Speed Control of the BLDC Motor Using PID Controller

S G Srivani[1], Sahana R[2]

[1]*Electrical and Electronics, RV College of Engineering, Bengaluru, India*
[2]*Electrical and Electronics, RV College of Engineering, Bengaluru, India*

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Abstract - *Effective temperature management is vital for enhancing performance and reliability in various cooling applications. In modern cooling systems, efficient temperature regulation is essential for maintaining optimal performance and extending the lifespan of electronic components. This paper introduces a method for dynamically controlling the speed of a Brushless DC (BLDC) motor using a Proportional-Integral-Derivative (PID) controller, where the motor speed is governed by temperature variations. The control strategy is designed to increase the motor speed as the ambient temperature rises, thereby enhancing the cooling effect to prevent overheating. The PID controller plays a critical role in this process by continuously adjusting the Pulse Width Modulation (PWM) signals based on feedback from a temperature sensor. This ensures that the motor responds accurately and promptly to temperature changes. By fine-tuning the PID parameters, the system achieves a balance between rapid response and minimal overshoot, reducing steady-state error and avoiding unnecessary power consumption. Experimental validation shows that this method effectively maintains the desired temperature range, even under fluctuating thermal conditions, demonstrating its suitability for applications where precise temperature control is crucial. The proposed approach not only optimizes the cooling efficiency but also enhances the overall stability and reliability of the system, making it a valuable solution for temperature-sensitive environments.*

***Key Words*: - BLDC motor, Cooling applications, PID Controller Temperature control**

1.INTRODUCTION

Thermal management is a critical aspect of modern electronic and mechanical systems, particularly in environments where components are sensitive to heat. In applications such as data centers, industrial automation, and consumer electronics, maintaining an optimal temperature is crucial to ensure the reliability and longevity of the equipment. Excessive heat can lead to component degradation, reduced performance, and even total system failure, which underscores the importance of effective cooling solutions [1]. One effective method to achieve precise temperature control is by dynamically adjusting the speed of cooling fans or motors based on real-time temperature readings. Brushless DC (BLDC) motors are commonly employed in these applications due to their high efficiency, compact size, and ability to provide precise speed control. BLDC motors are preferred over traditional brushed motors because of their longer lifespan, lower maintenance requirements, and superior performance characteristics. The absence of brushes in BLDC motors reduces friction and wear, making them ideal for continuous operation in cooling systems where reliability is essential. Furthermore, BLDC motors have a better torque-to-weight ratio and produce less noise and electromagnetic interference, which are desirable traits in sensitive environments like data centre[2]. However, to maximize the benefits of BLDC motors in temperature-sensitive applications, a robust control strategy is required to ensure the motor speed adapts accurately to temperature variations. In this context, Proportional-Integral-Derivative (PID) controllers have emerged as a reliable solution for motor speed control due to their simplicity, robustness, and effectiveness in a wide range of applications[3]. A PID controller continuously calculates the error between a desired setpoint and a measured process variable, adjusting the control inputs to minimize this error. In temperature-based speed control systems, the PID controller modulates the motor's speed by adjusting the Pulse Width Modulation (PWM) signals according to feedback from a temperature sensor. As the temperature increases, the controller increases the motor speed to enhance cooling, thereby preventing overheating and ensuring stable operation [4]. Conversely, when the temperature drops, the controller reduces the motor speed to conserve energy and reduce noise. The tuning of PID parameters—proportional, integral, and derivative gains—is crucial to the performance of the control system. Proper tuning ensures a rapid response to temperature changes, minimizes overshoot, and reduces steady-state error, all of which are essential for maintaining a stable and efficient cooling system. Various tuning methods, such as Ziegler-Nichols, Cohen-Coon, and manual tuning, can be applied to optimize these parameters based on the specific requirements of the application. Each tuning method offers distinct advantages: Ziegler-Nichols is quick and straightforward, Cohen-Coon provides good performance for systems with a known time delay. This paper presents a comprehensive study of using a PID controller for temperature-based speed control of a BLDC motor in cooling applications [5]. The control system is designed to dynamically adjust the motor speed in response to real-time temperature variations, optimizing cooling efficiency.

