D.J. Hemanth et al. (Eds.)
© 2022 The authors and IOS Press.
This article is published online with Open Access by IOS Press and distributed under the terms of the Creative Commons Attribution Non-Commercial License 4.0 (CC BY-NC 4.0).
doi:10.3233/APC220002

Performance Analysis of BLDC Motor Using Fuzzy Logic Controllers

J.Manjushree Kumari[a,1], R.Nagarajan[a] and S.Kannadhasan[a]
[a] *Research Scholar, Department of Electrical and Electronics Engineering, Gnanamani College of Technology, Tamil Nadu, India*

Abstract. The goal of this research is to illustrate how the quick tuning results of the recommended modified PID controller can be used to manage the motor's speed and keep it constant during load fluctuations. As a result, the PID regulator improves the overall performance of the BLDC motor. The PID controller's capability may be enhanced for better control based on the simulation results. Using MATLAB simulation, create a simulation model of a BLDC motor. A PID controller may enhance the performance of BLDC motors by lowering overshoot, rising time, and steady-state inaccuracy.

Keywords. BLDC Motor, PID Controller, AC & DC Motor, Efficiency and Fuzzy

1. Introduction

The beginning of the industrial revolution, which began with the invention of the vehicle, corresponds to the contemporary period. Despite the fact that several types of motors have been developed throughout time, they are normally categorized into two categories: AC and DC motors. DC motors come in a broad range of sizes and shapes, and they may be used in a number of applications. However, two types of DC motors are often utilised in industrial applications. The first form of magnetic flux is produced by current flowing through the field coil of a static pole structure, whereas the second type is produced by a permanent magnet [1]-[5]. A BLDC motor is a kind of DC motor that uses an electronic process system rather than a brush to transmit power. Brushless DC motors have been used in a number of industrial and domestic applications. Because the benefits of the motor have been exaggerated, there has been a persistent inclination to propose new control schemes to improve the motor's performance. Torque smoothness is crucial in high-performance motion control applications, and BLDC motors must provide exact and ripple-free instantaneous torque. The brushless DC motor is controlled by trapezoidal voltage strokes and the rotor position. To generate the most torque, the voltage strokes between the phases must be appropriately synchronized to keep the angle between the stator flux and the rotor flux at 1200 [6]-[10].By changing the speed of a DC motor, we may get excellent performance and controllability. BLDC motors are now used in electric autos, rolling mills, electric cranes, electric trains, and robotics. In 1981, Speed Ward Leonard was the first to employ voltage control to run a DC motor.

[1]J.Manjushree Kumari, Department of Networking and Communications, SRM Institute of Science and Technology, Kattankulathur, Chennai; E-mail: manjushree.pmc@gmail.com.

Electric switching devices for voltage control have included IGBT, MOSFET, GTO, and other semiconductor components [11–15]. Finally, the system's control is hard due to its nonlinear features. To address this problem, fuzzy logic controllers may be developed. Balogh Tiber has developed a mathematical model for managing BLDC motor communication by combining electrical and mechanical equations. In certain BLDC systems, further FPGA- and DSPIC-based controllers have been provided. Previously, a digital version of BLDC with fuzzy [16]-[18] was devised for a wide range of speed control. A neural-fuzzy-based emotional learning algorithm was also utilised to develop a method for controlling the speed of BLDC motors.

2. BLDC Motor with Controller

A controller circuit is needed to operate and regulate the speed of a BLDC motor. There have been many different types of speed control systems for controllers developed, but as illustrated in Figure 1, speed controllers must adapt to the times. The two most popular forms of control systems are closed loop and open loop control systems. Closed loop techniques are used in high-precision control systems. Figure 1 shows a block diagram of a two-closed-loop BLDC motor speed controller.

