Roma RINKEVICIENE[1], **Jonas KRIAUCIUNAS**[2]

Vilnius Gediminas technical University (1), Vilnius Gediminas technical University (2)

Fuzzy logic controller of the ventilation system

***Abstract**. This paper considers the closed loop model of ventilation system with induction motor drive. The Takagi-Sugeno fuzzy logic controller with PD created. Proposed fuzzy logic controller was created using Matlab and function ANFIS (adaptive neuro-fuzzy inference system).The ventilation system model was simulated with three types of different controllers: conventional PI (proportional-integral), PD (proportional-derivative) and Fuzzy logic PD controller. The advantages of created fuzzy logic controller and simulation results of proposed system were presented and analyzed.*

***Streszczenie.** W pracy rozpatrzono model systemu wentylacyjnego ze sprzężeniem zwrotnym wykorzystującego silnik indukcyjny. Dla tego systemu stworzono sterownik PD w oparciu o zasady logiki rozmytej (fuzzy logic). Sterownik zrealizowano w środowisku Matlab-Simulink. Przedstawiono i przeanalizowano metodą symulacyjną podstawowe charakterystyki zaproponowanego sterownika. (**Sterownik systemu wentylacyjnego wykorzystujący logikę rozmytą**).*

Keywords: fuzzy logic, controller, Simulink, Matlab, induction motor, closed loop.
Słowa kluczowe: logika rozmyta (fuzzy logic), sterownik, Matlab-Simulink, silnik indukcyjny, sprzężenie zwrotne.

Introduction

Synchronous rotation speed of the induction motor is determined by three phase supply voltage, frequency and the number of motor poles. Usually the rotation speed of motor must be controlled. Variable speed drives allow controlling technological process and saving electrical energy.

Modern premises usually are equipped with advanced ventilator systems, i.e., living or industrial premises. The main electric equipment of ventilation system is ventilator. Modern ventilation systems are equipped with frequency controlled induction motors. Usually ventilation systems use scalar control of frequency converters with PI, PD or PID regulators. The paper considers model of frequency controlled induction motor based on parameters of real ventilation system and transients in that [1, 2, 3].

In the last few years, fuzzy logic has met a growing interest in many motor control applications due to its non-linearities handling features and independence of the plant modeling.

The fuzzy logic controller (FLC) operates in a knowledge-based way, and its knowledge relies on a set of linguistic if-then-else rules, like a human operator[4].

In this paper, the induction motor with ventilator loadSimulink model was developed. The performance of the proposed closed loop control system with fuzzy logic controller is compared with PD and PI controllers controlled system. Simulation results are presented.

Dynamic model of induction motor drive

Dynamic performance of an AC machine is complex problem taking into account three phase rotor windings moving with respect to three-phase stator windings. The coupling coefficient changes continuously with the change of rotor positionΘ_r and machine model is described by differential equations with time varying mutual inductances. To simplify the problem solution, any three phase induction machine can be represented by an equivalent two phase machine, whered^s-q^s is direct and quadrature axes of stator as well asd^r-$q^r$are direct and quadrature axes of rotor. The problem becomes simple, but problem of time varying parameters still remains. Park transformation refers the stator variables to a synchronous reference frame, fixed on the rotor. It results to all time varying inductances being eliminated. The other kind of transformation widely used is G. Kron transformation, relating both stator and rotor variables to a synchronously rotating reference frame that moves with the rotating magnetic field. Time – varying inductances in the voltage equations of an induction machine also can be eliminated by transforming rotor variables to variables associated with fictitious stationary windings. In this case, the rotor variables are transformed to a stationary reference frame fixed on the stator. This method was proposed by H. S. Stanley [5].

The paper presents a mathematical model of the induction motor in a stationary reference frame. A mathematical model of the linear induction motor in stationary reference framed^s, q^scan be written as [6]:

$$(1)\quad \begin{cases} \dfrac{d\psi_{ds}^{s}}{dt} = u_{ds}^{s} - \left[\left(\dfrac{1}{L_s} + \dfrac{L_m k_1}{L_s L_r}\right)\times\psi_{ds}^{s} - \dfrac{L_m}{L_s L_r}\times\psi_{ds}^{r}\right]\times R_s\,; \\ \dfrac{d\psi_{qs}^{s}}{dt} = u_{qs}^{s} - \left[\left(\dfrac{1}{L_s} + \dfrac{L_m k_1}{L_s L_r}\right)\times\psi_{qs}^{s} - \dfrac{L_m}{L_s L_r}\times\psi_{qs}^{r}\right]\times R_s\,; \\ \dfrac{d\psi_{ds}^{r}}{dt} = u_{ds}^{r} - \left[\dfrac{1}{L_r}\left(\psi_{ds}^{r} - k_1\times\psi_{ds}^{s}\right)\right]\times R_r + \omega_r\times\psi_{qs}^{r}\,; \\ \dfrac{d\psi_{qs}^{r}}{dt} = u_{qs}^{r} - \left[\dfrac{1}{L_r}\left(\psi_{qs}^{r} - k_1\times\psi_{qs}^{s}\right)\right]\times R_r + \omega_r\times\psi_{qs}^{r}\,, \end{cases}$$

