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Speed Control of BLDC Motor Using Trapezoidal Commutation & PWM Technique

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***Abstract*— This paper deals with brush less dc motor which is often taken by the commutated dc motor. The BLDC is a PMSM motor which as numerous advantages compared to other motors like induction motors or DC motors. The BLDC motors are taken by the automotive industries due to its construction and capability of running at high speed with minimal losses compared to commutated DC motor. The BLDC motor as trapezoidal back emf as well as trapezoidal flux distribution ,which makes the drive to operate at ease by using trapezoidal commutation in a closed loop operation using PI controller along with PWM technique. This commutation method is also called as six-step commutation or block commutation. The PMBLDC can be operated as sensor less and by using sensors like Hall sensor which is used to track the position of the rotor ,by using the position of rotor the gating pulses are provided to the VSI inverter that switches the voltage transitions accordingly. And the PWM technique used is simple PWM ,which is used to control the voltage by varying the duty cycle which will results in overall control of motor ,which will be Providing effective control of the motor. This paper also provides the comparative study of various techniques which are implemented to control the BLDC motor ,which helps in better understanding of the motor through those techniques.**

Keywords*— *VSI , PWM technique , PMBLDC, Hall Sensor DC motor ,PI Controller ,120 deg mode.

I. INTRODUCTION

In the electrical drive technology the machines are categorized into different types according to supply and type of magnets used. According to the classification , they are stated as permanent magnets and electromagnetic drives that may be of Ac or Dc drives. The usage of permanent magnets gives the benefit of simple construction and less maintenance as well as high power density . The brushless Dc motor comes under the category of PMSM drive, the BLDC Motor as trapezoidal back emf and as seen in Fig. 1, rectangular stator currents are required to generate a constant electric torque [1] The BLDC motor are becoming common in alternative in the field of industrial electronics, robotics and as well as in automotive industry , especially in electric vehicles etc. This is because they are more efficient and require less upkeep than traditional brushed DC motors. Due to this rising demand, low-cost, effective motor control drives are now required, and a number of innovative methods, devices, and circuits are now accessible [2]. The design of the BLDC motor is comparable to that of the PMSM motor, and it would be comparable to the PM commutator DC motor. Generally BLDC motor is also called as electronically commutated motor. A BLDC motor's stator is comprised of vertical stacks of steel laminations with slots along the inner edge. The stator's windings can be set up in either a star or a delta configuration. Torque is high and speed is low when using a star-connected winding, which is made up of numerous interconnected coils with one or more coils inserted into the stator slots. Here, the rotor is built of ferrite magnetic material and contains a permanent magnet. Depending on the needs of the application, the poles may alter correspondingly [3]. There are two main types of PMBLDC motors, which as we know fall under the umbrella of PMSM motors. Although it is challenging to have an exact sinusoidal type motor due to complicated structure, size, and cost, one with a sinusoidal back-EMF waveform uses a vector control scheme to obtain torque that is ripple-free. The other, with a trapezoidal back-EMF waveform, allows for constant torque. Although though BLDC motors outperform all other motor types, their control algorithms are more complex than those of PMDC commutator motors because rotor position must be detected in order to commutate the motor at the precise location for proper commutation. Both sensored and sensorless BLDC motors are options for this. After the rotor position is understood, the inverter sends gating pulses to energise the winding.

