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Design and Evaluation of Different Permanent Magnet BLDC Motor Speed Control Techniques

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Abstract –
PMBLDC Motor: Permanent Magnet Brushless DC controlled by electronic commutation, which uses Hall sensors to detect the motor position. This research first uses Sliding Mode Controllers (SMC) and Proportional Integral to observe the reactions of PMBLDC motors. SMC replaced the PI Controller due of the PI's sensitivity to changes in constraints and unforeseen torque disturbances. For SMC is a practical synthesis technique for non-linear uncertain systems with fast and dependable transient responses. This paper investigates a new pulse width modulation (PWM)-based PMBLDC motor control technique. Power converter-controlled motors frequently use the PWM approach. Additionally, it manages analog systems that have outputs from digital processing.

Keywords: PMBLDC; SMC; PWM.

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I. Introduction

With a trapezoidal back EMF and an electronically commutated mechanism, the PMBLDC motor is a Permanent Magnet Synchronous Motor (PMSM). The benefits of PMSM, which meet the precise requirements of EVs, include high torque density, excellent efficiency, reduced volume and low upkeep. In addition to being more durable, PMBLDC motors produce less noise. The primary benefit of this motor is its controllability through feedback systems, which result in quicker speed responses and less torque ripples. Because of the sensitivity of the motor performance to the system's uncertainty and parameter variations, a standard PI controller may cause torque disturbances.

The use of SMC helps overcome this drawback. Practical PMBLDC motors are typically nonlinear and have a lot of disturbances; SMC is used to get around these issues and boost motor performance. Despite SMC's robustness to motor changes, the increase in gains employed for control leads in an undesirable chattering effect that creates High frequency switching in converters and response ripples for instance. This work implements PWM approaches with SMC controllers to solve these drawbacks. By regulating duty cycle, the PWM technology converts analog values to digital values. The SMC controller implementation method is as follows: 1. first noting the control law's convergence and setting. 2. Afterwards, to provide the robust behavior of the applied control rule throughout the system response, set up the sliding mode at the beginning. 3. the creation of the path that allows for convergence in a limited amount of time.

Researchers have used a variety of speed control strategies; in this study, we have examined and applied the application of fuzzy and PI controllers to BLDC motor speed control. For BLDC motor speed control, the majority of industrial applications use a traditional PI controller, which produces subpar results in non-linear and variable conditions.[1]. several techniques for adjusting speed and current, including as pulse width modulation (PWM), changing dc-link bus voltage, and hysteresis bands [2]. The BLDC drive's sensorless speed control uses the indirect back EMF zero-crossing detection technique. To gain efficient control over speed, a number of controllers are used and compared [3].

A bioinspired algorithm-based method allows a BLdc motor drive to rapidly stabilize. while reducing torque ripple. The control signal applied to the capacitor and the pulse width modulation signals applied generated to the inverter by a spider-based controller. Researchers investigate how using a modest dc-link capacitor affects speed control and torque ripple reduction [4]. An Examination of BLDC Motors: Current Developments, Sophisticated Control Methods, and Uses [5]. Adaptive SMC and fuzzy SMC are advanced SMC algorithms that effectively regulate BLDCM speed both with and without an external demand. A comparison between the simulation performance of speed regulation for BLDCM using the designed approaches and a classical Proportional-Integral-Derivative (PID) controller confirms the efficacy of the proposed advanced SMC techniques in improving the system characteristics (settling time, steady state error, rise time, and disturbance & noise rejection). [6].

In comparison to other controllers, the PID regulator is significantly more adaptable, better operating, and successful in producing sufficient control performance, according to the study's functional tests [7]. The proposed hybrid approach aims to effectively regulate the BLDC motor's speed while adhering to the specified parameters. The proposed hybrid system combines the Student Psychology Optimization Algorithm (SPOA) with the Radial Basis Function Neural Network (RBFNN) [8]. BLDC motor velocity control using a sliding mode observer technique based on back electromotive force (back EMF) estimation [9]. The sliding mode controller (SMC)-based field-oriented control (FOC) for brushless direct current (BLDC) motor was later investigated for speed and position estimates using a higher order sliding mode observer (HOSMO), which may be a solution for sensor-less operation. [10].

