

The Fuzzy PID Controller Performance in BLDC Motor Rotor Speed Variable

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Abstract—This study presents the performance of a fuzzy PID controller on a variable speed of brushless DC (BLDC) motor. BLDC motors are widely applied in industry and transportation. BLDC motor control still mostly uses conventional PID. The weakness of conventional PID control is that when the target input changes, the output performance also changes. Therefore, a controller with a simple structure with high performance is still necessary to be explored. This study uses a simple fuzzy control structure with three inputs and one output from the conversion of conventional PID controls. Membership functions (MFs) operating ranges for input/output are defined through error, integral error, and differential error parameters. Fuzzy PID controller performance was compared to conventional PID controllers. Simulations were performed using Matlab/Simulink. The results showed that the Fuzzy PID controller had superior performance without overshoot, had a rise time of 0.005 seconds, and a settling time of 0.009 seconds. The energy saving of a fuzzy PID controller reached 99.8%.

Keywords—Fuzzy PID controller, performance, conventional PID controller, BLDC motor, speed variable

I. INTRODUCTION

Recently, BLDC motors have become one of the most commonly used in electric vehicles [1], [2]. BLDC motors are the choice because they have advantages over DC motors. The advantages offer low maintenance, high dynamic response, high torque, and longer operating life [3]. BLDC motors are also widely used in industrial applications [4]. This is the reason why researchers [5], [6], [7], [8], [9], [10], [11], [12] are interested in conducting a performance study of BLDC motors. BLDC motors in electric vehicles are not run in one-speed conditions but are prepared for different speed conditions. Researcher [13] has carried out a study for multi-speed conditions on BLDC motors, which showed that the response time resulted in an overshoot at the time of speed shift.

Measuring controller performance for various conditions of speed change in BLDC motors is quite difficult [6], [14]. BLDC motors for electric vehicles must be able to be controlled under different speed conditions. Knowing and measuring controller performance will be an option in deciding what type of controller to use in the application.

Researcher [13] has developed a nonlinear PID controller (NPID) which was applied to BLDC motors. The results showed that NPID has a response time performance that was able to reduce overshoot. However, the rise time was greater than that of the PID controller and the fractional order PID controller. The controller design is also more complicated by using additional parameters that must be identified first with the constraints on each proportional, integral, and derivative controller.

Efforts to find good performance controllers through research are still being carried out. For example, researchers [15], [16] have combined two controllers, namely a PID controller and a Fuzzy Logic Controller (FLC). The arrangement of the controllers shows the complexity of the design. This shows that the two Fuzzy and PID controllers that work together have better performance than the PID controller alone. The results of the research showed improvements in rising time but have not been able to reduce overshoot. Meanwhile, researcher [17] took a different approach to the design of the FPID controller, namely using a rather wide setting range and MFs in the form of bells. The results showed that the overshoot could be reduced but the rising time is large.

A common problem that is often found in the design of fuzzy controllers is the uncertainty of determining the operating range of each MFs [3], [18]. This is due to the unclear theoretical basis regarding the determination of the right range. Therefore, this problem becomes a realm that only the researcher knows. The determination of the MF limits is usually done by trial and error [3], [17], [18], [19].

Based on the presented references, there is no fuzzy controller design that offers a simple controller structure model applied in the BLDC motor to measure its performance. Therefore, this study presents a simple fuzzy logic controller design that has three inputs and one output from the conversion of a conventional PID controller. This Fuzzy PID controller model is the result of research that was conducted previously [20]. The operating range limit for each MFs was obtained from the conversion of error measurement and the PID controller gain. The form of MFs for each input was presented in the form of a symmetrical triangle. While the MFs output form was declared in a single fuzzy tone. This Fuzzy PID controller was applied to control the BLDC motor with multi-variable speed through Matlab/Simulink simulation. The results were then compared with conventional PID controllers to measure their performance.

