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PERFORMANCE EVALUATION OF PID CONTROLLER AND HYSTERESIS CURRENT CONTROLLER OF THREE PHASE BLDC MOTOR USING MATLAB SIMULATION

[1]Sakshi Bora, [1]Ajay Srivastava, [1]S.K. Goel and [1]H.S. Rawat
[1]Department of Electrical Engineering, College of Technology, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand
E-mail: sakshibora156@gmail.com

Abstract: Brushless direct current (BLDC) motors are widely applied in industrial and automotive sectors owing to various performance factors viz. high efficiency, higher torque in low speed range, higher power density, compact structure, less noise and low maintenance needs. BLDC motors have a relatively high winding resistance and consequently current control loop can be avoided in some cases, but fast and accurate speed regulation is still a challenge. This paper focuses on the speed control of a three-phase Brushless DC (BLDC) motor comparing two different approaches: Proportional-Integral-Derivative (PID) control and Hysteresis Current Control using MATLAB and Simulink, developed by MathWorks. The PID-based configuration, the outer loop reduces speed error, ensuring smooth and stable operation with lower torque ripple. In contrast, the Hysteresis Current Control regulates phase currents within a predefined hysteresis band, enabling fast current response and strong resilience to disturbances. The results showed that the PID controller achieves a steady-state speed error of just 0.66% compared to 1.81% with hysteresis control. The PID approach delivers smoother torque and current waveforms, resulting in improved efficiency.
Keywords: BLDC motor, Matlab, PID controller, Hysteresis Current Controller

1. INTRODUCTION

BLDC motors have become increasingly popular in diverse range of sectors including industrial, automotive, household applications, avionics [1-4] due to their high efficiency, compact design, low maintenance needs and excellent speed-torque characteristics [5-6]. Due to increasing demand for electric cars and unmanned aerial vehicles in future, BLDC motors are likely to play a crucial role [7]. However, achieving precise speed control and current particularly under varying load conditions resulting in performance limitations and remains a key challenge [8]. Proportional-Integral-Derivative (PID) controller technique for controlling the speed of BLDC motors continuously calculates the error between a desired set point and the actual speed, applying corrective actions through proportional, integral and derivative components. Another effective control technique, the Hysteresis current controller uses a bang-bang strategy, maintaining the motor's phase currents within a specified hysteresis band around the reference current [9-11]. This study aims to develop and simulate an effective speed control strategy for a BLDC motor combining PID controller and Hysteresis current

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controller to achieve accurate speed tracking, fast dynamic response, reduced overshoot, reliable current regulation and cost effective motor operation in real-time applications.

2. METHODOLOGY

2.1 Speed Control Implementation

2.1.1 PID controller

The proposed control strategy has been developed and tested using the MATLAB/Simulink environment. The system is structured around a closed-loop speed control scheme in which the desired reference speed is continuously compared with the actual motor speed to determine the speed error. This error signal is fed into a PID controller, which processes it according to its proportional, integral, and derivative actions to generate an appropriate control signal. The resulting signal regulates the applied motor voltage, ensuring that the motor speed follows the reference command accurately. To validate the effectiveness of the controller, the system performance is analyzed through different simulation conditions, including step changes in the reference speed (such as 500 rpm) as well as variations in load torque, allowing a comprehensive assessment of both transient and steady-state behavior.