Bacterial Foraging Optimization optimizes a control method based on an adaptive neuro-fuzzy inference system (ANFIS). An algorithm for controlling the speed of a brushless direct current (BLDC) motor fed by a matrix converter (MC) is described. One of the most promising solutions for MC-fed electrical drive control is ANFIS [11]. Fast control prototyping utilizing the dSPACE DS1103 controller board to develop closed loop speed control for a brushless dc (BLDC) motor drive. In general, control methods designed for motor drives may produce good simulation results in both transient and steady state scenarios [12]. The purpose of this optimization tool is to assist in determining the ideal proportional-integral (PI) parameters for regulating the speed of the BLDC [13].

An adaptive PID controller uses the added error of a turnaround control sign to comprehend non-linearity, parameter fluctuations, and burden travel issues that arise in the BLDC motor drive framework.[14].Numerous industries and domestic applications, including robots, electric vehicles, defense, aviation, industry, ventilation, dryers, and refrigerators, have embraced BLDC motor drives [15].Brushless direct current motors in electric cars can be better controlled in real time by using the tilt integral derivative (TID) controller technology to regulate the speed of BLDC motors. Applying the TID controller to the model under consideration improves its torque and speed, for example [16].

This paper shows an overview of BLDC motor control utilizing sliding mode control and a PI controller. Later on, the SMC PWM approach is used to regulate the motor. The simulation findings and a conclusion that highlights the value of this control strategy.

II. Control Strategies of PMBLDC Motor

There are two groups into which DC motor control techniques fall. One of these is scalar control, which modifies the frequency and amplitude of the stator voltage to achieve the desired motor speed. This approach works well for motors with fixed loads, but it is inapplicable to motors with dynamically fluctuating loads. Vector control, on the other hand, has the best dynamic reactions The motor's open loop control is the ability to control the motor just by changing the supply voltage. Closed loop control is used to mitigate torque ripples, external disturbances, and deviations from the desired outcomes. Utilizing sensors that detect the PWM circuit, motor, and controller output to produce the inverter's pulses to ensure that each phase winding receives the appropriate amount of current.

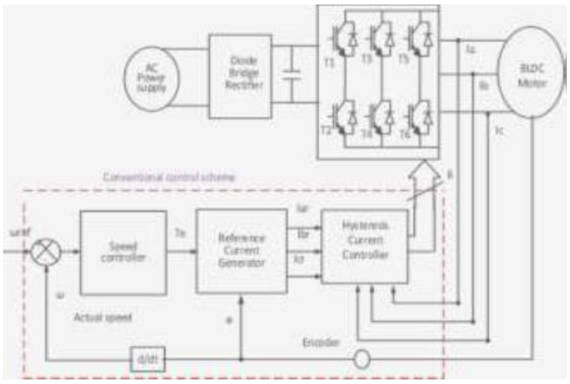

Fig.1. Overall control structure of PMBLDC motor

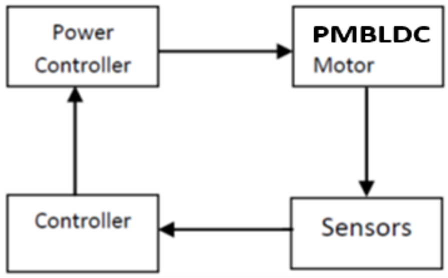

Fig.2. PMBLDC motor block diagram with Hall sensors

Using a PWM method and sensors to measure the rotor position, the inverters power the PMBLDC motor with a DC supply. The desired value and the measured value are not exactly the same. Therefore, controllers are used to control PMBLDC motors in order to rectify that problem.

a. Design of PI controller:

The PI controller has two distinct modes: proportional mode and integral mode. The integral mode determines the most recent error, whereas the proportional mode fixes the existing mistake. that the system is experiencing.