II. CONTROLLER DESIGN

A. The Conventional PID controller and FLC conversion

Conventional PID controllers have been commonly used in industrial applications. The conventional PID control equation in the time domain is shown below.

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt} \quad (1)$$

The control output signal consists of proportional control, integral control, and derivative control. Variables such as error $e(t)$, integral error $\int e(t)$, and differential error $\dot{e}(t)$ can be described as fuzzy variables in the FLC design [20]. They are assumed for $u(t)$, $e(t)$, $\int e(t)$, and $\dot{e}(t)$ as

operating ranges for $OR_u = [-a_u, a_u]$, $OR_e = [-a_e, a_e]$, $OR_i = [-a_i, a_i]$, and $OR_d = [-a_d, a_d]$ respectively. The graphical defining the four fuzzy variables in MFs is shown in Fig. 1. The input fuzzy variables ($e(t)$, $\int e(t)$, and $\dot{e}(t)$) are represented by fuzzy sets m in the form of equidistant triangles. The choice of the MFs triangle is related to the conversion results of (4) used [20] and must have an overlap of 50%. As for the output fuzzy variable, $u(t)$ is fuzzified by $3m - 2$ singleton MFs.

The overall fuzzy rules can be represented by sliced cube fuzzy associative memory (FAM), as shown in Fig. 2, and each fuzzy rule is defined as:

$$\begin{aligned} \text{IF } e(t) \text{ is } E_i \text{ and } \int e(t) \text{ is } I_j \text{ and } \dot{e}(t) \text{ is } D_k \\ \text{THEN } u(t) \text{ is } U_l, \quad l = i+j+k-2 \end{aligned} \quad (2)$$

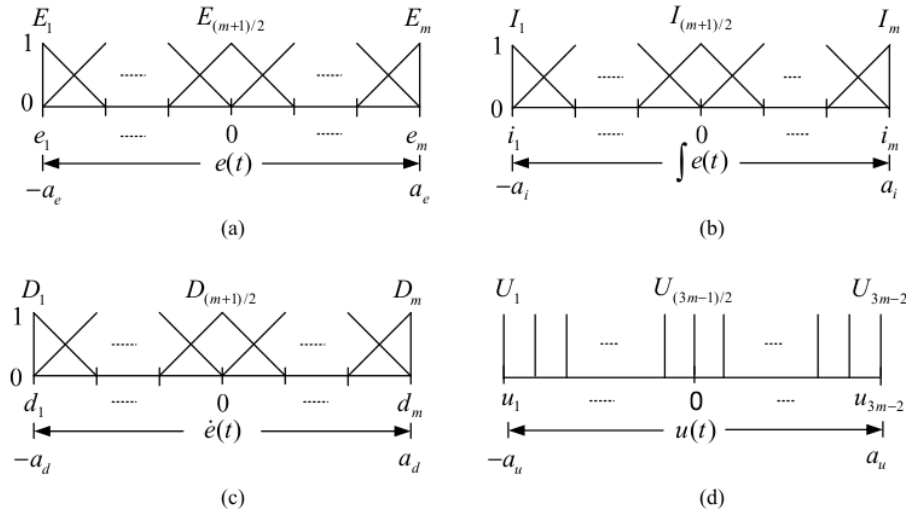


Fig. 1. The graphical definition of membership function for fuzzy variable (a) $e(t)$, (b) $\int e(t)$, (c) $\dot{e}(t)$, (d) $u(t)$ [20].