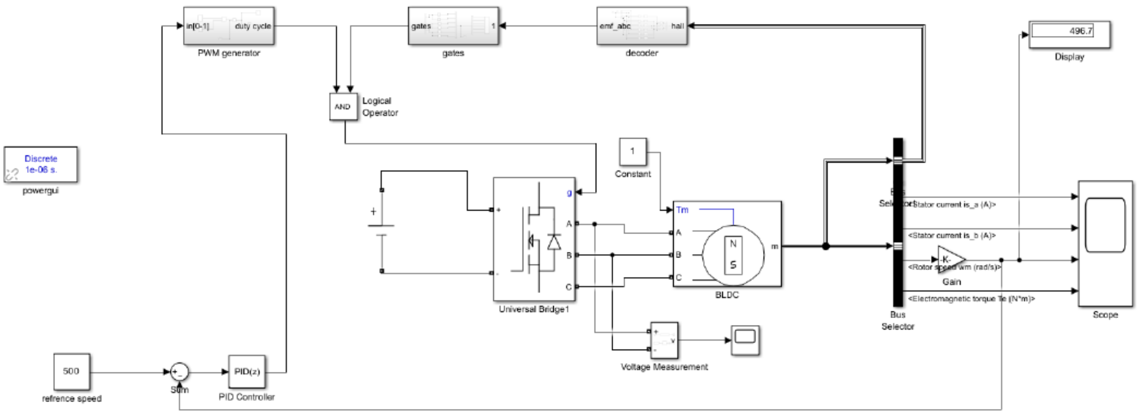

Fig1. MATLAB simulation of speed control of BLDC motor using PID controller

Figure 1 illustrates the Simulink model developed for closed-loop speed control of a BLDC motor using a discrete PID controller. In this model, a reference speed of 500 rpm is continuously compared with the actual rotor speed, and the resulting error signal is fed into the PID controller. Based on this error, the controller determines the appropriate control effort needed to minimize the speed difference. The controller output is then used to generate PWM pulses for the Universal Bridge inverter, which supplies the required three-phase voltage to drive the BLDC motor. The model captures both the electrical behavior of the motor and its mechanical response, allowing comprehensive performance analysis. Key parameters such as stator currents (Ia, Ib, and Ic), rotor speed, and electromagnetic torque are monitored through scope blocks to assess transient and steady-state characteristics, ensuring accurate speed regulation under different operating conditions.

2.1.2 Hysteresis Current Controller

A current control loop (using a hysteresis-based controller) continuously monitors the actual phase currents and keeps them within a predefined hysteresis band around the desired current reference.

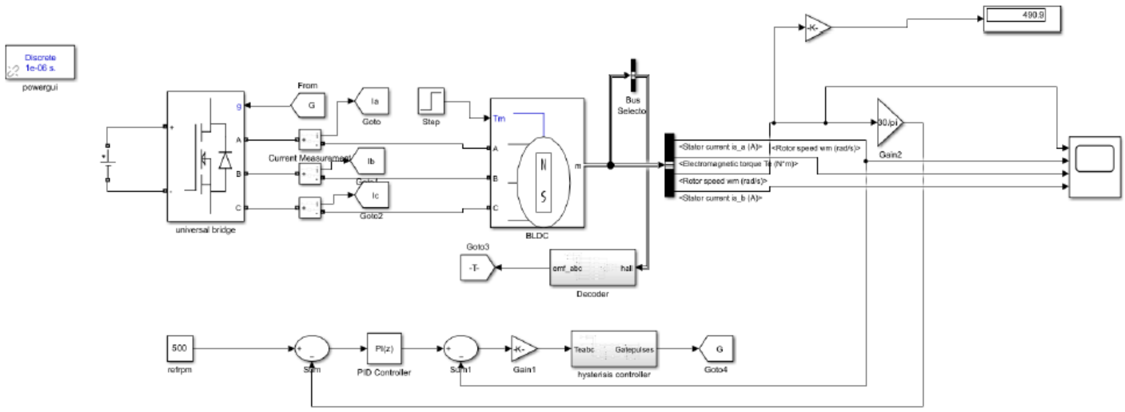

Fig 2. MATLAB simulation of speed control of BLDC motor using Hysteresis current controller

Simulink model in Fig. 2 represents a complete closed-loop control system for operating a BLDC motor using a hysteresis current control strategy. The system integrates electrical power conversion, feedback control and signal processing in a unified simulation environment. At the core of this model is a BLDC motor which receives three-phase signals generated by a power electronic converter, which is regulated through gate pulses generated by the control system. A reference speed (500 rpm) is given as input and the actual motor speed is continuously monitored and compared against this reference. The difference between the reference and actual speed is used to generate a control signal through a PID controller. These signals are used to update the controller and ensure the motor performance as desired. Additionally, signal processing elements such as gain blocks and decoders are used to refine and manage the feedback and control signals.