where: $\psi_{ds}^{s}, \psi_{ds}^{r}, i_{ds}^{s}$ and i_{ds}^{r} is stator flux linkages and currents aligned with the direct axis; $\psi_{qs}^{s}, \psi_{qs}^{r}, i_{qs}^{s}, i_{qs}^{r}$ is stator flux linkages and currents aligned with quadrature axis;$R_s$is stator phase resistance,$R_r$is rotor phase resistance, referred to stator; $u_{ds}^{s}, u_{qs}^{s}, u_{ds}^{r}, u_{qs}^{r}$ is stator and rotor voltages.

In the stationary reference frame $u_{ds}^{s} = U_{1max}cos\omega_0 t$, $u_{qs}^{s} = U_{1max}sin\omega_0 t$, where U_{1max} is amplitude of voltage and ω_0=$2\pi f$is angular frequency. L_m is magnetizing inductance, L_s=L_{1s}+$L_m$is stator inductance,$L_{1s}$is stator leakage inductance;L_r=L_{1r}+L_m,$L_{1r}$is rotor leakage inductance referred to stator andk_1=L_m/L_s.

Torque delivered by motor, is calculated as:

$$(2)\qquad T = \frac{3}{2}\,p\times\left(\psi_{ds}^{s}\times i_{qs}^{s} - \psi_{qs}^{s}\times i_{ds}^{s}\right),$$

where: p is number of pole pairs.

Model of induction motor with ventilator load

If the motor drives pump or ventilator, it operates with ventilator load. Then load torque is proportional to speed square:

$$T_L = k \times \omega^2 . \tag{3}$$

Rated torque of motor is calculated as:

$$T_r = \frac{P}{\omega_0} , \tag{4}$$

where P is motor power in watts,$\omega_0$is synchronous speed in rad/s. Rated parameters are given in Table 1.

Constant k is calculated from Eq. (5) in this way:

$$k = \frac{T_r}{\omega_0} = 1.29 \cdot 10^{-4}. \tag{5}$$

Model of frequency controlled drive with ventilator load is given in Fig. 2.

Motor model has 3 inputs: voltages U_{1A}, U_{1B} and torque load, proportional to speedsquare [7].

Parameters of modeled motor are presented in Table 1.

Table 1. Parameters of the motor

Parameter	U	P	N	f	cosφ	Rated current	Rated torque
Units	V	kW	rpm	Hz		A	N•m
Value	400	4	2850	50	0.88	7.9	13.22

Takagi-Sugeno fuzzy controller design

A fuzzy controller is a device which controls each and every operation in the system.In this section, the development of the control strategy for control of various parameters of the induction machine such as the speed, flux, torque, voltage, stator current is presented using the concepts of Takagi-Sugeno based fuzzy control scheme, the block diagram of which is shown in the Fig. 1.

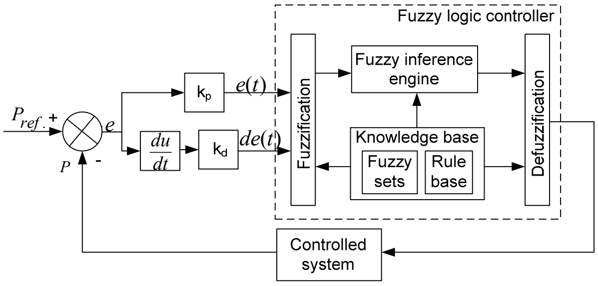

Fig. 1. Structure of a fuzzy logic controller

Gain coefficients k_d, k_p are used for tuning of fuzzy controller

Linguistic variables, defined as variables whose values are sentences in a natural language (such as large or small), may be represented by the fuzzy sets. Fuzzy set is an extension of a 'crisp' set where an element can only belong to a set (full membership) or not belong at all (no membership). Fuzzy sets allow partial membership, which means that an element may partially belong to more than one set [8,9].

A fuzzy logic controller is based on a set of control rules called as the fuzzy rules among the linguistic variables. These rules are expressed in the form of conditional statements. Our basic structure of the fuzzy logic coordination controller to damp out the oscillations in the power system consists of 3 important parts: fuzzification, knowledge base – decision making logic (inference system) and the defuzzification.