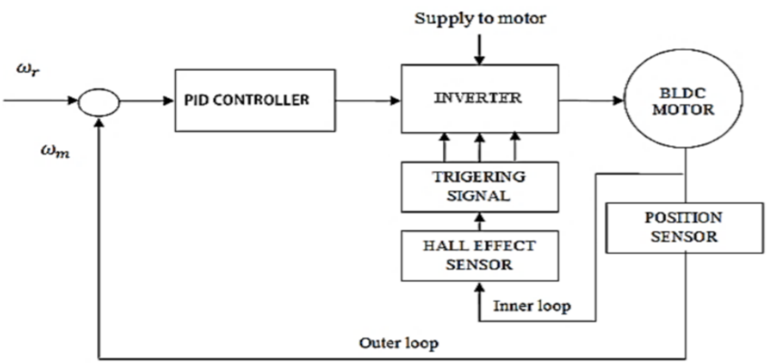

Figure 1. Block Diagram of BLDC

The power supply's polarity is adjusted and detected by the internal loop, while the speed is controlled by the outer loop. The DC bus voltage is adjusted using the motor speed controller. The motor speed (rpm) and capacity define the value of the DC supply, which is required to control the system. This setup also needs the use of a controller, in this case a PID controller for controlling the inverter output voltage. A sensor is a crucial part of a closed loop controller that regulates the speed of a motor. The fundamental function of the sensor is to convert the physical location and condition of the motor shaft into an electrical signal that the controller circuit may utilise. An inverter circuit is required to convert the DC power supply voltage into an equivalent AC supply voltage for a BLDC motor to function effectively.

.

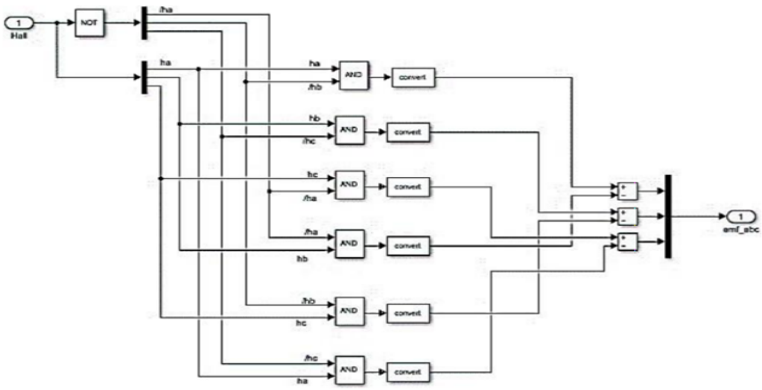

Figure 2. Back EMF of Decoder for MATLAB Drive

A full-bridge power converter for a three-phase BLDC motor normally uses six electronic switches to provide three-phase voltage at the same time (power transistors). The location of the transistors' rotors determines the switching sequence. Three hall sensor devices are employed to monitor the motor starter in the great majority of cases. Figure 2 shows how the data from the hall sensors is sent into the decoder block, which creates the sign of the back electromotive force's reference current signal vector. The current is reversed or the controller's switching sequence is changed to drive the motor in the other direction. The proposed 3-phase PID controller for the BLDC motor to turn in the clockwise direction includes a MATLAB simulation block diagram for generating the back EMF of the decoder. For MATLAB simulation, Table 1 shows the proposed 3-phase PID controller decoder sequences for making the BLDC motor spin counterclockwise, and Figure 3 shows the functional block diagram of the inverter switching.

.

Table.1. True Table for Inverter Switching

Table II.	**True Table For Inverter Switching**								
	emf_ a	***emf_ b***	***emf_ c***	***Q1***	***Q2***	***Q3***	***Q4***	***Q5***	***Q6***
	0	0	0	0	0	0	0	0	0
	0	-1	+1	0	0	0	1	1	0
	-1	+1	0	0	1	1	0	0	0
	-1	0	+1	0	1	0	0	1	0
	+1	0	-1	1	0	0	0	0	1
	+1	-1	0	1	0	0	1	0	0
	0	+1	-1	0	0	1	0	0	1
	0	0	0	0	0	0	0	0	0

2.1. Circuit Connections

It's common to use a permanent magnet with a synchronous BLDC motor with a trapezoidal back EMF waveform. High-performance BLDC motor technologies, as well as variable speed drives in electric cars, are now extensively employed in industrial applications across the world, according to current trends. In actuality, the control circuits for these motors are critical. These motors are really controlled by a circuit, and scientists are now developing a high-performance version. The fundamental control method of a BLDC motor is shown in Figure 4. This control framework may be used for BLDC motor tuning, project selection, simulation modelling, and other tasks. A BLDC motor's design structure is a difficult process that includes a number of processes such as project selection, modelling, and simulation, among others. A variety of current control techniques have been developed for the BLDC motor's rapid manufacture.

