FUZZY LOGIC CONTROLLER FOR VOLTS/HZ INDUCTION MOTOR CONTROL USED IN ELECTRICALLY DRIVEN MARINE PROPELLER

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ABSTRACT

This paper develops the usage of induction motor to drive the marine propeller for producing ship propulsion. In the electric propulsion system, load torque of induction motor is very dynamic because it is influenced by the torque produced propeller and disturbances. The disturbances come from ocean waves, ocean currents, wind, and ship motions. In this paper, a fuzzy logic controller (FLC) is designed to control the speed of induction motor using volt/Hz (V/f) control method. V/f method maintains a constant ratio of voltage and frequency to produce the optimum speed and torque of induction motor. The voltage and frequency is directly controlled by voltage inverter. Fuzzy logic (FL) is one of the artificial intelligence. FL performance is affected by its membership functions. Adaptive process in FL makes improvement of induction motor performance whenever there are changing parameters caused by change of load torque. To clarify robustness of FLC, the induction motor is employed in electric propulsion system. In this system, load torque of induction motor is torque produced by propeller, whereas propeller torque depends on the induction motor speed. Simulation results of designed FLC show that the induction motor rapidly reaches the speed reference, has small steady state error and overshoot. And also load disturbance can be rejected.

Keywords: Electric Propulsion System, Induction Motor, Volts/Hz, Fuzzy logic

INTRODUCTION

Nowadays, many marine transportation systems utilize electrical energy particularly in electric propulsion system. In this system, electric motor is used to drive the marine propeller to yield the ship propulsion. The electric motor can be directly coupled with the ship propeller (Faiz, J. et al., 1999; Adnanes, A.K., 2003; He-ping, H., 2007). The squirrel cage induction motor is the most popular electric motors because it has simple in construction, inexpensive, high efficiency and free maintenance. However, induction motor is difficult to control a constant speed whenever the load is changed. Many methods have been proposed by many researchers to solve such kind of problem. One of the popular methods to solve the problem is volts/Hz (*V/f*) method. This method maintains a constant ratio of voltage and frequency to produce the optimum speed and torque of induction motor. The voltage and frequency is directly controlled by voltage source inverter (VSI) (Fonseca, J. Et al., 1999; Ioannides, M.G. et al., 2003; Oros, R.C. et al., 2006; Nuno, P. et al, 2006; Khan, M., 2007; Win, T. et al., 2008; Kohlrusz, G. et al., 2011).

Variable speed control of induction motor drive is equipped with speed controller. Most popular the speed controller is PI controller. However, PI controller cannot produce the desired control performance whenever system parameters are changed or due the nonlinear operation. The nonlinearities or changing system parameters occur whenever a variable speed drive is connected to an induction motor. Many researchers have been proposed many strategy controls to solve the disadvantage of the PI controller using artificial intelligence

(AI) such as fuzzy logic, neural network and genetic algorithm. These methods are very promising for the identification and control nonlinear dynamic system without acknowledge the internal system behaviors (Zerikat, M. et al, 2005; Chitra, V. and Prabhakar, R.S., 2006; Nour, M. et al, 2008; Gadoue, S.M. et al, 2009; Purwahyudi, B. et al, 2011).

This paper discusses the usage of fuzzy logic (FL) in the speed control of induction motor. To clarify the robustness of this method, the induction motor is employed in electric propulsion system because its complexity for the speed and torque. In this system, load torque of induction motor is torque produced by propeller, whereas propeller torque depends on the speed of induction motor and pitch angle of the propeller.