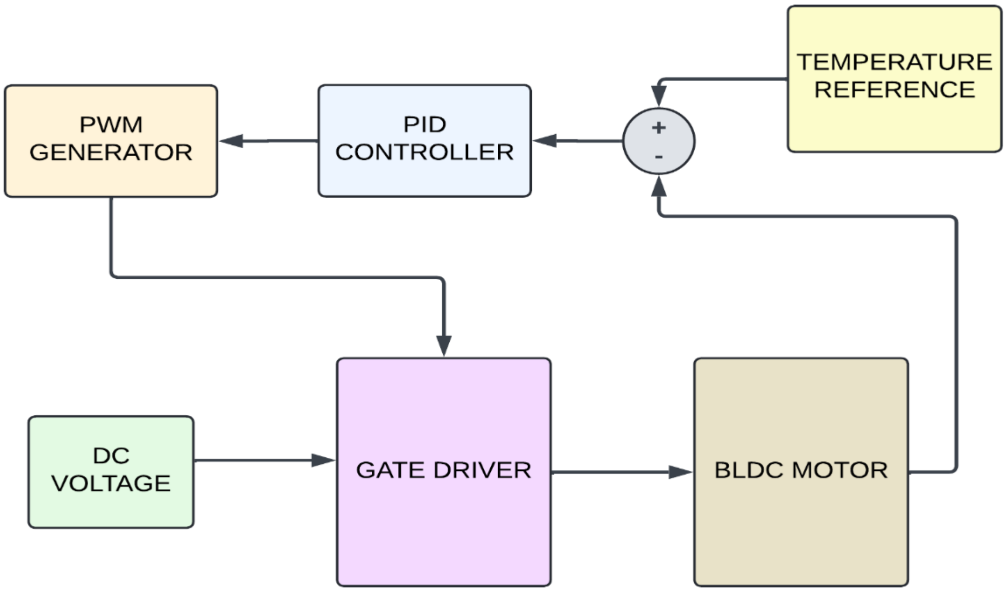

Fig-1: Architecture of the system

2. ARCHITECTURE OF THE SYSTEI

2.1 Temperature Reference

The system as shown in the Fig 1, begins with the Temperature Reference block, which is a critical component for determining the desired speed of the BLDC motor. In this application, the temperature reference is likely derived from a temperature sensor such as the LM35, which measures the ambient or system temperature. This reference provides a target temperature that is used to adjust the motor speed to achieve cooling.

2.2 Summing Block

The summing block subtracts the feedback signal from the temperature reference to compute the error signal. The error signal represents the difference between the desired speed (based on the temperature reference) and the actual motor speed. This difference is crucial for adjusting the motor's operation to align with the desired conditions.

2.3 PID Control

The PID Controller, or Proportional-Integral-Derivative controller, is a critical component in control systems for achieving precise and stable regulation of various processes. In the context of this architecture, the PID controller adjusts the motor speed based on the difference between the desired temperature and the actual motor speed. The Proportional term directly responds to the current error by producing an output that is proportional to the error signal, providing an immediate corrective action. The Integral term addresses any accumulated past errors by summing them over time, effectively eliminating any residual steady-state error that might persist after the proportional action.

This helps ensure that the system reaches and maintains the target speed. Meanwhile, the Derivative term predicts future errors by considering the rate of change of the error signal, which allows the system to preemptively counteract potential overshoot and oscillations, enhancing system stability. By carefully tuning the proportional, integral, and derivative gains, the PID controller dynamically adjusts the motor speed, ensuring that the error signal is minimized. This process enables the motor to operate at the optimal speed to maintain the desired temperature, providing effective control for temperature-sensitive applications.