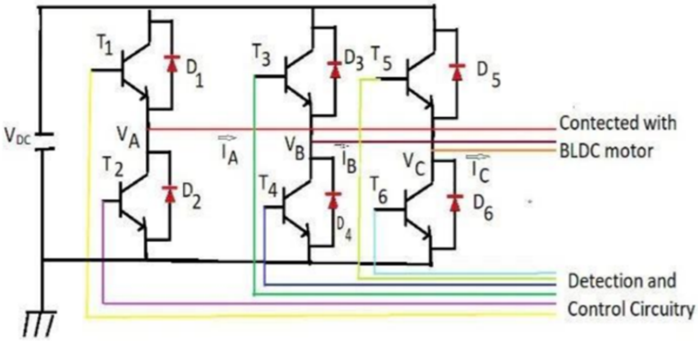

Figure.3. Circuit Diagram of BLDC

A basic PID controller algorithm's ease of modification, consistent behaviour, and simple design all contribute to its widespread usage in system control. The PID controller uses a commonly utilised speed control approach for practical reasons. Using fuzzy logic and a PID controller, a mathematical model for a BLDC motor was constructed and tested. In the vast majority of cases, when the volatility of well-structured prototypes, diverse units of nonlinear, low variability are at work, a different outcome in terms of practical value experiences is achieved. Because the settings of a PID controller are so intricate to construct, it's difficult to determine the perfect position under the tested conditions. The regulating speed of a BLDC motor may be improved by modifying the PID controller, as shown in this research. Parameters may be changed in real time while the PID controller is running. The input and membership functions of the PID controller scheme must be strengthened in order for it to work properly. At the same time, values for the PID controller's constant coefficients, Kp, Ki, and Kd, are applied. These choices may be utilised to tailor the suggested upgraded controller to any changeable dimension. The goal of this research is to demonstrate how the dynamic reaction to the recommended modified PID controller's quick tuning results may be utilised to manage the motor's speed and maintain it constant even while the load changes. As a result, the PID regulator may improve the BLDC motor's overall performance. Based on the results of the simulation, the PID controller's functions might be changed to enhance the control system's performance.

A classic PID controller algorithm's ease of tuning, consistent performance, and simple design are all essential reasons in its widespread usage in system control. The PID controller uses a common speed control technique for practical reasons. Using fuzzy logic and a PID controller, a mathematical model for a BLDC motor was devised and proven. The vast majority of scenarios result in a different outcome in terms of practical usefulness experiences when the volatility of well-structured prototypes, diverse units of nonlinear, low variability are at work. Due to the difficulties in determining the parameters of a PID controller, finding the best location under the researched conditions is difficult. Making exact tweaks to the PID controller may increase the BLDC motor's regulating speed, according to this research. You may modify settings in real time while the PID controller is running. The input and membership functions of the PID controller system must be strengthened in order for it to work properly. At the same time, values for the PID controller's constant coefficients, Kp, Ki, and Kd, are applied. These options may be used to tailor the suggested upgraded controller to any changing parameter.

2.2 Components for the Proposed Work

2.2.1 Inverter

An inverter is a device that transforms a DC input voltage into an AC output voltage of the correct frequency and amplitude. Adjust the input DC voltage while keeping the inverter's gain constant to change the output voltage. The periodic waveform of the output voltage is not entirely sinusoidal. Due to the need for a voltage source, the VSI (Voltage Source Inverter) is more often used in industrial settings.

2.2.2 BLDC Motor

Brushless DC motors differ from regular DC motors in that the armature current is electronically commutated rather than mechanically. A permanent magnet synchronous motor and a BLDC motor have comparable architectures. The polyphaser winding is housed in the stator, whereas permanent magnets are used in the rotor. A rotor position sensor and an electronic drive circuit are both included in a BLDC motor. The stator winding is fed by an electrical drive that is based on transistors.

