Performance Evaluation of Fuzzy-PID in Speed Control of Three Phase Induction Motor

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Abstract. Induction motor (IM) is one of AC motor type which mainly applied for adjustable speed applications and consumes approximately 60% of the total industrial electricity consumption. IM is chosen due to its simple structure, reliability, high efficiency, and low cost. There are two main methods in speed and torque control of IM which are scalar control and vector control. Scalar control is divided again as Field Oriented Control (FOC) and Direct Torque Control (DTC). In this research, DTC is chosen due to its simplicity compared with FOC. PID is reported that used by 90% industrial section because of its simplicity, applicability, and reliability. Fuzzy Logic Control (FLC) is one of the artificial intelligences that can be used to online tune the PID parameters. The simulation of speed control of the IM base on DTC has been carried out. The simulation result shows that in both no-load and loaded tests, Fuzzy-PID gives better results in speed tracking. In terms of control energy, Fuzzy-PID consumes more energy by 4.5% with better performance in the no-load test. Whereas for the loaded tests, it also has better performance with less energy by 1.03 % compared with PID.

1. Introduction
There are many industrial sectors using electrical motors. By the type of supply current, there are two kinds of electric motor which are AC and DC motor. Induction motor (IM) is one of AC motor type which mainly applied for adjustable speed applications and consumes approximately 60% of the total industrial electricity consumption [1]. An induction motor can be found in the industrial and traction system of electric vehicles. IM is chosen due to its simple structure, reliability, high efficiency, and low cost.

There are two main methods in speed and torque control of IM which are scalar control and vector control [2]. Scalar control has a simple structure with low precision. Conversely, vector control offers high performance with complicated algorithms. Vector control is divided again as Field Oriented Control (FOC) and Direct Torque Control (DTC). FOC has fast responses, a large speed control range, and high efficiency. Although this method has a high sensitivity to the parametric variation. On the other hand, DTC has good performance with respect to the variation of the IM’s parameters [3]. The drawback of DTC is the high torque and flux ripple. In this research, DTC is chosen due to its simplicity compared with FOC.

PID is reported that used by 90% industrial section because of its simplicity, applicability, and reliability [4][5]. However, PID has two major shortcomings, namely the determination of the
parameters of PID, and its performance decreases as system conditions change [6]. Therefore, the online tuning of PID parameters is needed to make the control system adaptable with condition changes of the plant. Fuzzy Logic Control (FLC) is one of the artificial intelligence that can be used to online tune the PID parameters as proven in [7].

Some research has done research in Fuzzy-PID for Induction Motor speed control for example in [8] and [9]. In [8], Fattah and Qader combine PID-fuzzy as a hybrid controller with a cascaded structure. From the simulation result, they conclude that hybrid PID-Fuzzy has a better performance compared to a conventional PI controller. However, in their proposed hybrid controller, the gain of PID is constant; hence, the controller cannot adapt to plant condition changes well. Umesh and Sanjay in [9] also compare the performance of PID and Fuzzy-PID. They said that the Fuzzy-PID controller is smooth and easy that PID controller. However, their simulation only was done in a small-signal system using the transfer function.

In this research, the performance of Fuzzy-PID in speed control of three-phase IM will be evaluated. Both performances and energy will be evaluated. This paper is organized as follows. Section II presents the research method including system design and control design. The result and analysis are described in Section III. Finally, the conclusion is provided in Section IV.

2. Research Method

2.1. Three Phase Induction Motor Drive

In this research, a three-phase induction motor drive or know as variable speed drive (VSD) is modelled in MATLAB/ Simulink environment as shown in Figure 1. This model is developed base on MATLAB motor drive example with some modifications to cope with the research objective. Speed reference and load torque block in contain speed reference for speed control and mechanical load model respectively. While the power supply used is the three-phase network model with specification 460 V, 60 Hz. DTC Induction Motor Drive is the main block for speed control. Demux block is used to choose the information that will be displayed at the Scope. While rate transition is to convert the two-difference sample time for simulation and for stored in the logger.