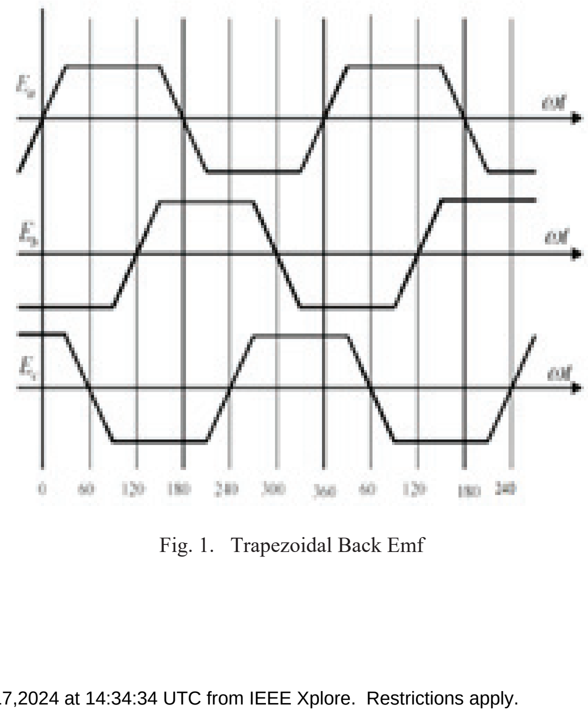

Fig. 1. Trapezoidal Back Emf

However some designs make use of encoders or other optical sensors [4][2].The trapezoidal commutation has 120 degree mode and as well as 150 degree mode. And it is the simplest method to control the BLDC motor at high speeds. The entire system is created using MATLAB/SIMULINK, and the MOSFET/IGBTS3 inverter circuit, which includes 6 switches from S1 to S6, is developed as shown in Fig. 2. The firing circuit is created using PWM techniques. There are so many other PWM techniques for VSI fed inverter such as sinusoidal PWM, space vector PWM technique ,Third harmonic PWM technique , single pulse PWM technique , and so on etc.

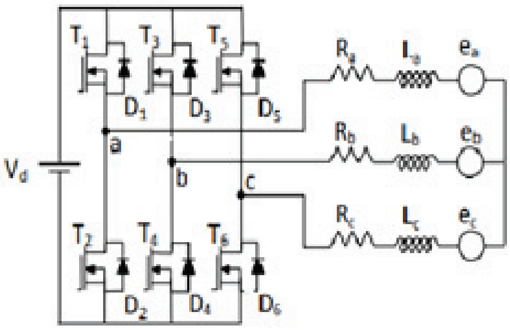

Fig. 2. BLDC motor connected to Three phase inverter

II. MATHEMATICAL MODELLING OF BLDC MOTOR

The mathematical of BLDC motor has be done with the help of state space equations . The state space are calculated by taking some considerations . As trapezoidal back emf implies that the mutual induction between stator and rotor in trapezoidal shape, and it has constant self-inductance and the mutual inductance is zero. As we know the speed depends upon the voltage that is speed and voltage are directly proportional to each other but were as speed and torque has inverse relation so by using this, we can derive the voltage and torque equations.

$$Va = R * Ia + L * \frac{dIa}{dt} + Emfa \tag{1}$$

$$Vb = R * Ib + L * \frac{dIb}{dt} + Emfb \tag{2}$$

$$Vc = R * Ic + L * \frac{dIc}{dt} + Emfc \tag{3}$$

The back-EMF induced are

$$Emfa = Ke * w_m * F(\theta_e) \tag{4}$$

$$Emfb = Ke * w_m * F\left(\theta_e - \frac{2\pi}{3}\right) \tag{5}$$

$$Emfc = Ke * w_m * F\left(\theta_e + \frac{2\pi}{3}\right) \tag{6}$$

we know electromagnetic power Pe can be written as and also the torque is given as

$$Pe = Ea * Ia + Eb * Ib * Ec * Ic \tag{7}$$

$$Te = \frac{Ea * Ia + Eb * Ib + Ec * Ic}{w} \tag{8}$$

From the mechanical considerations the torque equations can be written in terms of interia as

$$Te = B * w_m + \frac{dw_m}{dt} + Tl \tag{9}$$

III. COMMUTATION STRATEGIES

There are different strategies in order to control the PMBLDC motor.

- Trapezoidal commutation
- Sinusoidal commutation
- FOC

A. *Trapezoidal Commutation*

The trapezoidal commutation is also called as six-step commutation or block commutation. The six step can be achieved with the help of Hall sensor which provides the rotor position for effective speed control. This method regulates the flow of current through the motor's windings, resulting in the energization of only two terminals leaving the third terminal open or unconnected [2]. The six possible states of combinations are completed by doing this again to alternate the pair of powered terminals. In this, the name trapezoidal refers to the current waveform and as well as the Back-EMF which is in the shape of trapezoidal. In these 6 distinct steps according to an angle of 60^o electrical, here 3 Hall Sensors are placed 120^o apart .Through these sensors, six combinations are generated [5].The Hall Sensor signals at different position as shown in Fig 3.