Created Takagi-Sugeno fuzzy controller is a system with two inputs and single output, *e* and *de* are input variables, described as:

$$\begin{aligned} e(t) &= P_{ref.} - P, \\ de(t) &= e(t) - e(t-1), \end{aligned} \tag{6}$$

where $e(t)$ is pressure signal error,$P_{ref.}$is pressure reference signal, P is actual pressure signal and de is change of the error signal [10].

The decision-making unit uses the conditional rules of 'if-then-else', which can be observed from the algorithm for developing the fuzzy rules below. In the fuzzification process, i.e., in the first stage the crispvariables, speed error and the change in error are converted into fuzzy variables or the linguistics variables. The fuzzification maps two input variables to linguistic labels of the fuzzy sets. The fuzzy coordinated controller uses the linguistic labels. Each fuzzy label has an associated membership function. The inputs are fuzzified using the fuzzy sets and are given as input to fuzzy controller.

The fuzzy sets are designated by the labels: NL (negative large), NM(negative medium), *NS* (negative small), ZE(zero), PS (positive small),PM (positive medium), and PL (positive large) [8, 9, 11].

Controller decisions are based on the fuzzified variables. The inference involves a set of rules for determining the output decisions. As there are two input variables and seven fuzzified variables, the fuzzy logic coordination controller has a set of forty-nine rules for the fuzzy logic based TS controller. Now, the forty-nine output variables of the inference system are the linguistic variables and they must be converted into numerical output, i.e., they have to be defuzzified. Defuzzification is the process of producing a quantifiable result in fuzzy logic.

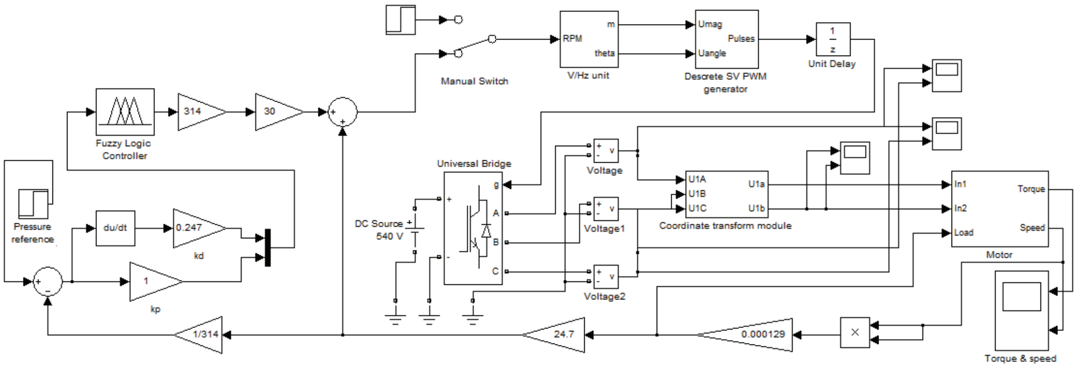

Fig. 2. Model of closed loop pressure control system with fuzzy controller

Simulation results

The model of induction motor with ventilator load and pressure feedback signal is elaborated. Required pressure value is maintained by fuzzy controller with two inputs. Computer model is elaborated for a motor, whose parameters are presented in Table1. The model of induction motor with ventilator loadis presented in Fig. 2.

Fig. 3 shows simulation results of pressure control system with fuzzy logic controller and conventional controllers PI and PD. It is seen, that pressure transient of fuzzy controlled system reaches steady state value fasterthan in PI and PD controlled system. The steady-state value, with TS fuzzy controller is equal to 0.5 s and 0.6 s with conventional PD and PI controller. As it is seen, transients have small oscillations at the start point and there is no overshoot.

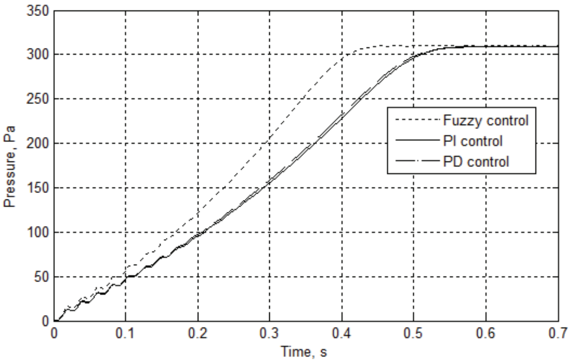

Fig. 3.Comparison of pressure transient with fuzzy logic, PD and PIcontrollers

Fig. 4 shows comparison of torque developed by the ventilator loaded motor. It is seen, that torque values slightly differs in fuzzy PI, and PD controlled systems. The torque peak during start up approximately 9.8 times exceeds the rated torque using TS fuzzy controller and approximately 7.5 times using PD or PI controller. Steady state torque oscillates because higher order harmonics of current.