PROPOSED FUZZY LOGIC SPEED CONTROL OF INDUCTION MOTOR

Constant *V/f* Operations

Constant *V/f* operations are based on voltage and frequency. Speed can be changed by increasing and decreasing frequency of input voltage. However, these variations yield the change of impedance. The change of impedance causes increasing and decreasing current. If the current is small, torque of induction motor will decrease. If frequency is decreased or voltage is increased, coils of induction motor can burn or saturation can occur in the core and coils. This matter can be solved by changing frequency and voltage together. Stator voltage value is expressed in Equation (1), where control of *V/f* constant provides stator flux constant (Win, T. et al, 2008; Kohlrusz, G. et al, 2011).

$$\frac{V}{f} = 4.44\, N \psi_S k \quad \ldots\ldots. (1)$$

Where, V, f, N, ψ_s, and k are stator voltage, frequency, number of coils, stator flux and constant, respectively. Whereas, electromagnetic torque of induction motor as speed function is shown in Equation (2).

$$T_m = \frac{3}{2\omega} I_r^2 \frac{R_r}{s} \ldots\ldots.. (2)$$

Where, T_m, ω, I_r, R_r and s are electromagnetic torque, angular speed, rotor resistance and slip, respectively.

Equation (2) shows that torque is inversely proportional to frequency and proportional to voltage. Speed and torque control can be solved by changing linear of two parameters shown in equation (3).

$$\frac{T}{f} = \frac{V^2}{2\pi f^2} \approx \frac{V}{f} \quad \ldots\ldots. (3)$$

With this method, torque can be obtained at every the operation point until to rated speed point and also induction motor can be operated exceeding the nominal speed. When induction motor speed is above rated, torque will decrease inversely proportional to increasing frequency, because voltage input cannot exceed the operation voltage of electric motor drive.

Block diagram of *V/f* control with marine propeller is shown in Figure 1. This control method consists of a slip control loop, because slip is proportional to torque of induction motor. Rotor speed feedback signal (ω_r) from speed sensor is compared with desired speed value (ω_r*). Its comparison result is processed in a controller to produce slip (ω_{sl}), so that induction motor can achieve desired speed (Oros, R.C. et al, 2006; Tunyasrirut, G. et al., 2008; Kohlrusz, G. et al., 2011).

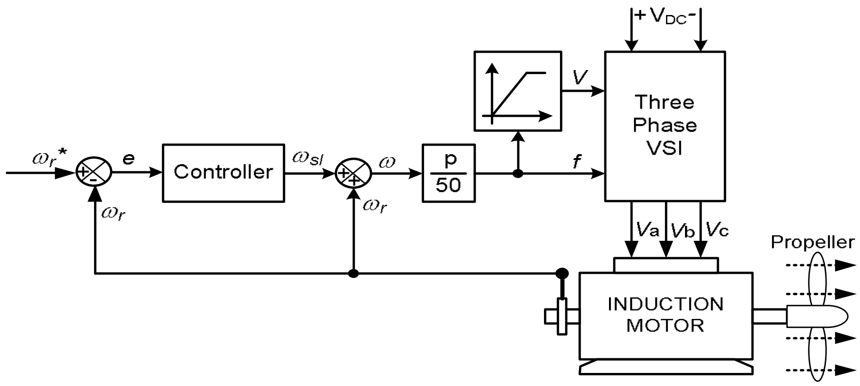

Figure 1. Block diagram of *V/f* control connected with marine propeller

Design of Fuzzy Logic Controller

Fuzzy logic control is one of most popular fields where fuzzy theory can be successfully applied. Fuzzy logic techniques attempt to imitate human thought processes in technical of environmental. Fuzzy logic can also solve nonlinear control problems or whenever the system model is unknown or difficult to build. In this paper, a fuzzy logic technique is used to control the speed of an induction motor. The fuzzy rules can be obtained through the knowledge of the process. The process knowledge is automatically extracted from sample process. The fuzzy logic control consists of three steps: fuzzification, control rules evaluation and defuzzification (Fonseca, J. Et al., 1999; Chitra, V. and Prabhakar, R.S., 2006; Oros, R.C. et al, 2006; Tunyasrirut, S. et al, 2008; Maloth, R., 2012).

In this paper, fuzzy logic controller has five membership functions (MF's) for two inputs and an output. Two inputs and an output are error (e), change of error (de) and slip of induction motor (ω_{sl}), respectively. The membership functions are built to represent its input and output value. Figure 2 shows the fuzzy sets and corresponding triangular MF description of each signal. The fuzzy sets are as follows: Z = Zero, PL = Positive Large, PS = Positive Small, NL = Negative Large and NS = Negative Small, respectively.