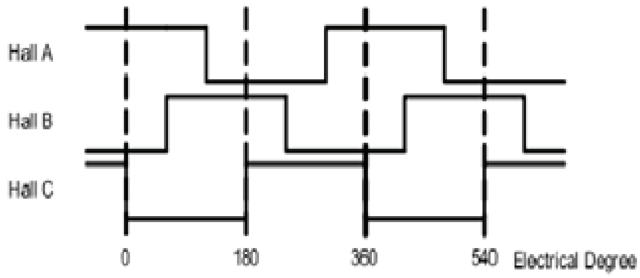

Fig. 3. Hall Sensor Signal

In this commutation the switches are turned ON and OFF on each phase in a specified order to get the exact sequence for switching. As we know that there exists a relation between the voltage and speed . The commutation logic states that the coils are to be powered for every 60° of electrical rotation based on Hall inputs since speed is exactly proportional to applied voltage. The resultant vector of the stator currents can point in six different directions and is merely the vector sum of the currents because two windings are always powered and producing equal-sized currents while the third winding is always zero. As this vector sum will be out of phase with the rotor position ,which will be causing 15% ripple in the torque as shown in Fig 4. This method is very popular because of its simple algorithm, which is used for low-speed requirement and the ripples are often noticeable at this speeds. It shortens the motor's lifespan significantly by causing mechanical noise and wear. The trapezoidal commutation has 150^o degree or also called as 12 step commutation .It is very efficient in motor control when compared to 120^o commutation and the torque produced is somewhat smooth that of 120 deg .These type of technic is used in sensor less operation of motors. And the shape of the output is similar to the sinusoidal waveform .They have better efficiency and speed control when compared to trap 120 deg commutation.

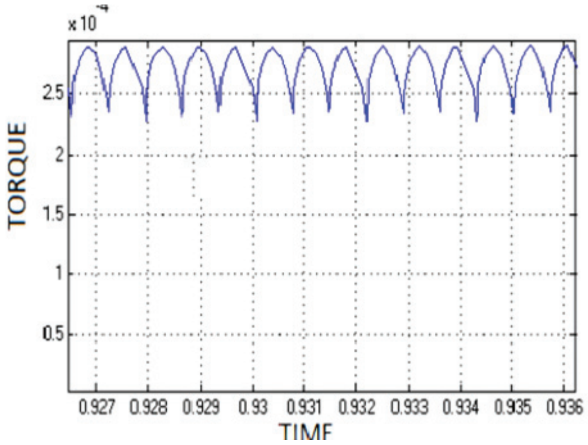

Fig. 4. Torque in Trapezoidal commutation

B. *Sinusoidal Commutation*

The flat wave of trapezoidal was replaced by sinusoidal wave form as we know that the PMSM motor can be operated as PMBLDC motor by giving either sinewave or trap wave .when compared to the trapezoidal commutation this commutation as far more advantages in terms of torque ripples or in terms of efficient control of speed during high-speed requirement of the motor. Here 3 power switches are turned ON and OFF for each phase were as in case of trapezoidal commutation only two windings are being energized and the third terminal being opened. In this it is very necessary to selectively fire more than one pair of power switching devices at once in order to overlap the commutation of phases . It can be operated as open or closed loop configuration using a feedback loop [6]. It is more accurate and advanced. The resulting vector currents are in phase with the rotor position, resulting in correct torque that is free of ripples, and the current values are 120° out of phase with one another.To generate sine modulated signals it uses the SVPWM technic. However, it requires precise rotor position measurement, which may be done using resolvers and encoders in sensored BLDC motors with high resolution. The Fig 5 shows that sinusoidal commutation with the Hall Sensor . This method performs and operates more effectively than the trapezoidal technique at low speeds. The cost of this technique is higher than the six-step commute. Nonetheless, it offers reduced torque ripple and permits accurate control. We can find this control in applications which required low noise, smooth and efficient motor performance. The performance of motor is very quiet because the phase current are sinusoidal without any higher order harmonics, it is very efficient for sinusoidal motors. When the back EMF voltage is aligned with the phase currents and produces low torque ripple all this are the advantages were as coming to disadvantages, they have more switching losses and poor speed torque regulation for dynamic loads.

