



MOGA TUNED PI-FUZZY LOGIC CONTROL FOR 3 PHASE INDUCTION MOTOR WITH ENERGY EFFICIENCY FOR ELECTRIC VEHICLE APPLICATION

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ABSTRACT

Induction motor (IM) is one of the Alternating Current (AC) motor having simple and rugged structure; moreover, they are economical and immune to heavy overloads. However the use of induction motor also has its disadvantages, mainly the controllability, due to its complex mathematical model and its nonlinear behavior. The conventional controllers are unable to handle this problem. To overcome this problem a nonlinear PI- fuzzy logic controller and the used of Multi objective Genetic Algorithm (MOGA) optimization to minimizing the error is used to control the speed of electric vehicle traction motor. The development of this control strategy with Energy Efficiency is presented in this paper. The proposed controller has simple structure and also due to its modest fuzzy rule in rule- base is relatively easy for implementation. The control is performed by Matlab/Simulink software. The simulation test results have been satisfactory in simulation results and demonstrated to confirm the performance of the MOGA optimized fuzzy can reduce the power consumption with good tracking performance. This controller has high accuracy, suitable performance, high robustness and high tracking efficiency.

Keywords: 3 phase induction motor, fuzzy logic control, MOGA optimization, electric vehicle.

INTRODUCTION

AC induction motors are the most common motors used in industrial motion control systems, as well as in main powered home appliances. Simple and rugged design, low-cost, low maintenance and direct connection to an AC power source are the main advantages of AC induction motors (Rakesh Parekh, 2003). Although AC induction motors are easier to design than DC motors, the speed and the torque control in various types of AC induction motors require a greater understanding of the design and the characteristics of these motors (Man Mohan *et al.*, 2012).

Like most motors, an AC induction motor has a fixed outer portion, called the stator and a rotor that spins inside with a carefully engineered air gap between the two. Virtually all electrical motors use magnetic field rotation to spin their rotors. A three-phase AC induction motor is the only type where the rotating magnetic field is created naturally in the stator because of the nature of the supply. DC motors depend either on mechanical or electronic commutation to create rotating magnetic fields. A single-phase AC induction motor depends on extra electrical components to produce this rotating magnetic field. Two sets of electromagnets are formed inside any motor. In an AC induction motor, one set of electromagnets is formed in the stator because of the AC supply connected to the stator windings. The alternating nature of the supply voltage induces an Electromagnetic Force (EMF) in the

rotor (just like the voltage is induced in the transformer secondary) as per Lenz's law, thus generating another set of electromagnets; hence the name - induction motor. Interaction between the magnetic field of these electromagnets generate twisting force, or torque. As a result, the motor rotates in the direction of the resultant torque (Man Mohan *et al.*, 2012).

Three-phase AC induction motors are widely used in industrial and commercial applications. At present, induction motor drives are the mature technology among commutatorless motor drives. Compared with DC motor drives, the AC induction motor drive has additional advantages such as lightweight nature, small volume, low cost, and high efficiency. These advantages are particularly important for Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) applications. There are two types of induction motors, namely, wound-rotor and squirrel cage motors. Because of the high cost, need for maintenance, and lack of sturdiness, wound-rotor induction motors are less attractive than their squirrel-cage counterparts, especially for electric propulsion in EVs and HEVs (Ali Emasi *et al.*, 2009).

Controlling the speed of a motor using modern AC drives not only provides users with much improved process control, but can also reduce wear on machines, increase power factor and provide large energy savings (Anon, 2013) AC drives can significantly reduce energy consumption by varying the speed of the motor to



precisely match the effort required for the application. To vary the speed of the motor dynamically, a closed-loop regulator (or control loop) that takes into account the measured output of a process is required.

The most common method of regulation is the PI (Proportional-Integral) and PID (Proportional-Integral-Derivative) control loop. Conventional PID approach in vector control is to use PID control schemes to operate the static and dynamic performance of control system (D. Y. Ohm, 1994). Due to the derivatives of the signals are difficult to pick up, the PI control becomes the most widespread control combination. In recent years, extensive research has been developed in order to overcome the deficiency of conventional PI controller and improve its performance (D. Y. Ohm, 1994). However, the nonlinear effects of motor system and model uncertainty such as external disturbances, unpredictable parameter perturbations and un-modeled plant nonlinear dynamics, the common PI and PID control is not able to get good transient response and small overshoot. Moreover, induction motor is a complex higher-order, nonlinear, strong coupling, and multi-variable control target. The fuzzy control is proved to an efficient way to implement engineering heuristics into control solution (B.S.K.K. Ibrahim *et al.*, 2012).