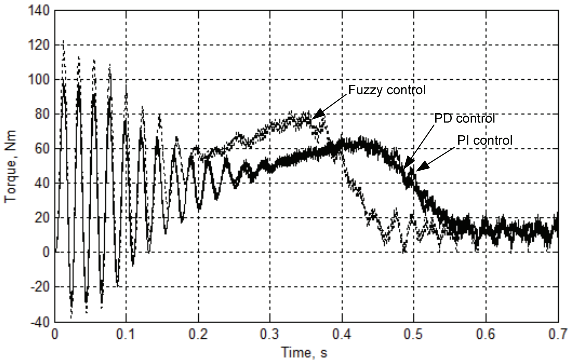

Fig. 4.Torque response of induction motor in fuzzy logic,PD and PI controlled system

Two inputs of Fuzzy controller error and its derivative are presented in Fig. 5.Both signals took part in producing control signal of frequency inverter.

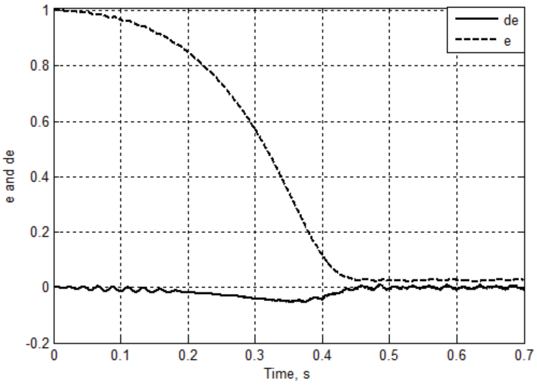

Fig. 5. Inputs of Fuzzy controller: error *e* and its derivative *de/dt*

Developed closed loop pressure control system with Takagi-Sugeno fuzzy controller has shorter settling time and steady state error less than 1.3%.

REFERENCES

[1] Smilgevičius A., Rinkevičienė R., Simulation of transients in the Mechanical part of Electromechanical system, Proc. 10-th Int. Conference on Mathematical Modeling and Analysis (2005), 155-162.

[2] Juraitis S., Rinkevičienė R., Kriaučiūnas J., Modelling of two-mass system with elasticity, Electrical and Control Technologies (2009), 227-230.

[3] Juraitis S.,Rinkevičienė R., Kilikevičius A., Modeling of Performance of two-mass variable speed drive in closed loop system, Electrical and Control Technologies (2010), 130-133.

[4] Tanaka, K., Wang, H. O., Fuzzy control systems design and analysis: a linear matrix inequality approach (2002).

[5] Bose B. K., Modern Power Electronics and AC Drives Prentice Hall PTR (2002).

[6] Rinkevičienė R., Batkauskas V., Influence of the Inverter Boost Voltage on the transients of variable speed drive, Electronics and Electrical Engineering (2009),No. 4(92), 75-78.

[7] Rinkevičienė R., Petrovas A., Modelling of Frequency controlled induction drive with ventilator load, Electronics and Electrical Engineering (2009), No. 6(94), 69-73.

[8]Keming X., Lin T., Jianwei Z., The Takagi-Sugeno fuzzy model identification method of parameter varying systems, Proc. Rough Sets Current Trends RSCTC'98 (1998), 155-163.

[9]Lisauskas S., Rinkevičienė R., Model of ventilation system drive with Fuzzy controller, Electronics and Electrical Engineering (2010),No. 10(106), 13-16.

[10]Chen G., Introduction to fuzzy sets, fuzzy logic, and fuzzy control systems, CRC press (2001).

[11]Nour M. I. H., Ooi J., Chan K. Y., Fuzzy logic control vs. conventional PID control of an inverted pendulum robot, Int. Conference on Intelligent and Advanced Systems (2007), 209-214.

***Authors**: prof. habil. dr Roma Rinkevičienė, Vilnius Gediminas technical university, faculty of Electronics, Naugarduko str. 41, LT-03227 Vilnius, E-mail: roma.rinkeviciene@el.vgtu.lt; Jonas Kriaučiūnas, Vilnius Gediminas technical university, faculty of Electronics, Naugarduko str. 41, LT-03227 Vilnius, E-mail: jonas.kriauciunas@el.vgtu.lt.*