C. *Field Oriented Control*

The FOC is likewise called as vector control which is PWM method that amplifies the force in the engine by controlling the stator current so it is consistently opposite to the rotor transition. A superior variant of sinusoidal replacement progressively regulates the PWM shifting voltages of the three stages to amplify engine power. Due to the BLDC Vectorial control is a challenging replacement process. This overcomes limitations on the exchanging sinusoidal's recurrence. This method is effective in regulating voltage and flows with relation to direct and quadrature hub rotors. For this, a constant field and quadrature with the rotor field are necessary [2]. The FOC control has various control transforms which includes clarke and park transformes .This transformes converts three-phase sinusoidal into two phase time variant systems (α, β) and as well as frequnecy is controlled.This system uses SV PWM control which has total of 8sectors ot of this 6 sectors are used and remaining 2 sectors are null states .In order to implement this technique especially in sensorless the rotor position is an important aspect .The Fig 6.shows the various coordinate transformations involved in FOC control.

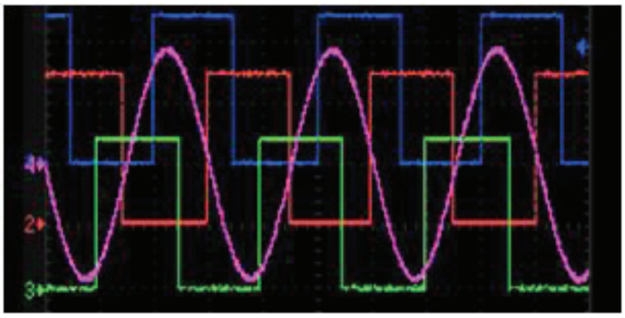

Fig. 5. Sinusoidal commutation with Hall Sensor signals

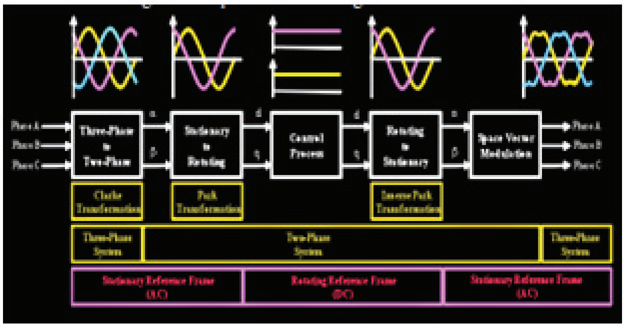

Fig. 6. FOC control coordinates

IV. COMPARISION OF 180 DEG AND 120 DEG

In the case of both commutation techniques there are 6 switches .In 120 deg mode out of 3 switches only two switches are supplied with the current and the third terminal is kept opened, were as in case of 180 deg mode 3 switches are energized from each phase and which conducts for the duration of 120 deg each. The torque produced from the trap 120 deg has ripples in its output waveform which is considered as one of the disadvantage. In case of 120 degree the torque is not exactly equal to 90 deg . And it contains a lot of ripples in its wave form which will results in huge losses and also effects the performance of the motor. The commutation logic Table 1.for this technique gives the information about the switching of the switches from one to the other accordingly the output will be in a six -step pattern. In case of 180- degree inverter they have non zero phase currents [7].The Torque ripples can be eliminated by using SV PWM in case of 180^{o} ,the Total harmonic distortion

(THD) is less when compared to that of 120^o commutation and it also enables the effective use of DC voltage and it also has one advantage is that it has less harmonic content which can be used in applications that required less harmonic content [8].In case of 120^o commutation the torque ripples are more as we discussed in section III .This ripples are common in every motors, They may caused due to different reasons from the supply end or through motor end . The causes of motor side torque include cogging torque, electromagnetic field harmonic torque, resistance torque, and others. and from the supply side, there are current ripples caused by high frequency switching, phase current commutation, etc. And they also proposed a Topology in [9]. The three sections that make up the sources of torque ripples in PM BLDC are broken down into control strategies that reduce ripples in BLDC motors from the control side[10].

TABLE I. COMMUTATION TABLE FOR 120 AND 180 DEGREE

	180 deg commutation		120 deg commutation	
Intervals	Switches	Polarities	Switches	Polarities
0 -60	T1,T6,T5	+ - +	T1,T6	+ 0 -
60-120	T1,T6,T2	+ - -	T3,T6	0 + -
120-180	T1,T3,T2	+ + -	T3,T2	- + 0
180-240	T4,T3,T2	- + -	T5,T2	- 0 +
240-300	T4,T3,T5	- + +	T5,T4	0 - +
300-360	T4,T6,T5	- - +	T1,T4	+ - 0

V. SIMULATION RESULTS

The BLDC motors can be controlled either sensor or sensor less. There are different methods through which these controls are implemented.