2.2.3 Triggering Signal

To drive BLDC motors, voltage strokes are coupled with rotor position.

2.2.4 Position Sensors

In a BLDC motor, position sensors assist in determining the location of the rotor pole and provide correct phase change information to the logic switch circuit. It converts the magnetic steel pole position signal from the rotor into an electrical signal, which is then used to control the phase shift of the stator winding.

2.2.5 Hall Effect Sensor

Brushless DC motors use Hall effect sensors instead of mechanical commutators and brushes. Hall effect sensors are a kind of solid-state magnetic field sensor. As a consequence, in order to keep the motor going, the stator magnetic field must alter position as the rotor field "catches up" with it. Bipolar Hall-effect sensors are used to identify the location of the spinning magnet in BLDC motors.

2.2.6 PID Controller

In BLDC motors, the PID controller is the most prevalent. The approach estimates the difference in speed between the reference and actual speeds, which leads to errors. The proportional gain Kp, integral gain Ki, and derivative gain Kd are all different types of gains. The system's overall performance is affected by PID settings. To meet specific performance requirements, the PID controller family includes various combinations of proportional, integral, and derivative terms. The circuit diagram of a PID controller is shown in Figure 5. PID (proportional–integral–derivative) is the name of the controller. Due to their excellent efficiency, PID controllers are often used in industry. PID controllers are used in 95 percent of closed loop operations in the industrial automation industry. A control signal is generated by coupling the proportional–integral–derivative controllers. The following is the definition of the PID control function:
u(t)=Kp*e(t)+Ki* Kd

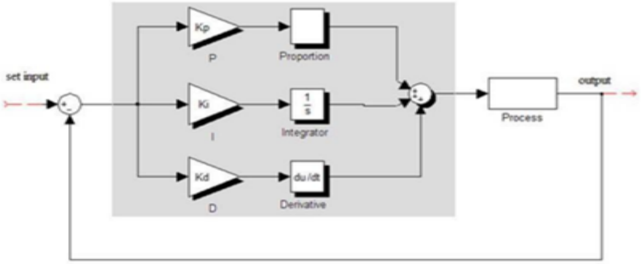

Figure.5. Circuit Diagram of PID Controller

2.2.7 Fuzzy Logic Controller

Fuzzy logic is often used in equipment for control reasons. The logic that determines whether a collection of values is true or false is referred to as "fuzzy logic." One of the many advantages of fuzzy logic is its ability to solve problems in a way that a human operator can understand and apply to the development of better controllers. The controller's design expedited the process and made it easy to incorporate into the system.

3. Results and Discussion

Figure 6 shows the performance of the suggested PID controller for a brushless DC motor at 2500 rpm. The BLDC motor's time (sec) and speed (rpm) with no load were shown on the X and Y axes, respectively. As indicated in the figure, the controller's settling time is roughly 0.018 seconds, with very little overshoot and undershoot. After 0.018 seconds, the motor operates at a constant speed of 2500 rpm, depending on the user's choices. Figure 7 shows the output torque response of the BLDC motor while it is not loaded. The no-load duration in seconds (sec) and electromagnetic torque value in Newton-meters (Nm) of the BLDC motor were shown on the X and Y axes, respectively. The motor's electromagnetic torque (Nm) is fixed after 0.03 seconds, as seen in the diagram.