2.4 PWM Generator

The PWM Generator takes the output from the PID controller and converts it into a Pulse Width Modulated signal. PWM is a technique used to control the amount of power delivered to an electrical load, in this case, the BLDC motor. The duty cycle of the PWM signal (the ratio of the on-time to the total period of the signal) directly correlates with the motor speed. A higher duty cycle means more power is delivered to the motor, increasing its speed, while a lower duty cycle decreases the power and slows the motor.

2.5 Gate Driver

The Gate Driver is an interface between the PWM signal from the PWM generator and the BLDC motor. It acts as a power amplifier, capable of delivering the required current and voltage levels to the motor's windings based on the PWM signal. Gate drivers are essential for effectively switching the power transistors (such as MOSFETs or IGBTs) that control the motor phases. In a BLDC motor,

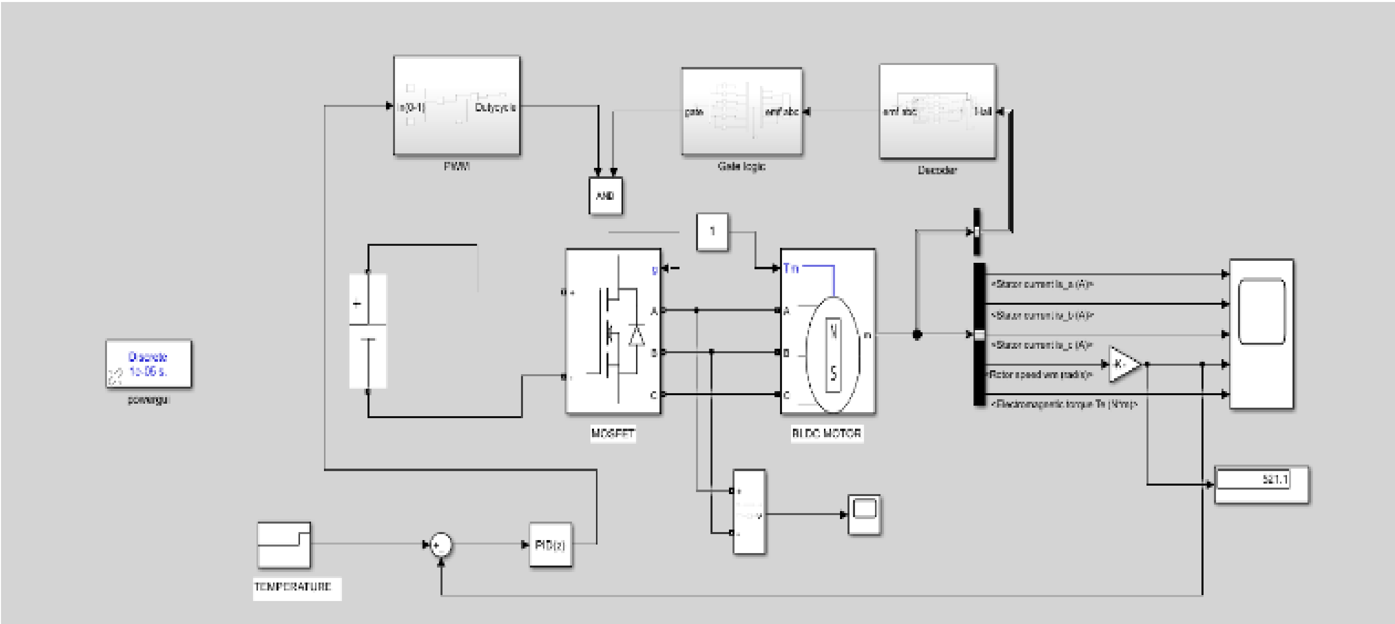

Fig-2: Schematic diagram

precise control of these switches is necessary for maintaining smooth and efficient motor operation.

2.6 BLDC Motor

The BLDC Motor (Brushless DC Motor) is the final actuator in this control system. Unlike traditional DC motors, BLDC motors do not have brushes. Instead, they use electronic commutation to switch the current in the motor windings, improving efficiency and reliability. The speed of the BLDC motor in this system is regulated based on the input from the gate driver, which is controlled by the PWM signal generated in response to the temperature reference.

