{s\alpha} - \delta L_s i_{s\alpha}) \tag{11}$$

$$\psi_{r\beta} = \frac{L_r}{L_m}(\psi_{s\beta} - \delta L_s i_{s\beta}) \tag{12}$$

5. Rotor angular speed calculation

Rotor angular speed in a presented control system may be determined by using the deffirential equations of stator current and rotor flux vectors products (equations 1 to 4). Rotor angular speed presents in deferent depends of stator and rotor deferential equations. In steady states the left-hand sides of equations (1 to 4) are equal to zero. This property, together with using new variables variables and power definitions, provides a lot of equations for rotor speed.

Rotor speed can be calculated using the state variables as:

$$\omega_r = \frac{-a_2 x_{12} - s_i i_s^2 + a_4 Q}{i_s^2 + a_3 x_{22}} \tag{13}$$

where a_2, a_3, a_4 are motor parameters, s_i is the slip frequency and Q is the imaginary reactive power [3]. X_{12} and x_{22} are new variables defined below.

The equations of used power is:

$$Q = u_{s\beta} i_{s\alpha} - u_{s\alpha} i_{s\beta} \tag{14}$$

where α and β denote a stationary frame. The slip frequency is:

$$s_i = \frac{R_r}{L_r} \frac{x_{12}}{x_{22}} \tag{15}$$

and the new variables are [6]:

$$x_{12} = \psi_{r\alpha} i_{s\beta} - \psi_{r\beta} i_{s\alpha} \tag{16}$$

$$x_{22} = \psi_{r\alpha} i_{s\alpha} + \psi_{r\beta} i_{s\beta} \tag{17}$$

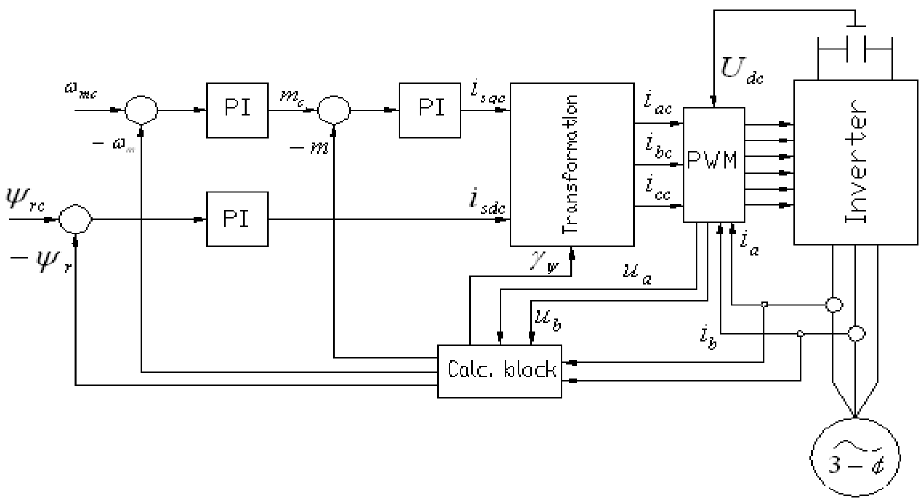

Fig. 2. Vector control system of induction motor

6. Fuzzy logic controller

In the system with not exactly known dynamic, and with difficult to describe analytical relationships, good results are obtained by using the fuzzy logic theory.

The system described in this paper has the mentioned characteristics, which are caused by non-precise variable identification and thus a complicated analytical system description. In the system presented, Mamdani type of fuzzy logic controller (FLC), presented in Fig. 3. is used for speed controller. The input signals for the controller are: control error, 'e' and the change of error, 'Δe' and the output is the change of control signal, 'Δu'. The controller consists of three elements: fuzzyfication block, block of rules (rules of inference) and defuzzyfication, which are related by proper relationships.