A. Sensored Control

The Brushless dc motor can be controlled by using different sensors like hall sensor ,resolvers and as well as encoders .the hall sensors are most probably used .because they are very simple ,when compared to other two sensors. This encoders and decoders make the circuit complex but they provide precise control.These seonsors provide rotor position information , by using this information the gating pulses are given to the inverter circuit. The PI sensor is used as speed controller and a feed back loop is taken by taking the speed error generated from the feedback loop is comapred with the actual speed and the motor is controlled according to it.

B. Sensorless Control

The rotor position sensors are costly and very reliable there are some of the techniques which is used to determine the rotor position are

1) Back-EMF detection techniques.
2) Flux estimation method
3) Observers based control techniques and so on etc.

Out of the above the most preferable technique is Back EMF detection and it is the easiest technic to implement

C. Open Loop Control

With an open loop system, the duty cycle is calculated straight from the set speed, and there is no feedback loop to calculate the error speed, therefore the output speed is less accurate and the voltage and torque may not be under control. Yet, the main layout is straightforward.

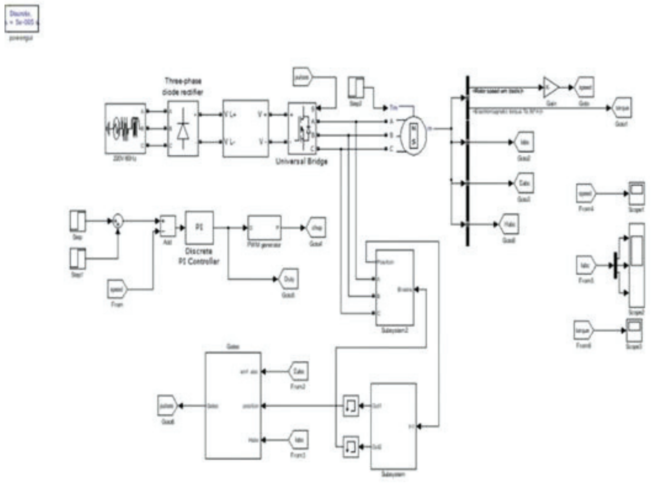

Fig. 7. Simulink model

D. Closed Loop Control

The closed loop system consists of a feed-back loop that is used to provide feedback on the speed. Here, the set speed and actual speed are compared, and an error signal is formed. This signal is supplied to the PI controller, which then produces the necessary output duty cycle to control the motor through the inverter.

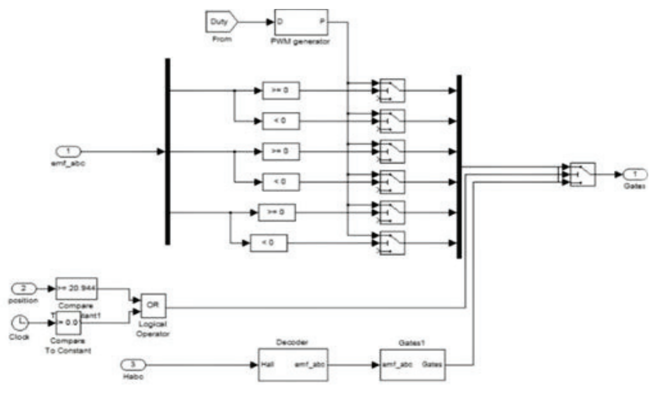

Fig. 8. Gating Pulse Logic

The Fig 7 and 8 are the Simulink model design of the motor control along with the gating pulses which are used to provide gating signals to the semiconductor switches S1-S6. Back-EMF and Hall Sensor along with state equations of the motor are consider subsystem as shown in Fig 9.