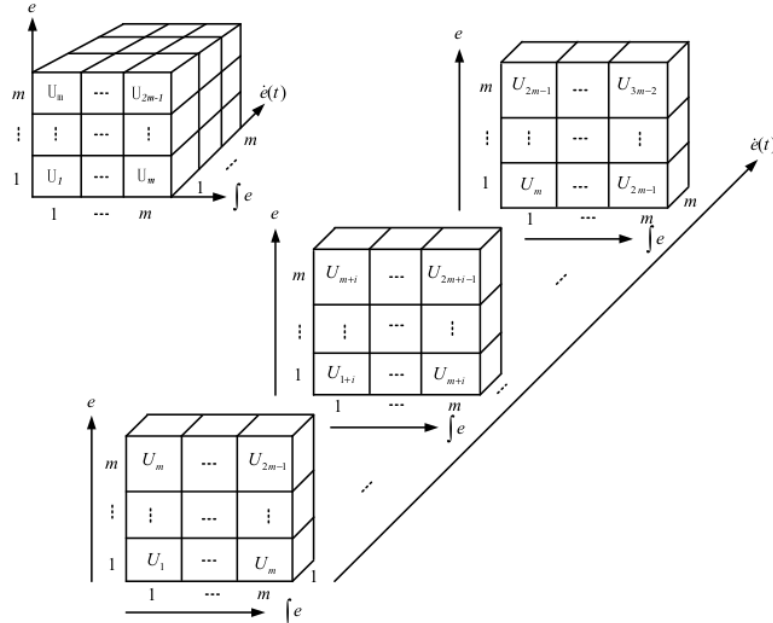


Fig. 2. Sliced cube fuzzy associative memory (FAM) for overall fuzzy rules [20].

Based on the explanation of the researcher [20], the graphical definition of the four fuzzy variables in MFs above has succeeded in deciphering its equation to become:

$$u(t) = \frac{a_u}{3a_e} e(t) + \frac{a_u}{3a_i} \int e(t) dt + \frac{a_u}{3a_d} \dot{e}(t) \quad (3)$$

Therefore, (3) implies the gain variable of the PID controller with:

$$K_p = \frac{a_u}{3a_e}, \quad K_i = \frac{a_u}{3a_i}, \quad K_d = \frac{a_u}{3a_d} \quad (4)$$

B. The Fuzzy PID controller Design

This section assesses the design of the F-PID controller by considering a BLDC motor. The simulation is verified using Matlab/Simulink. The specification of the BLDC motor is shown in Table 1.

TABLE I. BLDC MOTOR SPECIFICATION

Parameters	Value
Stator phase resistance R_s (Ω)	0.045
Stator phase inductance L_s (H)	6.85e-3
Back EMF constant (V_p L-L)	65.48
Back EMF flat area (e)	120
Inertia (kg.m^2)	0.0008
Viscos damping (N.m.s)	0.001
Pole pairs	13

A preliminary conventional PID controller design for BLDC motor with $K_p = 10$, $K_i = 90$, and $K_d = 0.025$ can be acquired through some basic traditional techniques.

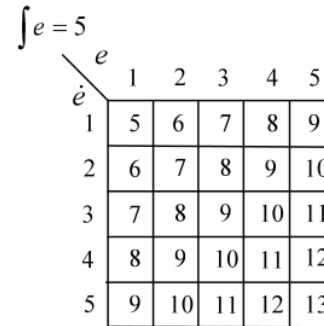
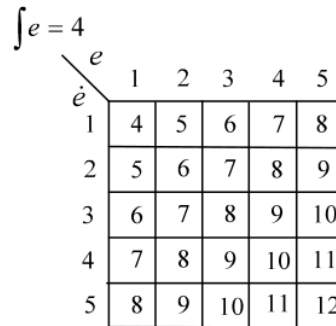
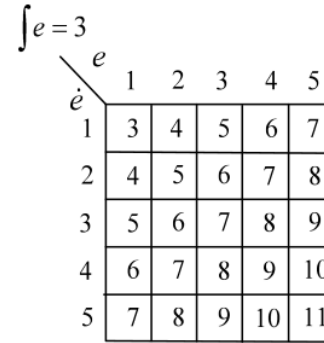
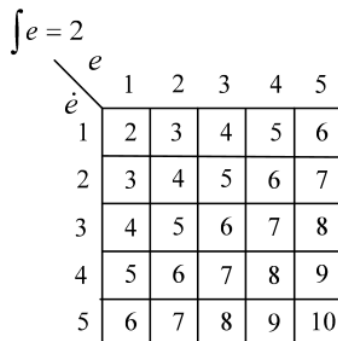
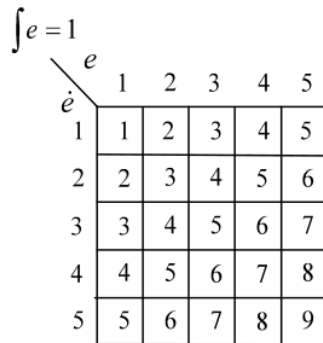