![Figure 1. Three phase induction motor drive in MATLAB/ Simulink](image)

Figure 2 shows the detailed structure inside DTC Induction Motor Drive. There are two controller blocks which are DTC itself and speed controller. DTC control the torque and flux of induction motor, whereas the speed controller controls its speed. The output bus selector is to choose the data that will be sent to the scope to be displayed. Rad2Rpm block is to convert speed unit from rad/s which the original output from the IM model in MATLAB to rpm. All the model mentioned is inside the controller in real implementation. The rest of the block is for hardware models which are three-phase rectifiers, braking chopper, inverter, measurement, and induction motor. Braking chopper is used to
absorb energy from regenerative braking when the brake takes place. Table 1 showing the specification of the induction motor used in this simulation.

2.2. Speed Controller

There are two controllers as shown in Figure 2, speed controller, and DTC. Figure 3 is the simplified block diagram of DTC speed control of the induction motor. The DTC methods include torque and flux control. The conventional DTC method with hysteresis control and switching table is adopted in this research due to its simplicity. While the speed controller in Figure 3 is PID. In this research, the Fuzzy-PID controller for speed control will be adopted and compared with the traditional PID controller.

The Fuzzy-PID controller is the controller that combines the PID and Fuzzy algorithms. In [10], the Fuzzy-PID controller is means using Fuzzy to tune PID parameters online that makes PID more adaptable. Figure 4 shown the Fuzzy-PID system which has two input which is error and change of error and two output which are $K_p$ and $K_i$. In this research, only $K_p$ and $K_i$ parameters used to reduce fuzzy rule and make the computation time faster.

| Parameters                  | Value  |
|-----------------------------|--------|
| Nominal power, kVA          | 149.2  |
| Line Voltage, Vrms          | 460    |
| Frequency, Hz               | 60     |
| Stator resistance (Rs), Ω   | 0.0015 |
| Stator inductance (Lls), H  | 0.0003 |
| Rotor resistance (Rr'), Ω   | 0.0092 |
| Rotor inductance (Llr'), H  | 0.0003 |
| Mutual inductance (Lm), H   | 0.0105 |
| Inertia (J), kgm²           | 3.1    |
| Friction factor, Nms        | 0.08   |
| Pole pair                   | 2      |
| Power factor                | 0.88   |
3. Result and Analysis
The simulation is carried out in MATLAB/ Simulink environment. In this research, the speed control of the induction motor is subject to traction application. Therefore, the speed rate is limited. Two condition testing is used which are the no-load and loaded test, both with speed variation. In this test, the tolerance of ± 1% is used.

![Figure 3. DTC speed control of induction motor](image)

![Figure 4. Fuzzy – PID system](image)

3.1. No-load Test
The no-load test is representing a linear road in an electric vehicle. The no-load test result is shown in Figure 5 which includes speed, torque, and energy profile. In the speed profile, Figure 5 (a) both systems can track the speed references well. However, in a detailed view, Figure 6(a) and 6(b), it can be seen PID control response has overshoot when the setpoint increase and vice versa. On the other hand, Fuzzy-PID only has a small overshoot with no undershoot. PID has a maximum overshoot of 1.6% whereas Fuzzy-PID has a lower than 1%. This proved that Fuzzy-PID has better performance in speed control compared to conventional PID control.
In the torque profile, Figure 5(b) both control algorithm has the torque response with ripple. The ripple is one of the disadvantages of the DTC method due to variable switching frequency. The torque is high in the starting until reference speed reaches, this is the characteristic of constant torque operating region of induction motor even with no-load. Therefore, the induction motor has high torque at low speed with suitable for traction application. When the reference speed is reached, the torque is becoming zero because no-load attached. Whilst, when the speed decreases or brake applied, the torque is becoming negative which means regenerative braking is applied. The power generated from the regenerative brake is sent to brake chopper and burn in resistor since no energy storage system used. In detail view, in Figure 6(c), the Fuzzy-PID controller has better torque performance which faster in following the reference.

The last curve is for energy consumed by the motor. Energy in calculated from the power which measured in between the inverter and the induction motor, Figure 5(c). The Fuzzy-PID consumes more power to get a faster response compared with the PID control algorithm. In the last simulation, the energy consumed by PID and Fuzzy-PID is 231230 J and 241560 J respectively. This means Fuzzy-PID consumes 4.5% higher energy than PID with better performance.