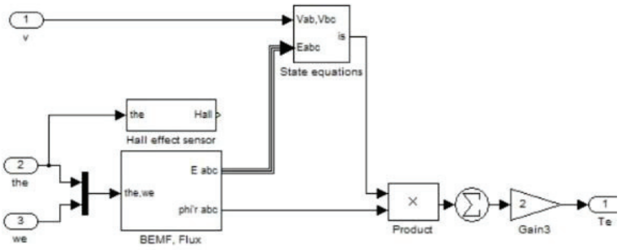

Fig. 9. Subsystem of Motor

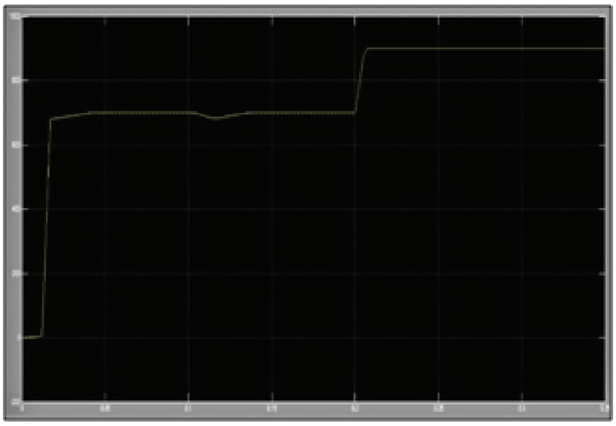

Fig. 10. Speed of the motor

The set speed of the motor is 1000 rpm, and the simulation time is 0.35 sec . Fig 10 shows that there is change in speed at 0.2 sec and it remains constant 900 rpm this change in speed occurs due to load torque.

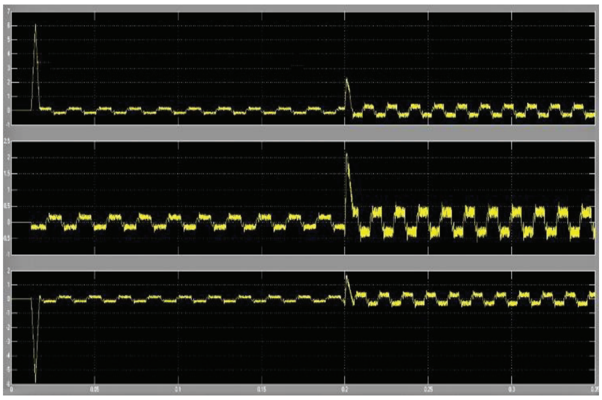

Fig. 11. Phase Currents of Motor

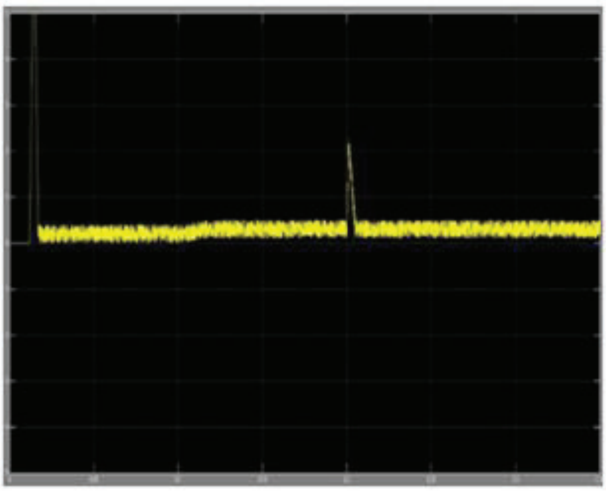

Fig. 12. Torque of The Motor

The currents in each phase are consider and when we observe closely the waveform look like a step which is shown in fig11, and also contains some ripples due to presence of harmonics along with the spikes which indicates the change is current due to change in torque.The torque of the motor is constant as we are taken input torque as step which can be seen in simulink model . Torque variation depends upon the load and as well as the current in the motor.

VI. CONCLUSION

The bldc motor controlcan be achieved by using different techniques not only by Trapezoidal commutation which is also called as six-step commutation . the PWM technique can be either sine or svpwm both have effective control. But in terms of torque trap 120 deg has torque ripples and as well as harmoincs along with acoustic which will degrade the performance and efficiency of the motor .The trap 120 deg is only suitable for low speed applications. Inorder to have effective torque control we can go with the SVPWM which has 15% maximum volatge compared to PWM which uses effective Dc volatge.The closed loop system with the sensored control is the best ,which will heps in determining accurate speed by taking a feedback conncetd PI controller. The overall control system is simple and efficient and the BLDC motor has different wide range of applications include aerospace, EV technology.

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