3. SIMULATION ANALYSIS

The simulation diagram in Fig 2, appears to depict a control system for a Brushless DC (BLDC) motor, focusing on temperature-based speed control using a Proportional-Integral-Derivative (PID) controller.

3.1 PID controller

The PID controller adjusts the motor speed based on the error between the desired temperature and the actual temperature measured by the sensor. The PID control law is given by,

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dT + K_d \frac{de(t)}{dt} \text{..............(1)}$$

where ,

$u(t)$ is the control output

$e(t) = T_{set} - T_{measured}$ is the error between the desired temperature and the measured temperature

K_p, K_i and K_d are the proportional, integral and the derivative gains respectively

3.2 PWM generation

The Pulse Width Modulation (PWM) signal is generated based on the control output u(t) from the PID controller. The duty cycle DDD of the PWM signal determines the average voltage applied to the motor,

$$V_{avg} = D \times V_{dc} \text{...(2)}$$

where,

V_{avg} is the average voltage applied to the BLDC motor

D is the duty cycle of the PWM signal ($0 \leq D \leq 1$)

V_{dc} is the supply voltage

3.3 BLDC Motor Control

The BLDC motor's dynamics are modeled by the electrical and mechanical equations. The stator phase voltage equation for each phase can be expressed as,

$$V_s = L\frac{di_s}{dt} + R\, i_s + e_s \text{..(3)}$$

where,

Vs is the phase voltage applied to the stator winding.

L is the inductance of the stator winding.

R is the resistance of the stator winding.

i_s is the stator current.

e_s is the back electromotive force (EMF).

The back EMF e_s for each phase is proportional to the rotor speed ,

$e_s = k_e \omega_m$ ....(4)

where k_e is the back EMF constant of the motor.

The mechanical equation governing the motor's speed is:

$J \frac{d\omega_m}{dt} = T_e - T_L - B\,\omega_m$ ....(5)

The feedback mechanism involves monitoring the motor's speed and current to adjust the PWM signal accordingly. The rotor speed w_m and stator currents $i_{a,} i_b, i_c$ are fed back into the control system:

w_m= f(hall signals)

$i_{a,} i_b, i_c$= measured currents from sensors

These feedback signals are used by the PID controller to adjust the PWM duty cycle and ensure that the motor speed responds correctly to the temperature variations.

3.3 System Operation

The system operates by continuously adjusting the speed of a BLDC motor based on temperature feedback to maintain a desired temperature. It begins with the temperature reference, which sets the target temperature for the system. This target is compared to the actual motor speed, generating an error signal that reflects the difference between the desired and actual speeds. This error signal is then processed by the PID controller, which calculates the necessary adjustment to minimize the error by tuning the proportional, integral, and derivative components. The PID controller output is converted into a Pulse Width Modulation (PWM) signal, which regulates the power delivered to the motor by controlling the duty cycle of the signal. The gate driver receives this PWM signal and amplifies it to drive the motor's phases with the appropriate current and voltage levels. As a result, the motor speed is adjusted according to the PID controller's output to match the temperature reference. The system continuously monitors the motor speed and temperature, repeating this process to ensure the motor operates at the optimal speed to achieve and maintain the desired temperature, ensuring effective temperature control.

4. RESULTS AND ANALYSIS

The waveform shown in the Fig 3 is the phase currents $I_{A,} I_{B,} I_C$ of a BLDC motor under speed control, with each phase current shifted by 120 degrees, indicating proper commutation. The trapezoidal shape and consistent magnitude suggest stable motor operation, while the small fluctuations are due to PWM control used for adjusting motor speed. Overall, the waveforms confirm balanced and efficient BLDC motor performance under speed control conditions.