Fig. 3. The FAM of three inputs Fuzzy PID controller.

Subsequently, using (4) to convert from the conventional PID controller to the fuzzy logic controller. The error amplitude measured was 700 as a_e value. Therefore, a_u , a_i , and a_d respectively calculated with values 21000, 77.77, and 280000. The output MFs for $OR_u = [-a_u, a_u]$ were presented in the form of a fuzzy singleton namely (-21000, -17500, -14000, -10500, -7000, -3500, 0, 3500, 7000, 10500, 14000, 17500, 21000).

The parameter m was set as 5 for each input variable and 13 for the output variables of the FLC. The form of FAM is shown in Fig. 3 with total fuzzy rules for three inputs being 125. Meanwhile, the settings of all the MFs in the Matlab environment are shown in Fig. 4.

The conventional PID controller and Fuzzy PID controller system are shown in Fig. 5 and Fig.6. The magnitude of the rotor speed control's input signal of BLDC motor is declared in multi-speed with 100, 400, 700, and 200 as shown in Fig. 7. Then a load of BLDC motor is conditioned with 10.

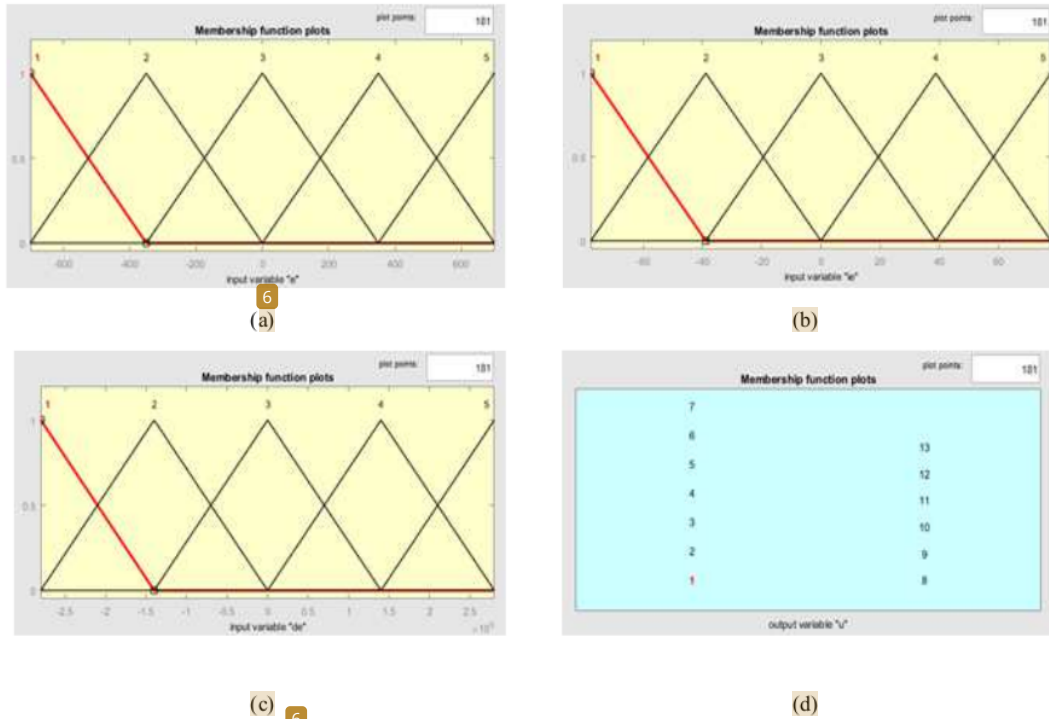


Fig. 4. MFs adjustment for fuzzy variables (a) $e(t)$, (b) $f e(t)$, (c) $\dot{e}(t)$, (d) $u(t)$.