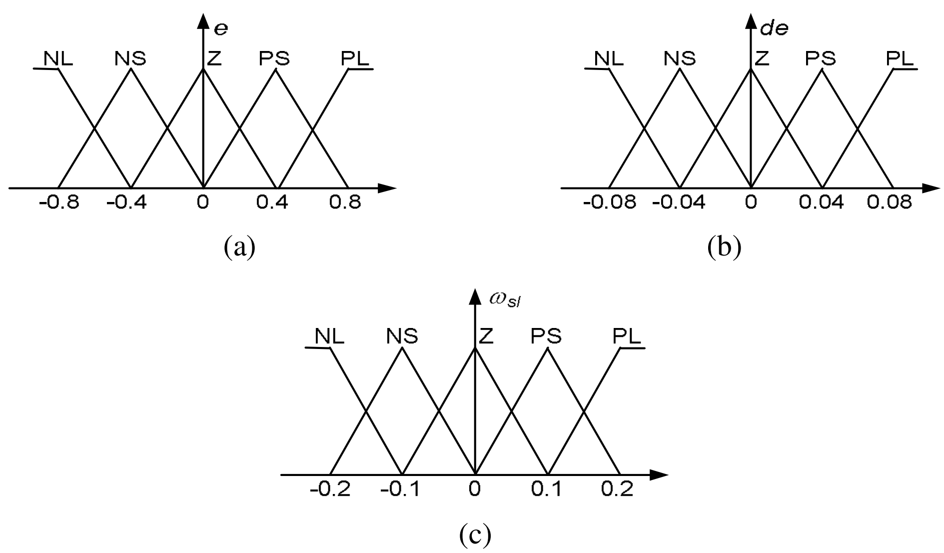

Figure 2. Membership functions

The universes of discourse of all the membership functions are expressed in per unit values. There are five MF's for each e, de and ω_{sl}. All the MF's are symmetrical for positive and negative values of variables. Whereas, the fuzzy rule base of the speed controller is shown in Table 1. Table 1 show that there may be 5 x 5 = 25 possible rules.

Table 1. Rule base of fuzzy speed controller

Error (e)	*change of error (de)*				
	NL	*NS*	*Z*	*PS*	*PL*
NL	PL	PL	PL	NS	Z
NS	PL	PL	NS	Z	PS
Z	PL	NS	Z	PS	PL
PS	NS	Z	PS	PL	PL
PL	Z	PS	PL	PL	PL

Load Torque Model of Electric Propulsion

The electric energy generated by the power plant is utilized to propel the marine vehicle. It must be utilized to rotate a shaft connected between induction motor and propeller. In the electric propulsion system, load torque has a specific characteristic. Load torque of induction motor is torque produced by propeller which depends on its rotation speed and pitch angle. According to the work principle of propeller, the load torque produced by it can be modeled as given by Equation (4) (Faiz, J. et al., 1999; Adnanes, A.K., 2003; Pivano, L. et al, 2006; He-ping, H., 2007; Yu S.D. et al, 2009; Sorenson A.J., 2009).

$$T_P = K_T \rho \omega^2 D^5 \quad \ldots\ldots (4)$$

Where, K_T, ρ, ω, and D are the propeller torque coefficients, seawater density, speed of propeller, and diameter of propeller.

At the ship having full load and the speed reaches the reference speed, the ship will archive steady state condition. This condition causes K_T having constant value and load torque of propeller is approximately the square of the propeller speed (Ren, J. et al., 2010; De-xi, S. et al., 2008).

SIMULATION RESULTS AND DISCUSSIONS

Some simulation results are shown to examine the effectiveness of the proposed fuzzy logic controller (FLC). Strategies of simulation are conducted in the operating condition of normal and disturbance. A block diagram of simulation model can be seen in Figure 3. The induction motor used for the simulation has the following parameters (in per unit, pu): 2 poles, stator resistance of 0.01, rotor resistance of 0.02, stator inductance of 0.10, rotor inductance of 0.10, mutual inductance of 4.50, inertia moment of 0.30, and friction coefficient of $1e^{-5}$.