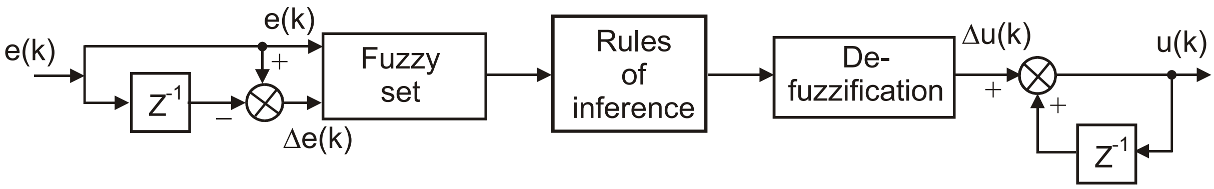

Fig. 3. fuzzy logic controller (FLC)

On the basis of the values, ‘e’ and ‘Δe’, the fuzzy numbers are calculated in the fuzzyfication block using the membership function presented in Fig 6. Simple membership functions for the three linguistic variables: ‘N’ – negative, ‘Z’ – zero and ‘P’ – positive are used. . The resulting block consists of logic table like, ‘If…Then’ which are described in Table 1. Symbol ‘’B’’ means big and symbol ‘’S’’ means small. On the basis of the membership of fuzzy numbers to such sectors, which are defined in Table 1, the output function is described, which is the fuzzy quantity of the control signal function. This quantity must be subject to defuzzyfication, to identify a signal, which will be used to control the object. From many defuzzyfication methods the Center of Area method (COA) is chosen. In the COA method, the quantity of the fuzzy set after defuzzyfication is described by:

$$y^* = \frac{\sum_{i=1}^{n} F(y_i) y_i}{\sum_{i=1}^{n} y_i} \qquad (18)$$

where: n – number of quantization levels, y_i – value for i-th quantization function Δu for i-th quantization level, Fi - value of membership function Δu for i-th quantization level.

For the specified number of input signal samples, it is possible to elaborate a proper look-up table, which contains the error values.

Table 1: Conclusion rules

				e				
		NB	NM	NS	Z	PS	PM	PB
	NB	NVB	NVB	NVB	NB	NM	NS	Z
	NM	NVB	NVB	NB	NM	NS	Z	PS
	NS	NVB	NB	NM	NS	Z	PS	PM
Δe	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PM	PB	PVB
	PM	NS	Z	PS	PM	PB	PVB	PVB
	PB	Z	PS	PM	PB	PVB	PVB	PVB
								Δu

7. Simulation results

The results of the simulations in C language of the system presented in Fig. 2 are shown for step changes of the rotor speed set values and of the load torque. Data of a 1.5 kW squirrel cage motor have been used in investigations.

On figures 4, 5 and 6 it is shown the response of speed, torque and currents. The indexes XY denote the stationary components. The estimated and actual speeds are shown.

It is shown very good and smooth response of the control system.

On Fig. 7 it is shown the results of the system control with fuzzy logic controller with speed measurement. It is seen that the action of fuzzy controller is significantly better that the PI one.