Materials and method

Modeling, and hence simulation study can greatly facilitate to test and tune various controllers. The role of simulation was to design, test, and tune the control strategies, thus reducing time-consuming trial and error adjustments during real experiments.

Induction motor

The main advantages of IM include: (1) Robust structure and relatively low cost; (2) Good dynamic performance which can be achieved by for example vector control and direct torque control; (3) Light weight, small volume and high efficiency. The disadvantages include: (1) The constant power range can only extend to 2-3 times the base speed. But in EV machines, it requires an expansion of 4-5 times above the base one. Hence, the design of IM is more complicated to satisfy the EV demand; (2) the control schemes are a little difficult due to the variable equivalent parameters (Goldberg, D. E., 1989).

Vector control and AC motor drive

The principle of vector control of electrical drives is based on the control of both the magnitude and the phase of each phase current and voltage. For as long as this type of control considers the three phase system as three independent systems the control will remain analog and thus present several drawbacks.

The most common accurate vector control is Field Orientated Control, a digital implementation which

demonstrates the capability of performing direct torque control, of handling system limitations and of achieving higher power conversion efficiency. The electrical drive controls become more accurate in the sense that not only are the DC current and voltage controlled but also the three phase currents and voltages are managed by so-called vector controls. This vector control scheme Field Oriented Control is discussed here. It is based on three major points: the machine current and voltage space vectors, the transformation of a three phase speed and time dependent system into a two co-ordinate time invariant system and effective Pulse Width Modulation pattern generation. This control structure, by achieving a very accurate steady state and transient control, leads to high dynamic performance in terms of response times.

The Field Orientated Control (FOC) consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. These projections lead to a structure similar to that of a DC machine control. Field orientated controlled machines need two constants as input references: the torque component (aligned with the q co-ordinate) and the flux component (aligned with d coordinate).

Fuzzy logic control

Recently, Fuzzy logic control has found many applications in the past decade. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1 (Man Mohan *et al.* 2012). MATLAB Fuzzy logic Toolbox is used to design fuzzy logic controller. Basically, the Fuzzy Logic controller consists of four basic components: fuzzification, a knowledge base, inference engine, and a defuzzification interface. Each component affects the effectiveness of the fuzzy controller and the behavior of the controlled system. In the fuzzification interface, a measurement of inputs and a transformation, which converts input data into suitable linguistic variables, are performed which mimic human decision making. The results obtained by fuzzy logic depend on fuzzy inference rules and fuzzy implication operators.

Fuzzy logic controller is also introduced to the system for keeping the motor speed to be constant when the load varies. Because of the low maintenance and robustness induction motors have many applications in the industries. The fuzzy logic is a technique to embody human-like thinking into a control system. A fuzzy controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions. Fuzzy logic is widely used in machine control. Fuzzy logic has the advantage that the solution to the problem can be cast in terms that human



operators can understand, so that their experience can be used in the design of the controller.

The knowledge base provides necessary information for linguistic control rules and the information for fuzzification and defuzzification. In the defuzzification interface, an actual control action is obtained from the results of fuzzy inference engine. In this controller, two input variables have been defined which are speed error and change of speed error. Meanwhile the output of this fuzzy logic controller is a demand current as shown in Figure-1. The aim of this paper is that it shows the dynamics response of speed with design the fuzzy logic controller to control a speed of induction motor.

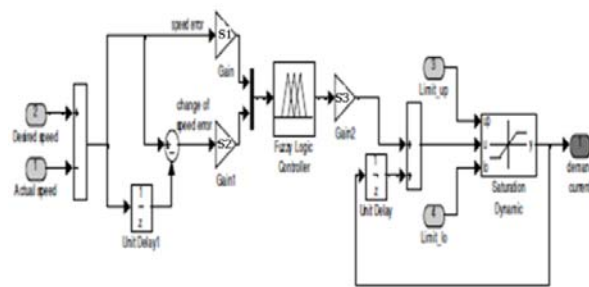


Figure-1. Block diagram of discrete-time PI-FLC.

Figure-2 shows the input and output memberships of the fuzzy controller. The fuzzy rules of 2 inputs and an output are in Table-1 with 7x7 fuzzy control rules.

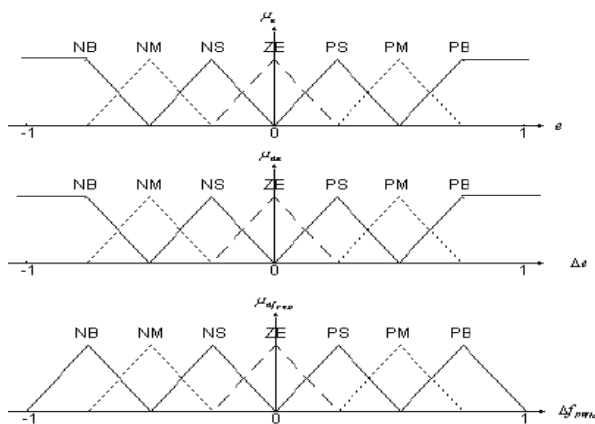


Figure-2. Inputs and output membership function.