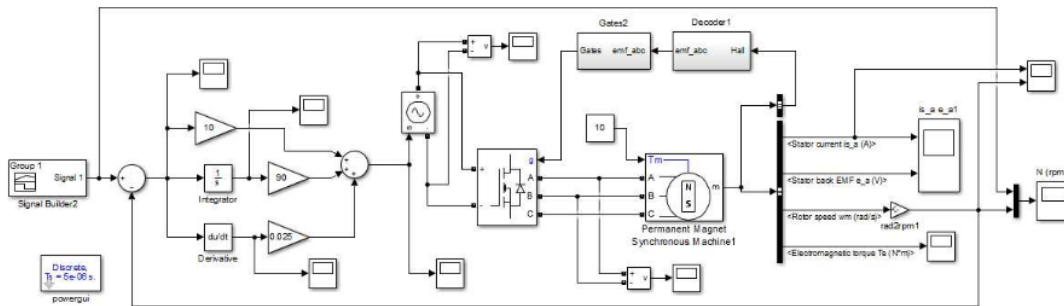


Fig. 5. The conventional PID controller system

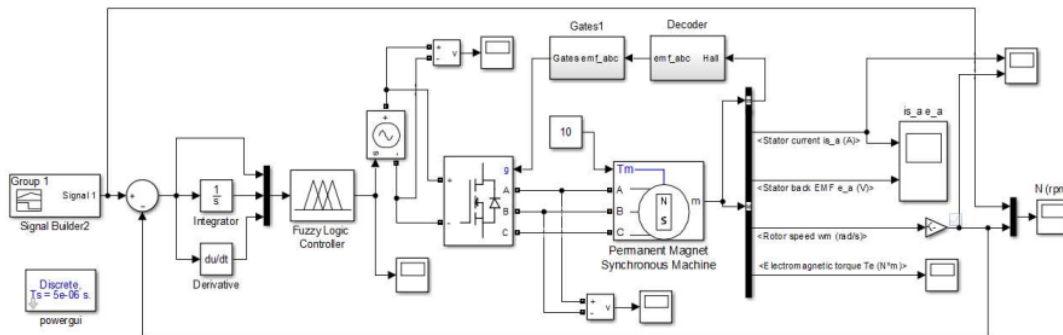


Fig. 6. The Fuzzy PID controller system

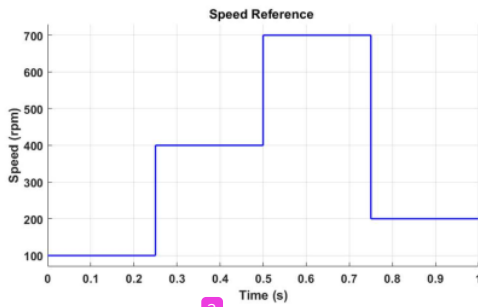


Fig. 7. The multi-variable input for speed control of BLDC motor

III. RESULT AND DISCUSSION

This section presents the comparison performance between the conventional PID controller and the Fuzzy PID controller in rotor speed control of BLDC motor with multi-variable inputs in constant load.

The speed response of the conventional PID controller and the Fuzzy PID controller are shown in Fig. 8. The performance of the rise time (T_r), the settling time (T_s), the percentage overshoot ($P.O.$), and the steady-state error (E_{ss}) are summarized in Table 2. Compared with the conventional PID controller, the Fuzzy PID controller has the best performance. The Fuzzy PID controller has T_r , T_s , and $P.O.$ smaller than the conventional PID controller.