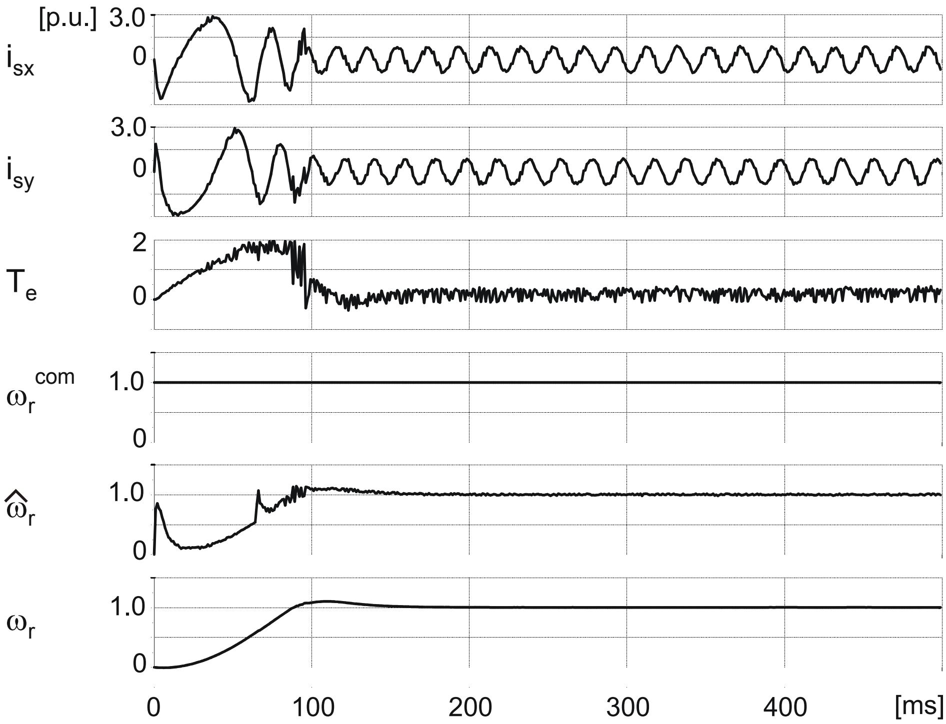

Fig. 4. Motor starting

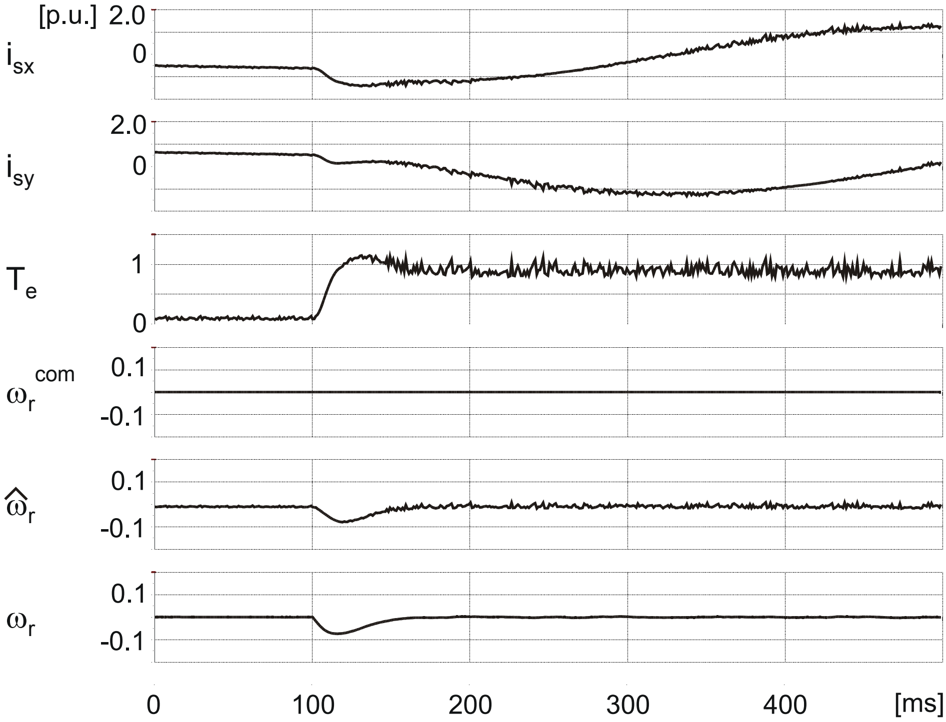

Fig. 5. Step change of torque load

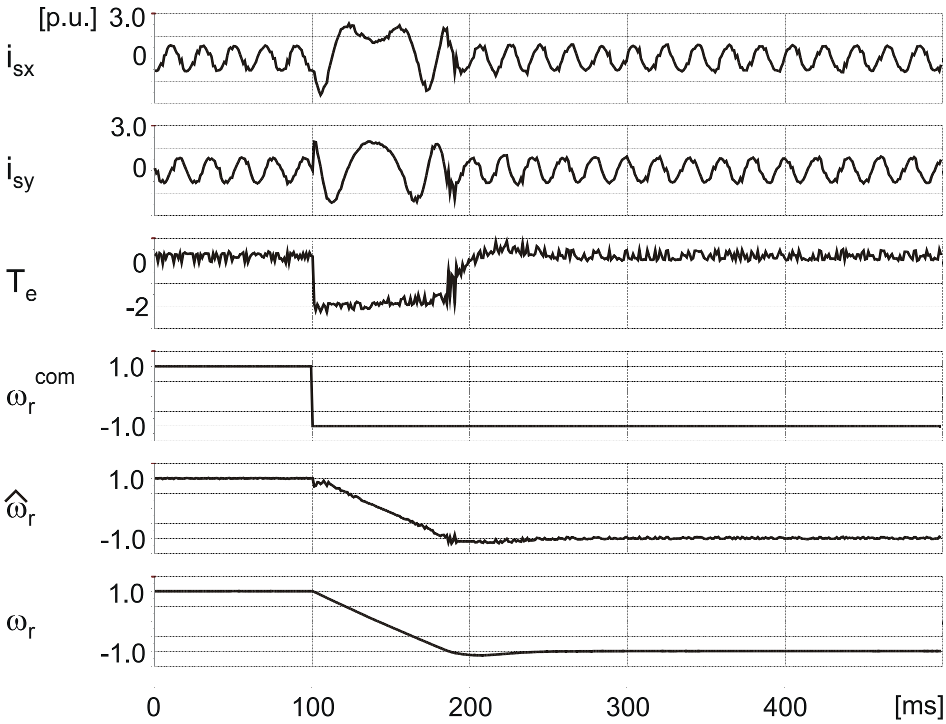

Fig. 6. Reversing of rotor speed

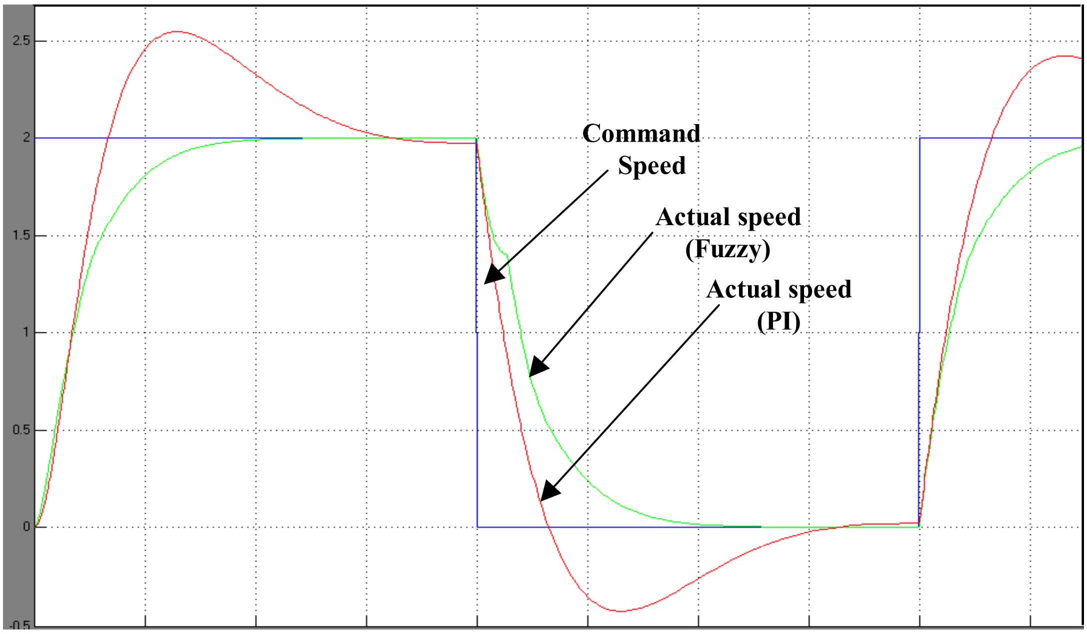

Fig. 7. The response of the system control – comparison between fuzzy and PI controllers

8. Conclusion

In this paper a sensorless vector control of induction motor is presented. The rotor speed was calculated in simple way using steady state relationships. The use of imaginary reactive power simplifies the estimation procedure.

Simulation results are presented for PI and fuzzy logic controllers. All presented results show that the proposed sensorless control system works properly for different operating points and for wide range of rotor speed.

9. References

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