One way to create a PI controller is as an output $u(t) = K_P e(t) + K_I \int_0^t e(t)\, d\tau$

$$U(s) = K_P E(s) + \frac{K_I}{s} E(s)$$

$$\Rightarrow \quad U(s) = E(s)\left(K_P + \frac{K_I}{s}\right)$$

The following provides the PI controller's transfer function:

$$D(s) = \frac{U(s)}{E(s)}$$

$$□ D(s) = \frac{K_P s + K_I}{s}$$

where K-P and K-I are the PI speed controller's gains, and e(t) = set reference value-actual determined.

b. Design of SMC controller:

Although the PI controller is straightforward, it is susceptible to changes in parameters brought on by temperature fluctuations, other external disruptions, and the motor's nonlinear characteristics. SMC works well for monitoring system performance in the face of uncertainties and disruptions in real-world motors.

Mode of Sliding Choosing the state sliding surface and creating the control law are the two tasks involved in design.

The control law's purpose is to force the trajectory toward the sliding surface, S, and toward the stable equilibrium. which is where the origin of the coordinate axes is taken into consideration.

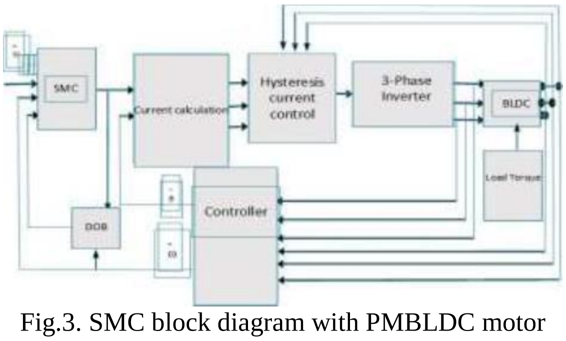

Fig.3. SMC block diagram with PMBLDC motor overall

Anywhere on the sliding surface,

$S = 0 \Rightarrow \dot{s} = 0$

(1)

The method it moves towards the origin by switching after hitting a spot on the sliding surface is known as Sliding Mode.

Above Sliding Surface, $S > 0$ then $\lim_{S \to 0^+} \dot{S} < 0$

Below Sliding Surface, $S < 0$ then $\lim_{S \to 0^-} \dot{S} > 0$

□ $S\dot{S} < 0$(This is Reaching Condition)

Think about S1 and S2, two sliding surfaces. S1 represents the current control, which is thought to be the error in current, and S2 represents the speed control, which is thought to be the mistake in speed.

Equation yields the motor's electrical component, which is

$$V = iR + L\frac{di}{dt} + E$$

$\frac{di}{dt} = (-E - iR + V)\frac{1}{L}$(2)

And mechanical part from equation

$T = J\frac{d\omega}{dt} + B\omega + T_L$

$\frac{d\omega}{dt} = \frac{1}{J}(-B\omega + T + T_L)$ (3)

The S2 Sliding Surface design reduces the speed error.

Error,$e_2 = \omega_{ref} - \omega$ (□ consider$S_2 = e_2$)

$$\Rightarrow \; S_2 = \omega_{ref} - \omega$$

$$\Rightarrow \; \dot{S_2} = \dot{\omega_{ref}} - \dot{\omega}$$

Reaching the sliding surface in a finite amount of time is the switching law. To get this, you add the sliding surface S-2 and two switching functions with gains ϒ and ζ, or sgn, S-2 .. and S-2.

i.e., $U_{sw} = \Upsilon \mathrm{sgn}(S_2) + \zeta S_2$

Taking into account both proportional and constant rate switching,

$$\dot{S} = \Upsilon \mathrm{sgn}(S_2) + \zeta S_2$$

$$\Rightarrow \quad \dot{\omega} = \dot{\omega}ref + \Upsilon \mathrm{sgn}(S_2) + \zeta S_2$$

Consider equation (3.3)

$$\Rightarrow \frac{1}{J}(-B\omega + T + T_L) = \dot{\omega}ref + \Upsilon \mathrm{sgn}(S_2) + \zeta S_2$$

$\Rightarrow T = J(\dot{\omega}ref + \Upsilon \mathrm{sgn}(S_2) + \zeta S_2) + B\omega - T_L$

(4)

The control law that governs a motor's speed is

$$T = J(\dot{\omega}ref + \Upsilon \mathrm{sgn}(S_2) + \zeta S_2) + B\omega - T_L$$

The current error is controlled by designing S_1 sliding surface.