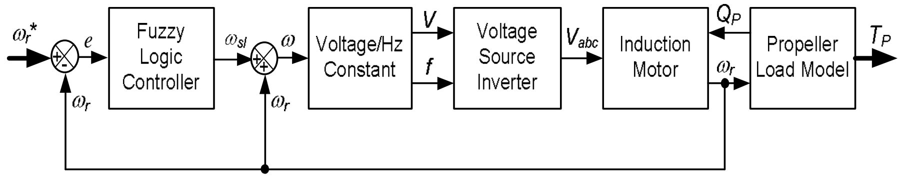

Figure 3. Block diagram of simulation model

Comparison of speed response between PI controller and FLC for speed reference of 0.8 pu is shown in Figure 4. Figure 4 shows that FLC provides settling time of 0.437 s, overshoot of

1.25 % and small steady state error. Whereas, PI controller provides settling time of 0.486 s, overshoot of 3.75 % and small steady state error. From their simulation results see that FLC give the good improvement of performance compared to PI controller.

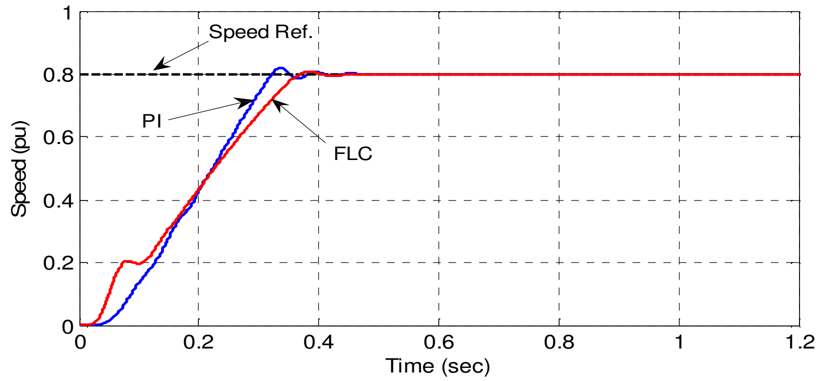

Figure 4. Speed response for normal condition

Figure 5 shows the load torque applied to the system for both controllers. From Figure 5 see that the load torques for both controllers is torque produced the propeller and depends on the propeller speed.

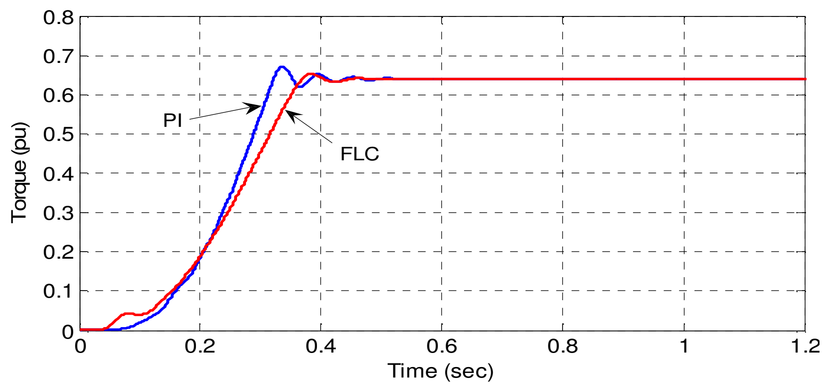

Figure 5. Load torque for normal condition

Figure 6 shows comparison of electromagnetic torque response between PI controller and FLC. In this figure, FLC needs the greater electromagnetic torque than PI controller. This electromagnetic torque is used by FLC to rapidly achieve the speed reference.