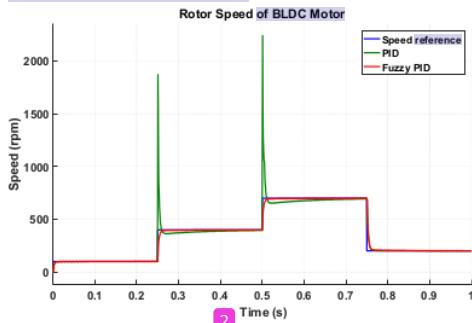


Fig. 8. The step response: (green) the conventional PID controller; and (red) the Fuzzy PID controller.

TABLE II. CONTROLLER TIME RESPONSE

Controller	T_r (s) 10% - 90%	T_s (s) $\pm 2\%$	$P.O.$ (%)	E_{ss}
PID	0.007	0.219	367.5	0
Fuzzy PID	0.005	0.009	0	0

Fig. 9 shows that the output signal from the Fuzzy PID controller is much smaller than the conventional PID controller. The difference in the output signal of the two controllers is very contrasting. The amplitude for the Fuzzy PID controller is between 3000 – 5000. While the amplitude for the conventional PID controller is between 1.5×10^6 – 2.5×10^6 . This is because an FLC has a fuzzy inference system (fis) which involves fuzzy rules and defuzzification in determining the amount of output. Whereas in conventional PID control, the output value is obtained from the sum of the multiplication results between the signal from error, integral error, and differential error with each gain of K_p , K_I , and K_D .

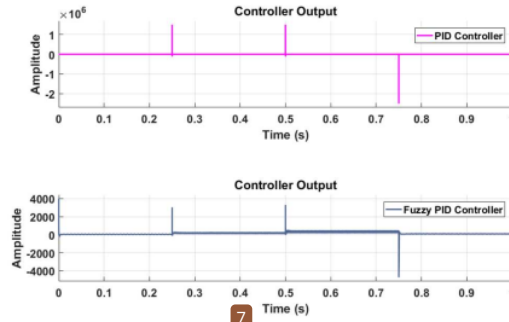


Fig. 9. The output signal of the conventional PID controller and Fuzzy PID controller

The observations in the stator current as shown in Fig. 10, the stator current amplitude of the Fuzzy PID controller is smaller than the conventional PID controller. This has an impact on stator back EMF in Fig. 11. Where stator back EMF amplitude of the Fuzzy PID controller is also smaller than the conventional PID controller.

The observations were also directed to the electromagnetic torque of the Fuzzy PID controller and the conventional PID controller as shown in Fig. 12. The electromagnetic torque of the BLDC motor on the fuzzy PID controller has a lower magnitude than the conventional PID controller when the speed is increased suddenly. This shows that for lifting the weight, the FLC emits little force-torque than the PID controller.

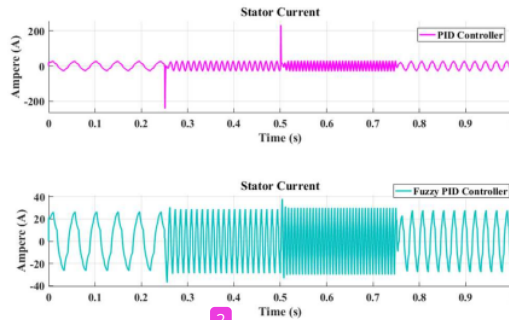


Fig. 10. The stator current of the conventional PID controller and Fuzzy PID controller

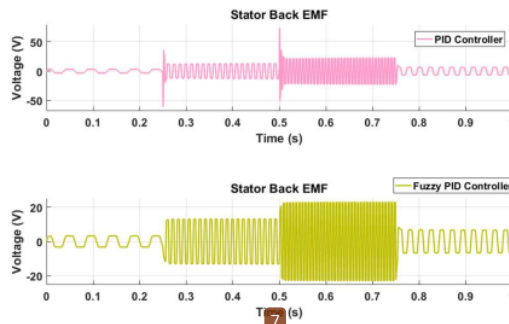


Fig. 11. The stator back EMF of the conventional PID controller and Fuzzy PID controller