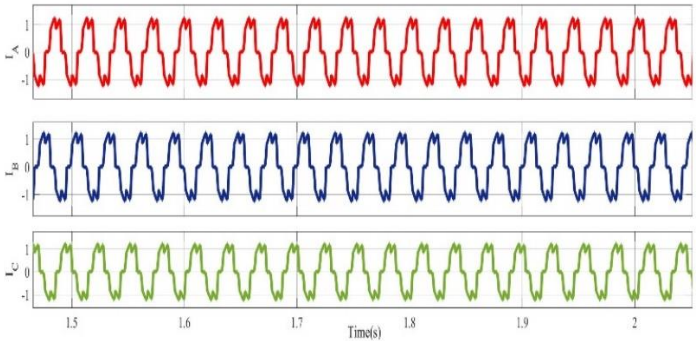

Fig-3: Phase current of BLDC Motor

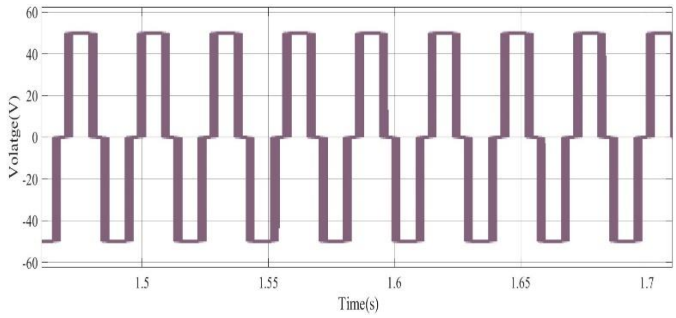

Fig-4: Phase Voltage of BLDC Motor

Fig 4 shows the phase voltage of the BLDC motor that is measured between phase A and phase B.

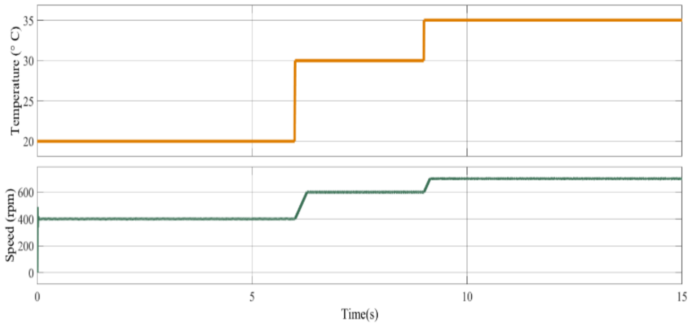

Fig-5: Speed vs Temperature

Fig 5, shows the linear change of the temperature vs speed graph ,as the temperature changes the speed of the motor changes. The figure shows how the motor speed changes with temperature, illustrating the system's response as the temperature rises. This relationship gives an understanding of the temperature-based control of the BLDC motor.Figure ,depicts the back EMF waveform of the BLDC motor , giving insight into the motor's electrical behavior during operation. The figure displays the current waveforms for phases A, B, and C, showing how the current is distributed across the motor's phases.

4. CONCLUSION

The performance evaluation of the BLDC motor under temperature-based speed control reveals a high degree of operational efficiency. The phase currents exhibit proper commutation, with each phase shifted by 120 degrees, and stable trapezoidal waveforms, indicative of consistent motor operation. The phase voltage between phases A and B further corroborates the motor's stable behavior during operation. A linear relationship between temperature and motor speed is observed, highlighting the system's responsive adjustment of speed in accordance with temperature variations. These findings substantiate the effectiveness of the temperature-based speed control mechanism in maintaining the motor's balanced and efficient performance.

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BIOGRAPHIES

S.G SRIVANI (Senior Member, IEEE) received the ME degree from Bangalore University and Ph. D degree from NITK, Surathkal, is currently the Professor and HOD of EEE, RV College of Engineering, Bengaluru.

Sahana R received the B.E. degree in EEE from Visvesvaraya Technological University, Belagavi, She is currently pursuing her M. Tech in Power Electronics in RV College of Engineering, Bengaluru.