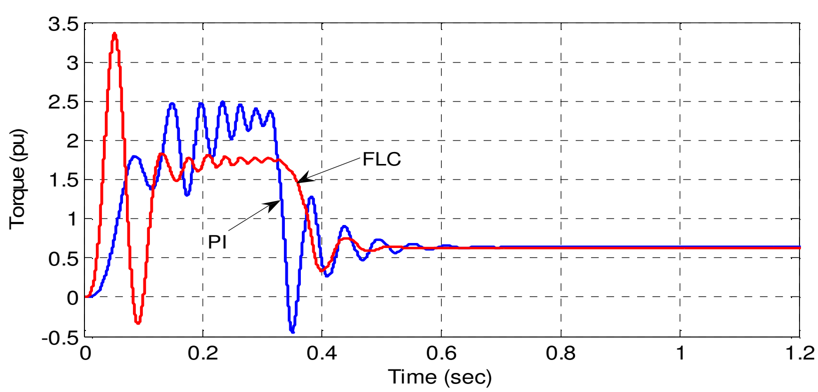

Figure 6. Electromagnetic torque response for normal condition

For disturbance conditions, the load torque of induction motor suddenly changes 0.05 pu at t = 1.6 s and also returns again at t = 1.7 s. Change of load torque influences electromagnetic torque of induction motor shown in Figure 7. PI controller requests the greater electromagnetic torque than FLC. Disturbance also causes change of induction motor speed shown in Figure 8. Simulation result shows that FLC provides better disturbance rejection than PI controller. Both controllers also still produce speed fluctuation, but FLC quickly achieves the speed reference if compared with PI controller.

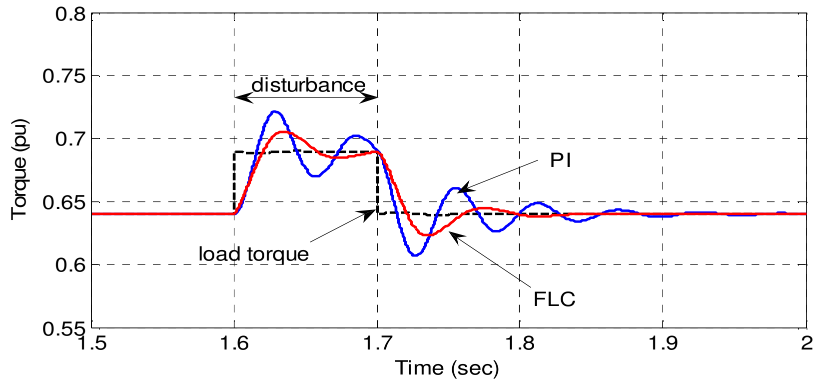

Figure 7. Electromagnetic torque for disturbance condition

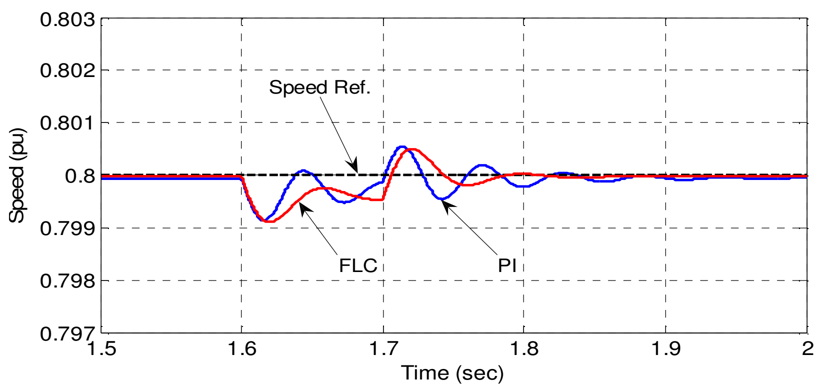

Figure 8. Speed responses for disturbance condition

CONCLUSION

Voltz/Hz (V/f) method for electrically driven marine propeller has been presented. This method maintains a constant ratio of voltage and frequency to produce the optimum speed and torque of induction motor. Fuzzy logic technique is used as speed controller of induction motor drives. Adaptive process in fuzzy logic controller (FLC) can make improvement of induction motor performance whenever there are changing parameters caused by change of load torque. Load torque applied to the induction motor uses the electric propulsion system which depends on the rotor speed of the induction motor directly coupled to the propeller. Simulation results show that the designed FLC is better than PI controller. FLC provides a good dynamic performance of induction motor with a rapid settling time, small overshoot and steady state error and also rejection of load disturbance.

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