2.2 BLDC Motor Performance

2.2.1 Under PID Control

The performance of the BLDC motor was analyzed through detailed simulation studies. The overall response can be divided into three main stages: the initial condition, the startup transient and steady-state operation. In each stage, the motor behavior corresponds well with the expected response of a drive system controlled by a PID regulator.

1. Initial Condition

At the start of the simulation, no reference speed command is applied. As a result, the motor remains at rest, with the rotor speed at 0 rpm and electromagnetic torque equal to zero. This stage represents the idle condition of the system before the controller becomes active.

2. Startup Phase

When a reference speed of 500 rpm is introduced, the PID controller begins operating and adjusts the motor input to drive the rotor toward the commanded speed.

During this transient period:

• The motor produces a comparatively high electromagnetic torque to overcome rotor inertia and any applied load.

• A noticeable spike in stator current appears, which is a typical and expected characteristic during motor startup.

• These temporary current surges indicate that the controller is responding effectively to accelerate the motor quickly toward the target speed.

This phase highlights the dynamic capability of the PID controller, particularly its ability to reduce rise time and ensure rapid acceleration.

3. Steady-State Operation

After the initial transient period, the motor speed settles at approximately 496.7 rpm, which is very close to the 500 rpm reference. The small steady-state deviation is within acceptable limits and may result from nonlinearities in the system, parameter uncertainties, or slight imperfections in PID tuning.

During steady-state operation:

• The electromagnetic torque becomes stable, reflecting balanced operating conditions.

• The stator current waveform reaches a steady pattern with minor ripple components.

• These small ripples are typical in BLDC motors and are mainly caused by commutation processes and PWM switching in the inverter.

Overall, the PID-controlled system demonstrates reliable speed tracking, stable operation, and minimal steady-state error, confirming its effectiveness for BLDC motor drive applications.

2.2.2 Performance Under Hysteresis Current Control

With hysteresis current control, the motor is able to maintain the commanded speed with satisfactory tracking accuracy.

• The controller responds very quickly to any variation in current, since it continuously monitors the current limits and takes immediate corrective action.

• The rotor speed remains close to the reference value, though small speed ripples can be observed due to the rapid switching behavior.

• Because hysteresis control relies on frequent ON–OFF switching of the inverter devices, switching losses tend to increase, which can lower overall system efficiency and potentially impact the durability of power electronic components over extended operation.

When compared to conventional PID control, hysteresis current control provides quicker current regulation and improved dynamic response; however, this benefit comes at the expense of higher switching frequency and the additional losses associated with it.