$S_1 = I_{ref} - I$

$\dot{S}_1 = \dot{I}_{ref} - \dot{I}$

The connection between current and torque is

$$T = K_t I$$

From equation (4)

$$I = \frac{1}{Kt}(J(\dot{\omega}ref + \Upsilon sgn(S_2) + \zeta S_2) + B\omega - T_L)$$

The following is the switching law for S1:

$$U_{sw} = \alpha sgn(S_2) + \beta S_2$$

When we use equation (2) to create the control law for speed error again, we get the control law for current error as

$$V = L\left(\dot{I_{ref}} + \alpha\, sgn(S_1) + \beta S_1\right) + E + IR$$

III. Results and Discussions

Taking gains Kp=5.09 and Ki=2.255 into account. The PMBLDC reference speed is 1000 rpm. Thus, the speed response ripples up to 0.08 seconds before settling at the reference speed of 1000 rpm in 0.1 seconds.

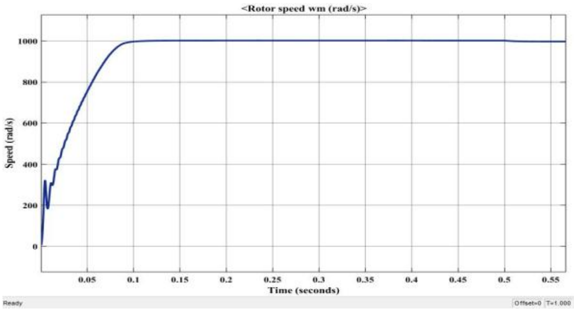

Fig. 4: PMBLDC motor speed response with PI controller

There are constant ripples in torque that don't settle to a single spot. The torque reaches its maximum value at 0.0038 seconds, decays to zero at 0.082 seconds, and then oscillates around zero again without ever settling to a single value.

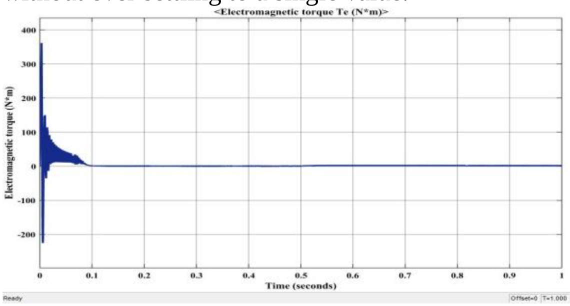

Fig. 5: PMBLDC motor torque ripple response with PI controller

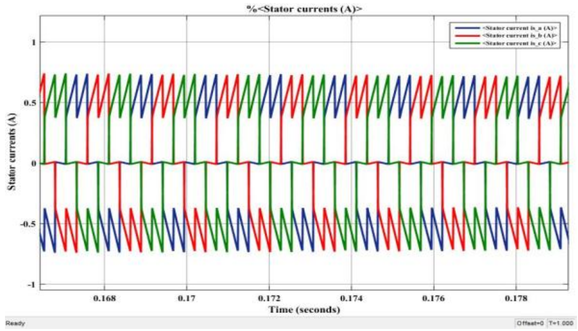

Fig.6: PMBLDC motor stator currents using a PI controller

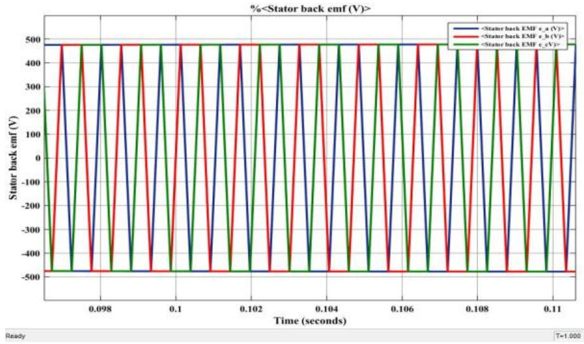

Fig. 7: PMBLDC motor stator back EMF with PI controller

With ramp input, the steady state error and torque ripples are seen, and the associated outcomes are displayed in the figures below.