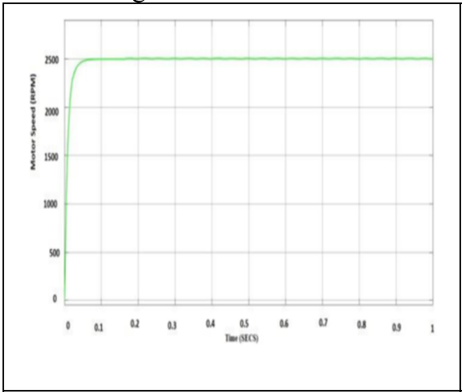

Figure.6. No-Load Performance of the BLDC Motor

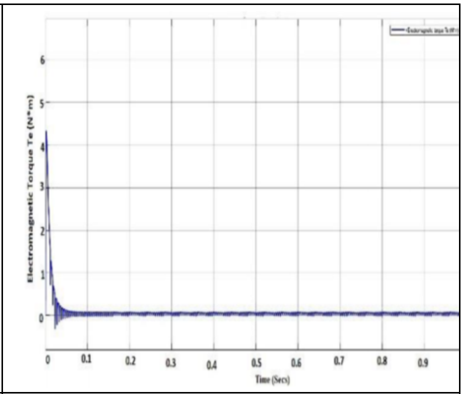

Figure.7. Time vs Electromagnetic Torque Response of the BLDC Motor

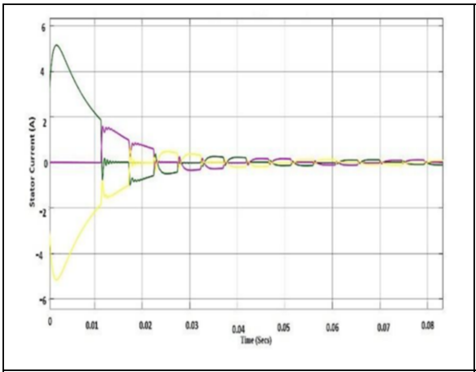

Figure.8. Phase Stator Current of the BLDC Motor

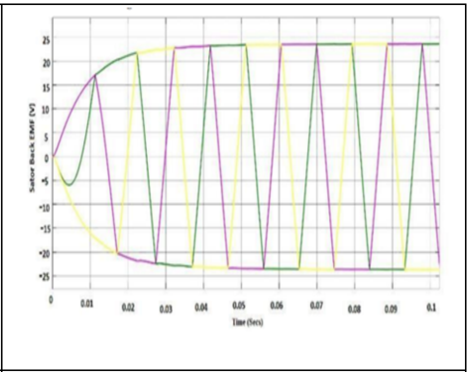

Figure.9. BLDC Motor 3-Phase Back Electromotive Force

Figure 8 shows the BLDC motor's no-load reverse electromotive force (emf). The no-load duration in seconds (secs) and back emf value in volts are shown on the X and Y axes in this figure (V). The 3-phase back emf voltages of a BLDC motor are represented by the green, pink, and yellow colour lines in this figure. After 0.030 seconds, the 3-phase back emf voltages are adjusted to 24V, confirming Figure 9.

As seen in Figures 8 and 9, the PID controller settles in 18 milliseconds. Overshoots and undershoots for this controller are 0.4 percent and 1.9 percent, respectively, which are within the allowed working range of a BLDC motor. The PID controller has a shot rate of 2.5 percent and a slew rate of 92.27 milliseconds (msecs). The PI controller, on the other hand, has a shorter rise time than the PID controller but a much higher slow rate (621.35). (msecs). The PI controller also has a 0.66 percent pre-shoot, a 32.67 percent overshoot, a 1.68 percent undershoot, and a 15.20 msec settling time. High frequency noise may be decreased by applying a filter to reduce pre-shoot, overshoot, and undershoot. According to the Fuzzy logic controller output (msecs), the pre-shoot is 0.67 percent, the slew rate is 598.15 percent, the overshoot is

30.92 percent, the undershoot is 3.2 percent, and the settling time is 9.2 percent. PID controller will deliver the greatest results for BLDC motor control.

Advantages

- ❖ This work is easy to do because the PID controller has simple mathematical equations and uses fewer resources than other control methods like model-based or matrix-based controllers.
- ❖ It will be more resilient to turning mismatches (leading to a satisfactory solution for most instances) and can be turned without requiring a great deal of knowledge.
- ❖ PID controllers respond more quickly to unmeasured disturbances. Model-based controllers can only react to unmeasured disturbances with an integral action, but PID can react immediately to both proportional and derivative actions.
- ❖ It is commonly known that traditional PID controllers provide superior transient and steady state responses when the system parameters stay constant throughout operation.

4. Conclusion

Due to the absence of speed control, controlling a DC Series Wound Motor is challenging. To solve this issue, a controller is required, and the PID controller will be employed. The series-wound motor was chosen because no other motor in its class can match its torque load characteristics. Controllers today come in a wide range of forms and sizes, each with its own set of benefits and drawbacks. This paper makes use of the PID controller, PI controller, P controller, and Fuzzy Logic Controller (FLC).