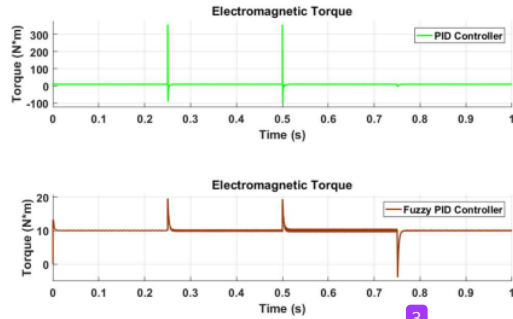


Fig. 12. The electromagnetic torque of the conventional PID controller and Fuzzy PID controller.

IV. CONCLUSION

The Fuzzy PID with three inputs and one output has been successfully designed. Its performance outperforms the conventional PID controller. The Fuzzy PID controller shows no overshoot. The signal follows the target speed in ascending or descending steps. The rise time of the Fuzzy PID controller is 0.005 seconds and the settling time is 0.009 seconds. In comparison, the conventional PID controller has a very high overshoot, around 367.5% with a rise time of 0.007 seconds, and a settling time up to 0.219 seconds. Therefore, Fuzzy PID has decreased the rise time to 28%, the settling time to 95.9%, and the overshoot attenuation to 100%. The two controllers have no steady-state error when the speed reference is raised and lowered. The controller output, the stator current, the stator back EMF, and the electromagnetic torque from the Fuzzy PID controller have smaller peak values than the conventional PID controller. Energy saving for the Fuzzy PID controller reaches 99.8%.