Table-1. FLC rule table.

	Δe	NS	NM	NS	ZE	PS	PM	PB
e	Output	NB	NB	NM	NM	NS	NS	ZE
	NB	NB	NM	NM	NS	NS	ZE	PS
	NM	NM	NS	NS	ZE	PS	PS	PM
	NS	NS	ZE	PS	PS	PM	PM	PB
	ZE	ZE	PS	PS	PM	PM	PB	PB
	PS	PS	PM	PM	PB	PB	PB	PB
	PM	PM	PB	PB	PB	PB	PB	PB
	PB	PB	PB	PB	PB	PB	PB	PB

NB=Negative big, NM=Negative medium, NS=Negative small, ZE=Zero, PS=Positive small, PM=Positive medium, PB=Positive big,

Optimisation process

If a reliable expert knowledge is not available or if the controlled system is too complex to derive the required decision rules, development of a fuzzy logic controller become time consuming and tedious or sometimes impossible. In the case that the expert knowledge is available, fine-tuning of the controller might be time consuming as well. Therefore in this research, MOGA (Multi Objectives Genetic Algorithm) has been used for to tune the fuzzy controller's parameters with appropriate objectives.

MOGA optimization for control with energy efficiency mechanism

MOGA differs from standard GA (B.S.K.K. Ibrahim *et al.*, 2012) in the way fitness is assigned to each solution in the population. Since these control design stages may not be independent, it is important to consider them simultaneously to find the optimal solution using MOGA. Fitness sharing technique as proposed by Fonseca and Fleming (1993) is applied (Fonseca *et al.*, 1993). Optimization of fuzzy logic controller using MOGA is shown in Figure-3. The automatic optimization was implemented in MATLAB with MOGA Toolbox.

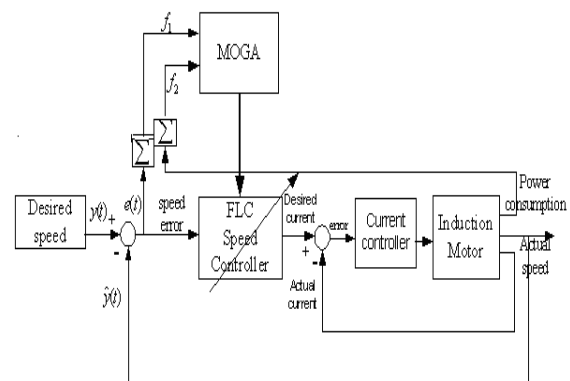


Figure-3. MOGA optimization with two objectives.



The first objective of MOGA optimization process is to minimize the error between the desired speed and actual speed. The error is defined as:

$$e(t) = y(t) - \hat{y}(t) \quad (1)$$

where $y(t)$ is the desired speed and $\hat{y}(t)$ is the actual speed. The 'goodness of fit' of the identified model is determined using the objective function by minimizing the MSE:

$$f_1 = \left\{ \frac{\sum_{i=1}^N (y(t) - \hat{y}(t))^2}{N} \right\} \quad (2)$$

The second objective function $f_2(y)$ is defined as the time-integral of the power consumption of induction motor without compromising the first objective:

$$f_2(y) = \int_0^t P(t) dt \quad (3)$$

where $P(t)$ is the total power consumption of induction motor for a cycle of simulation.

GA optimization for control without energy efficiency mechanism

The same controller scheme without taking into account energy saving was developed as shown in Figure-4. The fuzzy controller was optimised with only one objective; minimizing the error. The performances of both control schemes were then investigated in terms of energy reduction.

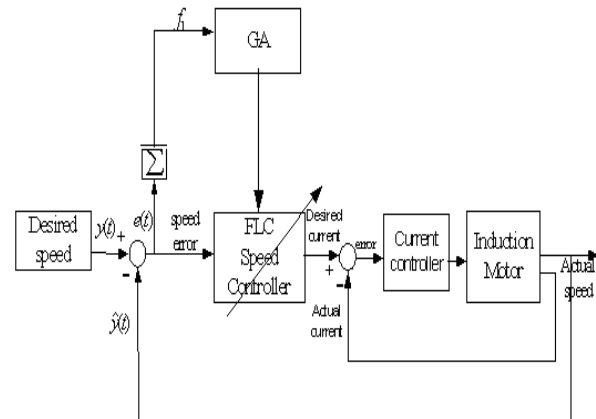


Figure-4. GA optimization of FLC for induction motor.