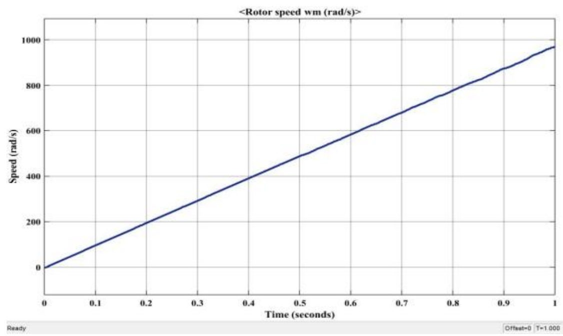

Fig. 8: PMBLDC motor speed response with PI controller (ramp input)

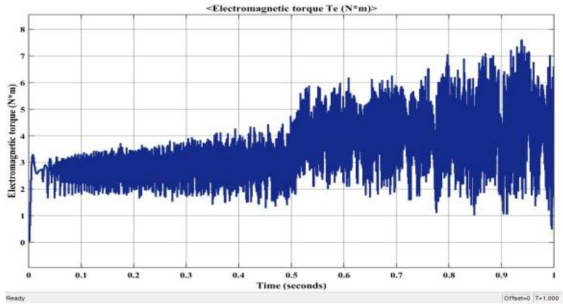

Fig.9: PMBLDC motor torque ripple response with PI controller (ramp input)

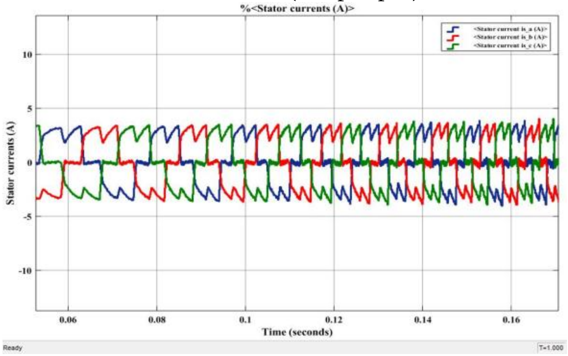

Fig. 10: PMBLDC motor stator currents with PI controller (ramp input)

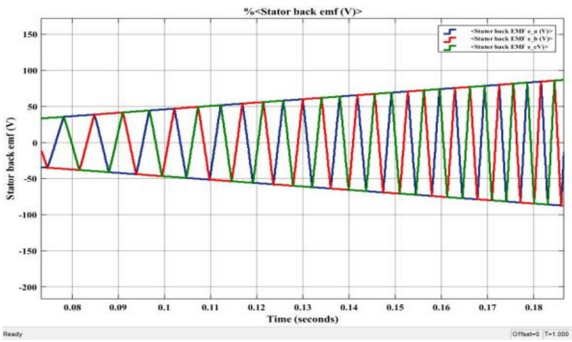

Fig. 11: PMBLDC motor's back EMF with PI controller (ramp input)

II. Conclusion:

When using a PI controller, the BLDC motor experiences significant overshoot and a weak anti-interference capability. SMC is intended to address these issues. Nevertheless, the improvements made to the sliding mode controller to improve the motor's performance reduce the motor's robustness and boost its chattering effectiveness. Simulation data are analyzed and comparative simulation experiments are conducted. Although the simulation results from the traditional sliding mode controller are superior to those from the method, the PI controller suggested in this document outperforms the conventional SMC because it increases the motor's robustness and lessens the chattering effect in comparison to earlier methods. With the SMC-PWM technology, BLDC motors can achieve high performance and efficiency. There are fewer torque ripples under various loading conditions. The suggested approach achieves faster speed responses and lessens torque ripples caused by currents in motors passing throughout the commutation intervals via the freewheeling diodes.

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