REFERENCES

- [1] I. Anshory, I. Robandi, W. Wirawan, and J. Jamaaluddin, "Identification and implementation hybrid fuzzy logic and PID controller for speed control of BLDC motor," *Journal of Physics: Conference Series*, vol. 1402, no. 3, 2019, doi: 10.1088/1742-6596/1402/3/033080.
- [2] X. Peng, M. Jia, L. He, X. Yu, and Y. Lv, "Fuzzy sliding mode control based on longitudinal force estimation for electro-mechanical braking systems using BLDC motor," *CES Transactions on Electrical Machines and Systems*, vol. 2, no. 1, pp. 142–151, 2020, doi: 10.23919/tems.2018.8326461.
- [3] A. Jaya, E. Purwanto, M. B. Fauziah, F. D. Murdianto, G. Prabowo, and M. R. Rusli, "Design of PID-fuzzy for speed control of brushless DC motor in dynamic electric vehicle to improve steady-state performance," *Proceedings IES-ETA 2017 - International Electronics Symposium on Engineering Technology and Applications*, vol. 2017-Decem, pp. 179–184, 2017, doi: 10.1109/ELECSYM.2017.8240399.
- [4] M. Sall, A. Kebe, I. Gueye, and M. Diop, "Comparative Study between the PID Regulator and the Fuzzy Regulator Applied to the Operation of a Brushless DC Motor," *Energy and Power Engineering*, vol. 13, no. 11, pp. 365–376, 2021, doi: 10.4236/epe.2021.1311025.
- [5] C. T. Chao, N. Utama, J. S. Chiou, and C. J. Wang, "An optimal fuzzy PID controller design based on conventional PID control and nonlinear factors," *Applied Sciences (Switzerland)*, vol. 9, no. 6, 2019, doi: 10.3390/app9061224.
- [6] J. S. Lee and J. W. Jiang, "Enhanced fuzzy-logic-based power-assisted control with user-adaptive systems for human-electric bikes," *IET Intelligent Transport Systems*, vol. 13, no. 10, pp. 1492–1498, Oct. 2019, doi: 10.1049/iet-its.2019.0092.
- [7] I. Shehur and D. Jancarczyk, "Electromagnetic torque ripple in multiple three-phase brushless dc motors for electric vehicles," *Electronics (Switzerland)*, vol. 10, no. 24, Dec. 2021, doi: 10.3390/electronics10243097.
- [8] M. Sumega, Š. Zoššák, P. Varecha, and P. Rafajdus, "Sources of torque ripple and their influence in BLDC motor drives," in *Transportation Research Procedia*, 2019, vol. 40, pp. 519–526, doi: 10.1016/j.trpro.2019.07.075.
- [9] H. Yin, W. Yi, K. Wang, J. Guan, and J. Wu, "Research on brushless DC motor control system based on fuzzy parameter adaptive PI algorithm," *AIP Advances*, vol. 10, no. 10, Oct. 2020, doi: 10.1063/5.0025000.
- [10] S. Usha, P. M. Dubey, R. Ramya, and M. v. Suganyadevi, "Performance enhancement of bldc motor using pid controller," *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 3, pp. 1335–1344, Sep. 2021, doi: 10.11591/ijpeds.v12.i3.pp1335-1344.
- [11] M. A. Ibrahim, A. K. Mahmood, and N. S. Sultan, "Optimal PID controller of a brushless DC motor using genetic algorithm," *International Journal of Power Electronics and Drive Systems*, vol. 10, no. 2, pp. 822–830, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp822-830.
- [12] A. K., M. S., M. S., and F. F., "Brushless DC Motor Speed Control using PID Controller, Fuzzy Controller, and Neuro Fuzzy Controller," *International Journal of Computer Applications*, vol. 180, no. 30, pp. 47–52, Apr. 2018, doi: 10.5120/ijca2018916783.
- [13] M. A. Shamseldin, M. A. A. Ghany, and A. M. A. Ghany, "Performance study of enhanced non-linear PID control applied on brushless DC motor," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 2, pp. 536–545, 2018, doi: 10.11591/ijpeds.v9n2.pp536-545.
- [14] N. B. Hung, J. Sung, K. Kim, and O. Lim, "A Simulation and Experimental Study of Operating Characteristics of an Electric Bicycle," *Energy Procedia*, vol. 105, pp. 2512–2517, 2017, doi: 10.1016/j.egypro.2017.03.723.
- [15] R. Kristiyono and Wiyono, "Autotuning fuzzy PID controller for speed control of BLDC motor," *Journal of Robotics and Control (JRC)*, vol. 2, no. 5, pp. 400–407, 2021, doi: 10.18196/jrc.25114.
- [16] A. A. El-samahy and M. A. Shamseldin, "Brushless DC motor tracking control using self-tuning fuzzy PID control and model reference adaptive control," *Ain Shams Engineering Journal*, vol. 9, no. 3, pp. 341–352, 2018, doi: 10.1016/j.asej.2016.02.004.
- [17] H. Maghfiroh, M. Ahmad, A. Ramelan, and F. Adriyanto, "Fuzzy-PID in BLDC Motor Speed Control Using MATLAB/Simulink," *Journal of Robotics and Control (JRC)*, vol. 3, no. 1, pp. 8–13, 2022, doi: 10.18196/jrc.v3i1.10964.
- [18] L. Jin, R. Zhang, B. Tang, and H. Guo, "A Fuzzy-PID scheme for low speed control of a vehicle while going on a downhill road," *Energies (Basel)*, vol. 13, no. 11, Jun. 2020, doi: 10.3390/en13112795.
- [19] I. Anshory, I. Robandi, J. Jamaaluddi, A. Fudholi, and Wirawan, "Transfer function modeling and optimization speed response of bldc motor e-bike using intelligent controller," *Journal of Engineering Science and Technology*, vol. 16, no. 1, pp. 305–324, 2021.
- [20] C.-T. Chao, N. Utama, J.-S. Chiou, and C.-J. Wang, "Equivalence between fuzzy PID controllers and conventional PID controllers," *Applied Sciences*, vol. 7, no. 6, p. 513, 2017.

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