RESULTS AND DISCUSSIONS

A new method comprising a MOGA to automatically design fuzzy controllers to obtain the less power consumption is assessed. MOGA with two point crossover and mutation operators was used to optimize 3 parameters. Population size was set to 50 and crossover and mutation probabilities were 0.8 and 0.001 respectively. A MOGA with 50 binary coded individuals was run for up to 100 generations for this control strategy. The best solution achieved from the optimization with the minimum MSE achieved as 2.51.

Then the same control scheme without considering power consumption by using GA optimization process is assessed. The population size of GA was set to 50 and crossover and mutation probabilities were 0.8 and 0.001, respectively. The automatic GA optimization process was set to generate up to 100 generations of solutions. The minimum MSE achieved as 2.49. Finally a conventional control scheme based on PI control has been assessed to the same model. This comparative test has been conducted in term of the power consumption. The performances of these three controllers have been tested and the results are shown in Table-2.

Table-2. Results of three controller's performance.

Performance parameter	MOGA-Fuzzy with energy efficiency	GA-Fuzzy without energy efficiency	PI-Fuzzy
Sum of error (rpm)	2.51	2.49	2.50
Rise time (s)	0.31	0.31	0.30
Overshoot (%)	0	0	0
Steady state error	0	0	0
Power consumption (kW)	1.26	1.28	1.30



The results show that all these controllers show a good performance on tracking the desired speed. However MOGA optimized FLC has shown a reduction in the power consumption around 1.6% if compared with GA optimized FLC and 3.17% power reduction if compared with PI control. Therefore this simulation study has proven that MOGA optimized FLC able to reduce the power consumption.

The computer simulation tests on the MOGA optimized FLC were performed. The tests were aimed to assess the capability of the controllers to track a desired speed. The good performance has been achieved without overshoot and oscillation and able to reach steady state at 3sec as can be seen in Figure-5.

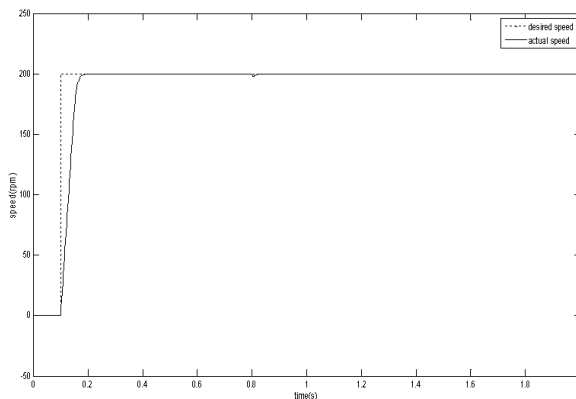


Figure-5. Step response of MOGA optimized FLC.

In another test, random changing has exerted in motor command speed based on NEDC (New European Driving Cycle). It can be noted that this MOGA optimized PI-Fuzzy speed control achieved the objective; to track the motor speed in very short rise time, without overshoot and thus maintain a steady speed without error as shown in Figure-6.

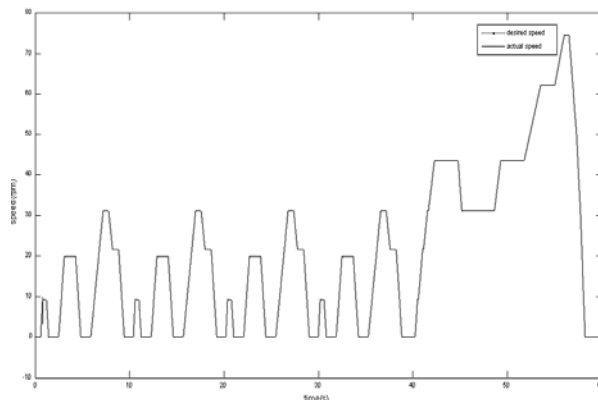


Figure-6. NEDC speed command.

CONCLUSIONS

Three-phase induction motor speed control is a difficult task due to the highly nonlinear and time-variant nature of the system. In this study two control strategies; with and without energy efficiency mechanism have been developed. The control scheme with energy efficiency mechanism has been proposed to control the induction motor with less energy consumption. In these control design approach, PI-fuzzy logic controller has been optimized using genetic optimization technique with multi objectives. The power consumption has been taken as the optimization criterion to design this controller. Simulation results are demonstrated to confirm the performance of the MOGA optimized fuzzy can reduce the power consumption with good tracking performance. Future work will investigate the performance of this control approach in a practical environment.

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