3. SIMULATION ANALYSIS AND RESULTS

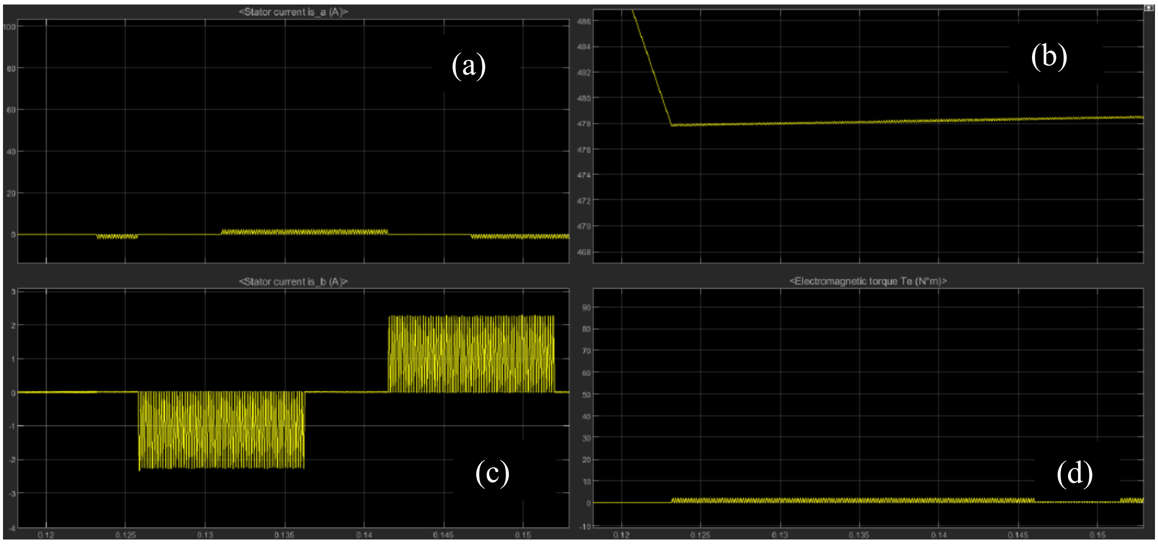

Fig.3. Simulink results with PID controller

Figure 3 presents the simulation results of the BLDC motor drive system operating under a PID controller. As shown in Fig. 3(a), the phase-A stator current remains well regulated with only minor ripples caused by PWM switching, indicating stable current control in steady state. The rotor speed response in Fig. 3(b) shows that the motor accelerates quickly after the reference speed is applied, experiences a small overshoot, and then gradually settles close to the desired speed, demonstrating satisfactory dynamic performance with negligible steady-state error. In Fig. 3(c), the phase-B stator current follows a similar magnitude pattern as phase-A but is electrically shifted by 120°, confirming proper three-phase operation and balanced current distribution. Finally, Fig. 3(d) illustrates that the electromagnetic torque becomes nearly constant after the transient period, with only small ripple components, ensuring smooth and stable motor operation under closed-loop PID control.