![Figure 5. No-load test result](image)

3.2. Loaded Test

The loaded test is representing the road with some gradient in an electric vehicle application. Figure 7 shows the result of the loaded test. The speed reference is the same as the previous test. The differences can be seen clearly in the torque curve. The load gives effect in speed tracking as can be seen in the detailed view of the speed curve in Figure 8(a) and 8(b). Figure 8 (a) shows that the rapid
increase in the load at time 0.5s makes the speed decreases. Both algorithms affected by these load changes, but Fuzzy-PID is more stable. On the other hand, PID can reach the set-point well whereas Fuzzy-PID can’t, but still inside the tolerance which is ± 1%. Then at time 2.2s to 3.2s, Figure 8(b), Fuzzy-PID perform better with no undershoot.

In the torque response, both algorithms can perform well. Although, in detail view Figure 8(c), Fuzzy-PID shown faster responses. In the energy curve, Figure 7(c), the energy consumed by the two algorithms is nearly the same which are 421190 J and 416850 J for PID and Fuzzy-PID respectively. This means that in this test Fuzzy-PID consumes 1.03% lower than PID.

![Image](a) Detail view of speed curve at time 0.6s to 2s

![Image](b) Detail view of speed curve at time 2.4s to 3.4s

![Image](c) Detail view of torque at time 0s to 0.6s

**Figure 6.** Insert of speed curve in Figure 5
Figure 7. Loaded test result

(a) Detail view of speed curve at time 0.5s to 2s

(b) Detail view of speed curve at time 2.2s to 3.2s

(c) Detail view of torque at time 0s to 0.6s

Figure 8. Insert of speed curve in Figure 7
4. Conclusion
The simulation of speed control of the induction motor base on DTC has been carried out. Two difference condition which is no-load and loaded was tested. Both performance and energy needed by the controller are evaluated. The classical PID control algorithm is used as a comparison based to evaluate speed control performance. The simulation result shows that in both no-load and loaded tests, Fuzzy-PID gives better results in speed tracking. This method also gives better torque response compare with classical PID. In terms of control energy, Fuzzy-PID consumes more energy by 4.5% with better performance in the no-load test. Whereas for the loaded tests, it also has better performance with less energy by 1.03% compared with PID.

References
[1] M. A. Hannan, J. A. Ali, A. Mohamed, and A. Hussain 2017 Optimization techniques to enhance the performance of induction motor drives: A review Renew. Sustain. Energy Rev., no. April, pp. 1–16.
[2] A. Alwadie 2018 A Concise Review of Control Techniques for Reliable and Efficient Control of Induction Motor Int. J. Power Electron. Drive Syst., vol. 9, no. 3, pp. 1124–1139.
[3] N. El Ouanjli et al. 2019 Modern improvement techniques of direct torque control for induction motor drives - a review Prot. Control Mod. Power Syst., vol. 5.
[4] K. H. Ang, G. Chong, S. Member, and Y. Li 2005 PID Control System Analysis, Design, and Technology IEEE Trans. Control Syst. Technol., vol. 13, no. 4, pp. 559–576.
[5] S. M. Rakhtala and E. S. Roudbari 2016 Application of PEM Fuel Cell for Stand-alone Based on a Fuzzy PID Control Bull. Electr. Eng. Informatics, vol. 5, no. 1, pp. 45–61.
[6] A. Balestrino, A. Caiti, V. Calabró, E. Crisostomi, and A. Landi 2011 From Basic to Advanced PI Controllers: A Complexity vs. Performance Comparison Advance in PID Control, Intech, pp. 87–100.
[7] I. K. Bousserhane, A. Hazzab, M. Rahli, M. Kamli and B. Mazari 2006 Adaptive PI Controller using Fuzzy System Optimized by Genetic Algorithm for Induction Motor Control IEEE International Power Electronics Congress, Puebla, 2006, pp. 1-8.
[8] A. J. Fattah and I. A. Qader 2015 Performance and Comparison Analysis of Speed Control of Induction Motors using Improved Hybrid PID-Fuzzy Controller IEEE Int. Conference on Electro/Information Technology (EIT), pp. 575–580.
[9] B. Umesh and S. Sanjay 2013 Speed Control of Three Phase Induction Motor Using Fuzzy-PID Controller Int. J. Eng. Res. Technol., vol. 2, no. 11, pp. 3794–3799.
[10] U. K. Bansal and R. Narvey 2013 Speed Control of DC Motor Using Fuzzy PID Controller Adv. Electron. Electr. Eng., vol. 3, no. 9, pp. 1209–1220.