References

[1] Pragasan Pillay and R. Krishnan,"Modeling Simulation and Analysis of Permanent Magnet Motor Drives, Part II: The Brushless DC Motor Drives", in IEEE Trans. on Industrial Applications, vol. 25, no. 2, pp. 274-279, MarchiApril 1989.

[2] Pragasan Pillay and R. Krishnan,"Modeling of Permanent Magnet Motor Drives", in IEEE Trans. On Industrial Electronics, vol. 35, no. 4, pp. 537-541, November 1988.

[3] R. Krishna, "electric motor drives" (modeling, analysis and control), low price Edition.

[4] A. Halvaei Niasar, A. Vahedi, H. Moghbelli "Speed Control of a Brushless DC Motor Drive via Adaptive Neuro-Fuzzy Controller Based on Emotional Learning Algorithm," International Conference on Electrical Machines and Systems (ICEMS), vol. 3, pp 230-234, 2005.

[5] Chung-Jin Kwon, Woo-Yong Han, Sung-Joong Kim and Chang-Goo Lee "Speed Controller with Adaptive Fuzzy Tuning For BLDC Motor Drive Under Load Variations" at SICE Annual Conference in Fukui, pp 311S3121,2003.

[6] Chang Liang Xia, Permanent Magnet Brushless DC Motor Drives and Controls, Wiley Press, Beijing, 2012

[7] A.Accetta, M.Cirrincione, M.Pucci, ―TLS EXIN based neural sensorless control of a high dynamic PMSM,‖ Control Engineering Practice, vol.20, issue.7, pp.725-732, July 2012.

[8] R.Nagarajan and M,Saravanan, "Performance Analysis of a Novel Reduced Switch Cascaded Multilevel Inverter," Journal of Power Electronics, Vol.14, No.1, pp.48-60, Jan. 2014, DOI-http://dx.doi.org/10.6113/JPE.2014.14.1.48, Springer Publication

[9] Hinkkanen, M., Tuovinen, T., Harnefors, L., Luomi, J, Miao-―A Combined Position and Stator-Resistance Observer for Salient PMSM Drives: Design and Stability Analysis‖ vol.27, issue.2 pp.601-619, February 2012.

[10] Marwa Ezzat, Jesus de Leon, Alain Glumineau, ―Sensorless speed control of PMSM via adaptive interconnected observer,‖ International Journal of Control, vol.84, no.11, pp.1926-1943, 2011.
[11] K. Muta, M. Yamazaki, and J. Tokieda, ―Development of new-generation hybrid system THS II—Drastic improvement of power performance and fuel economy,‖ presented at the SAE World Congress Detroit, MI, Mar. 8–11, 2004, SAE Paper 2004-01-0064.
[12] Suneet NayakVaruneetVarun, G. Bhargavi. Speed control of induction motor using fuzzy logic approach.
[13] T. Sebastian, G. Slemon, and M. Rahman, "Modelling of permanent magnet synchronous motors," Magnetics, IEEE Transactions on, vol. 22, pp. 1069-1071, 1986
[14] J.S.Ko, "Robust position control of BLDC motors using Integral-Proportional-Plus Fuzzy logic controller", IEEE Trans. On IE, Vol, June 1994, pp.308-315.
[15] M.Ali Akcayol, Aydin cetin, and cetinemas "An educational tool for fuzzy logic Controlled BDCM"IEEE transaction on educational vol.45.no.1 February 2002.
[16] M.Ali Akcayol, Aydin cetin, and cetinemas "Design of fuzzy speed control of the Brushless dc motor" IEEE transaction on educationa vol.45.no.1 February 2002.
[17] C. Elmas and M. A. Akcayol, "Fuzzy logic controller based speed control of brushless DC motor," J. Polytechnic, vol. 3, no. 3, pp. 7–14, 2000.
[18] J.S.Ko, "Robust position control of BLDC motors using Integral-Proportional-Plus Fuzzy logic controller", IEEE Trans. On IE, Vol, June 1994, pp.308-315