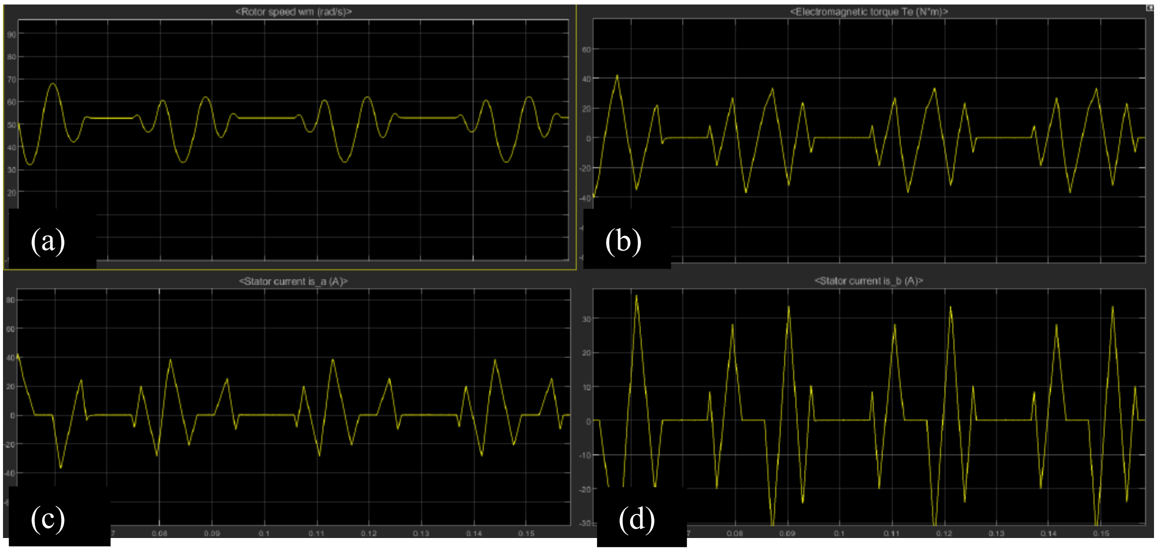

Fig 4. Simulink results with hysteresis current controller

Figure 4 shows the simulation performance of the BLDC motor when hysteresis current control is applied. As seen in Fig. 4(a), the rotor speed does not remain perfectly smooth but fluctuates slightly around the reference value because the inverter switches operate continuously to keep the current within the hysteresis band; however, the average speed still stays very close to the desired setting. In Fig. 4(b), the electromagnetic torque waveform contains noticeable ripple due to the rapid and repeated switching action, yet its average value remains adequate to sustain stable motor operation. Figures 4(c) and 4(d) display the stator currents of phases A and B, respectively, where the currents are restricted within fixed upper and lower limits, resulting in a characteristic zig-zag pattern with variable switching frequency; phase-B is electrically shifted by 120° relative to phase-A, confirming proper three-phase balance. Overall, hysteresis current control ensures quick response and effective current regulation, though it introduces higher torque ripple and switching losses compared to smoother control methods.

3.1 Speed Error Calculation

The comparison between the efficiency of speed control of BLDC motor using PID controller and Hysteresis current controller is as follows:

3.1.1 Using PID controller

1. Reference Speed = 500 rpm

2. Motor Speed Response = where the initial speed starts at 1000 rpm and quickly settles around ~500 rpm. The speed settles to ~500 rpm in less than 0.2 seconds.

3. PID Controller Input Error = (Reference Speed – Actual Speed)

4. Display Block = 496.7 rpm

5. Error Calculation:

To convert rpm to rad/s = (2π x RPM)/60 = (2π x 500)/60

Reference Speed = 500 rpm = 52.36rad/s

Actual Speed = 496.7 rpm = 52.01rad/s (from the Display block)

Error = Reference – Actual = 52.36 – 52.01 = 0.35rad/s

Percentage error = (0.35/52.36) X 100 = 0.66%

3.1.2 Using Hysteresis current controller

1. Reference Speed = 500 rpm

2. Motor Speed Response = where the initial speed starts at 1000 rpm and quickly settles around ~500 rpm

3. Display Block = 490.0 rpm

4. Error Calculation:

To convert rpm to rad/s = (2π x RPM)/60 = (2π X 500)/60 = 52.36 rad/s

Actual Speed = 490 rpm = 51.41rad/s

Error Calculation = Reference – Actual = 52.36 – 51.41 = 0.95rad/s

Percentage error = (0.95/52.36) X 100 = 1.81%

The steady-state speed error is about 0.95 rad/s (~1.81%).

Table 1: Performance comparison: PID controller vs. Hysteresis current controller for BLDC motor speed control

Parameters	PID Controller	Hysteresis Current Controller
Reference speed	500 rpm (52.36 rad/s)	500 rpm (52.36 rad/s)
Actual speed	496.7 rpm = 52.01 rad/s	490 rpm = 51.41 rad/s
Speed	error 0.35 rad/s	0.95 rad/s
% error	0.66%	1.81%
Torque ripple	Low to moderate	High
Current ripple	Moderate	High
Response time	Slightly slower (but smooth)	Fast (due to switching)
Control smoothness	Smoother	Rough with more switching
Switching losses / Stress	Low	High
Overall accuracy	High	Moderate

4. CONCLUSION

This work focused on detailed modeling, simulation, and comparison of PID and Hysteresis Current Control techniques for regulating the speed of a three-phase BLDC motor in the MATLAB/Simulink environment. For a reference speed of 500 rpm, the PID controller delivered better steady-state behavior, achieving a very small speed error of 0.66% along with smoother torque output and lower current ripple, which contributed to improved stability and overall efficiency. In contrast, the hysteresis current controller responded more quickly in terms of current dynamics because of its high-frequency switching action; however, this advantage came with increased torque ripple, higher switching losses, and a relatively larger steady-state error of 1.81%. The comparative results suggest that PID control is more appropriate for applications where precision and efficiency are critical, whereas hysteresis control is beneficial in situations requiring rapid current adjustment and strong disturbance handling capability. Overall, the study highlights the importance of selecting an appropriate control strategy to optimize BLDC motor performance and sets the groundwork for future exploration of hybrid or intelligent control methods that can combine fast dynamic response with excellent steady-state accuracy in advanced electric drive systems.

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